GEOLOGY AND TECTONICS OF PRE-TERTIARY ROCKS IN THE MERATUS MOUNTAINS
SOUTH-EAST KALIMANTAN, INDONESIA

By
NAFRIZAL SIKUMBANG, B.Sc(Bandung), M.Sc(Otago)

SUBMITTED FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
IN
GEOLOGY

ROYAL HOLLOWAY AND BEDFORD NEW COLLEGE
UNIVERSITY OF LONDON
EGHAM HILL, EGHAM
SURREY TW20 0EX
GREAT BRITAIN
GEOLOGY AND TECTONICS OF PRE-TERTIARY ROCKS IN THE MERATUS MOUNTAINS
SOUTH-EAST KALIMANTAN, INDONESIA

By
NAFRIZAL SIKUMBANG, B.Sc(Bandung), M.Sc(Otago)

SUBMITTED FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
IN
GEOLGY
AT
ROYAL HOLLOWAY AND BEDFORD NEW COLLEGE
UNIVERSITY OF LONDON, EGHAM HILL, EGHAM, SURREY TW20 0EX, GREAT BRITAIN
MAY 1986

Certified by Supervisor : Dr A J BARBER
Reported to : 1. The British Council
           2. Geological Research and Development Centre,
              Directorate General of Geology and Mineral
              Resources, Department of Mines and Energy,
              Indonesia
Between 1981 and 1982 the Banjarmasin Quadrangle in South-East Kalimantan was mapped by the Geological Research and Development Centre, Bandung at the scale of 1 : 250,000. This thesis reports the results of a follow-up study to the mapping programme, which was directed towards determining the age, origin and tectonic evolution of the Pre-Tertiary rocks which form the Meratus Mountains in the eastern part of the Banjarmasin Sheet.

The study consists of detailed field-mapping of Pre-Tertiary rocks in well exposed river sections at the scale of 1 : 10,000. Measured sections of sedimentary units were made and all structural features were recorded. A comprehensive collection of rock samples was made for laboratory studies. Thin sections were used to determine the composition and origin of sedimentary and igneous rocks. Macro- and microfossils have been examined to determine the depositional environments and the ages of the sedimentary units.

From these studies the Pre-Tertiary rocks are divided into a number of tectonostratigraphic units, whose age, origin, structural and tectonic evolution has been determined as far as possible. This information has been used to compile a synthesis of the tectonic development of the Meratus Mountains in the context of plate tectonics and the development of the western Indonesian region.

Isotopic and palaeontological dating has shown that the units exposed in the Meratus Mountains range in age from Early Cretaceous to Early Palaeocene. The oldest unit is the Paniungan Formation of Berriasian to Barremian age. It grades upward into the Upper Barremian to Lower Aptian Batununggal Formation. These formations are interpreted as shelf to slope sediments. It is suggested that shortly after deposition, most parts of the shelf to slope sediments were juxtaposed by strike-slip faulting with oceanic crust now represented by the Meratus Ophiolite Complex. Subduction generated a calcalkaline volcanic arc which then collided with the Sunda continent in the Cenomanian time. This collision zone was disrupted and sliced by strike-slip faults, forming a pull-apart basin within it. The absence of Palaeocene to Lower Eocene deposits reflects uplift, subsequently followed by rifting, regional subsidence and deposition of an Eocene-Miocene transgressive sequence. The present configuration of the Meratus Mountains resulted from late Middle Miocene and Plio-Pleistocene tectonic events.
# CONTENTS

**ABSTRACT**

**ACKNOWLEDGEMENTS**

## CHAPTER I  INTRODUCTION

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>1</td>
</tr>
<tr>
<td>1.2</td>
<td>1</td>
</tr>
<tr>
<td>1.3</td>
<td>3</td>
</tr>
<tr>
<td>1.4</td>
<td>5</td>
</tr>
<tr>
<td>1.5</td>
<td>6</td>
</tr>
</tbody>
</table>

## CHAPTER II  GEOLOGICAL AND TECTONIC SETTING

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>7</td>
</tr>
<tr>
<td>2.2</td>
<td>13</td>
</tr>
<tr>
<td>2.3</td>
<td>15</td>
</tr>
</tbody>
</table>

## CHAPTER III  MERATUS OPHIOLITE

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>17</td>
</tr>
<tr>
<td>3.1.1</td>
<td>17</td>
</tr>
<tr>
<td>3.1.2</td>
<td>21</td>
</tr>
<tr>
<td>3.1.3</td>
<td>22</td>
</tr>
<tr>
<td>3.1.4</td>
<td>22</td>
</tr>
<tr>
<td>3.1.5</td>
<td>22</td>
</tr>
<tr>
<td>3.1.5.1</td>
<td>28</td>
</tr>
<tr>
<td>3.1.5.2</td>
<td>40</td>
</tr>
<tr>
<td>3.1.5.3</td>
<td>49</td>
</tr>
<tr>
<td>3.1.6</td>
<td>51</td>
</tr>
<tr>
<td>3.1.7</td>
<td>51</td>
</tr>
<tr>
<td>3.1.8</td>
<td>54</td>
</tr>
<tr>
<td>3.2</td>
<td>56</td>
</tr>
<tr>
<td>3.2.1</td>
<td>56</td>
</tr>
<tr>
<td>3.2.2</td>
<td>56</td>
</tr>
<tr>
<td>3.2.2.1</td>
<td>56</td>
</tr>
<tr>
<td>3.2.2.2</td>
<td>63</td>
</tr>
<tr>
<td>3.2.3</td>
<td>63</td>
</tr>
<tr>
<td>3.2.4</td>
<td>64</td>
</tr>
<tr>
<td>3.2.5</td>
<td>64</td>
</tr>
</tbody>
</table>
# CHAPTER IV  SEDIMENTARY DEPOSITS

## 4.1 PANIUNGAN FORMATION

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1.1 Introduction</td>
<td>66</td>
</tr>
<tr>
<td>4.1.2 Definition</td>
<td>66</td>
</tr>
<tr>
<td>4.1.3 Occurrence</td>
<td>68</td>
</tr>
<tr>
<td>4.1.4 Field Description</td>
<td>69</td>
</tr>
<tr>
<td>4.1.4.1 Northwestern Province: Julung-Paniungan</td>
<td>69</td>
</tr>
<tr>
<td>A. Paniungan Traverse and Adjacent Area</td>
<td>71</td>
</tr>
<tr>
<td>B. Julung and Tiwaang Traverses</td>
<td>84</td>
</tr>
<tr>
<td>4.1.4.2 Southeastern Province: Sungai Satui</td>
<td>87</td>
</tr>
<tr>
<td>4.1.5 Age and Correlation</td>
<td>97</td>
</tr>
<tr>
<td>4.1.6 Environment of Deposition</td>
<td>100</td>
</tr>
<tr>
<td>4.1.7 Source Areas</td>
<td>102</td>
</tr>
<tr>
<td>4.1.7.1 Terrigenous Source</td>
<td>102</td>
</tr>
<tr>
<td>4.1.7.2 Calcium Carbonate Source</td>
<td>103</td>
</tr>
<tr>
<td>4.1.7.3 Tuffaceous Source</td>
<td>104</td>
</tr>
</tbody>
</table>

## 4.2 BATUNUNGGAL FORMATION

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2.1 Introduction</td>
<td>105</td>
</tr>
<tr>
<td>4.2.2 Definition</td>
<td>106</td>
</tr>
<tr>
<td>4.2.3 Occurrence</td>
<td>106</td>
</tr>
<tr>
<td>4.2.4 Description of Lithology and Petrography</td>
<td>110</td>
</tr>
<tr>
<td>4.2.4.1 Northwestern Province: Tambak and Tamban</td>
<td>110</td>
</tr>
<tr>
<td>A. Sungai Kintap</td>
<td>113</td>
</tr>
<tr>
<td>A.1 Bioclastic Limestone (packstone) Lithofacies</td>
<td>114</td>
</tr>
<tr>
<td>A.2 Ammonite foraminiferid-bearing lithofacies</td>
<td>117</td>
</tr>
<tr>
<td>A.3 Massive Limestone (wackestone and packstone) Lithofacies</td>
<td>122</td>
</tr>
<tr>
<td>A.4 Argillaceous Limestone (Lime Mudstone) and Orbitolina bearing bioclastic limestone (wackestone and packstone) Lithofacies</td>
<td>124</td>
</tr>
<tr>
<td>A.5 Sponge Spicular Limestone Lithofacies</td>
<td>128</td>
</tr>
<tr>
<td>B. Sungai Batubeguntur</td>
<td>132</td>
</tr>
<tr>
<td>B.1 Massive Limestone Sub lithofacies</td>
<td>132</td>
</tr>
<tr>
<td>B.2 Bedded Orbitolina-bearing Limestone Sublithofacies</td>
<td>135</td>
</tr>
<tr>
<td>B.3 Graded Limestone Sublithofacies</td>
<td>137</td>
</tr>
<tr>
<td>4.2.5 Age and Correlation</td>
<td>138</td>
</tr>
<tr>
<td>4.2.6 Depositional Environments</td>
<td>141</td>
</tr>
</tbody>
</table>

## 4.3 PITANAK FORMATION

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.3.1 Description</td>
<td>149</td>
</tr>
<tr>
<td>4.3.2 Age</td>
<td>151</td>
</tr>
<tr>
<td>4.3.3 Environment and Source</td>
<td>152</td>
</tr>
</tbody>
</table>
CHAPTER V  ALINO GROUP: SUBMARINE VOLCANICLASTIC DEPOSITS

5.1 INTRODUCTION 153

5.2 PUDAK FORMATION: Coarse Volcano - Sedimentary Deposits 154

5.2.1 Definition 154
5.2.2 Occurrence 156
5.2.3 Southern Belt: Pudak - Satui - Parang Ilang 156
5.2.4 Northern Belt: Gunung Keramaian - Imban 157
5.2.4.1 Description of Lithology, Petrography and Structures 160
A.1 Plutonic Breccia Conglomerate 162
A.2 Polymictic Breccia Conglomerate - "Melange" 163
A.3 Volcanic Breccia Conglomerate 182
A.4 Radiolarian Volcanic Mudstone 190
A.5 Volcaniclastic Turbidite 192
A.6 Limestone Breccia Conglomerate 198
5.2.5 Depositional Environment 204

5.3 KERAMAIAN FORMATION: VOLCANICLASTIC TURBIDITE WITH CHERT 208

5.3.1 Definition 208
5.3.2 Occurrence 208
5.3.3 Northern Belt: Keramaian-Waringin-Batarung-Kuringkit 213
5.3.4 Southern Belt: Satui River Section 213
5.3.4.1 Description of Lithology 216
A.1 Volcanic Sandstone 217
A.2 Volcanic Mudstone 222
A.3 Cherts with or without Radiolarians 223
5.3.4.2 Petrography 231
B.1 CFX-PL-bearing volcanic litharenite 234
B.2 Lithic Volcanic CFX-PL Arenite 237
B.3 Pure Volcanic Litharenite 238
B.4 Volcanic Carbonate Litharenite 239
5.3.5 Depositional Environment 241

5.4 PALEONTOLOGY AND AGE 249

CHAPTER VI  MANUNGGUL GROUP: VOLCANIC AND SEDIMENTARY STRATA

6.1 INTRODUCTION 250
6.2 DEFINITION 251
6.3 OCCURRENCE 251
6.4 SUBDIVISION OF THE MANUNGGUL GROUP

6.4.1 Southern Portion of the Manunggul Basin
   - Riam Kanan Subbasin

6.4.2 Northern Portion of the Manunggul Basin
   - Riam Kiwa Subbasin

6.5 PAMALI FORMATION

6.5.1 Name and Type Section

6.5.2 Description of Lithology and Interpretation
   6.5.2.1 Riam Kanan Subbasin
      A.1 Lower Member
      A.2 Upper Member
      A.3 Petrography
      A.4 Environment of Deposition
   6.5.2.2 Riam Kiwa Subbasin
      B.1 Sungai Paning-Paning and Tambulihin
      B.2 Sungai Pitanak and Hananai
      B.3 Petrography
      B.4 Environment of Deposition

6.5.3 Age of the Pamali Formation

6.5.4 Synthesis

6.6 BENUARIAM VOLCANIC FORMATION

6.6.1 Name and Type Section

6.6.2 Lithological Characteristics
   6.6.2.1 Paau Volcanic Breccia
   6.6.2.2 Malinau Basaltic Andesite
   6.6.2.3 Mandiangin Rhyolite

6.6.3 Age

6.6.4 Source and Depositional Environment

6.7 TABATAN FORMATION

6.7.1 Name and Type Section

6.7.2 Occurrence

6.7.3 Description of Lithology
   6.7.3.1 Mihak Member - Conglomerate and Sandstone
   6.7.3.2 Pahiyangan Member - Sandstone

6.7.4 Age

6.7.5 Environment of Deposition

6.7.6 Provenance

6.8 RANTAULAJUNG FORMATION - ESTHERID BEARING BLACK SHALE

6.8.1 Name and Type Section

6.8.2 Occurrence and Description of Lithology

6.8.3 Age

6.8.4 Environment of Deposition

Page 255
Page 255
Page 256
Page 257
Page 258
Page 258
Page 259
Page 269
Page 274
Page 279
Page 280
Page 282
Page 289
Page 295
Page 303
Page 315
Page 320
Page 321
Page 324
Page 324
Page 324
Page 327
Page 329
Page 329
Page 331
Page 332
Page 332
Page 334
Page 334
Page 338
Page 340
Page 340
Page 341
Page 342
Page 342
Page 343
Page 343
Page 343
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.9</td>
<td>KAYUJOHARA VOLCANIC FORMATION</td>
<td>344</td>
</tr>
<tr>
<td>6.9.1</td>
<td>Name and Type Section</td>
<td>344</td>
</tr>
<tr>
<td>6.9.2</td>
<td>Lithology and Petrography</td>
<td>344</td>
</tr>
<tr>
<td>6.9.3</td>
<td>Alimukim Agglomerate</td>
<td>345</td>
</tr>
<tr>
<td>6.10</td>
<td>INTRUSIVE ROCKS</td>
<td>347</td>
</tr>
<tr>
<td>6.10.1</td>
<td>Julung Microdiorite</td>
<td>347</td>
</tr>
<tr>
<td>6.10.2</td>
<td>Age</td>
<td>348</td>
</tr>
</tbody>
</table>

**CHAPTER VII** PLUTONIC ROCKS

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>INTRODUCTION</td>
<td>349</td>
</tr>
<tr>
<td>7.2</td>
<td>RIMUH PLUTONIC COMPLEX</td>
<td>349</td>
</tr>
<tr>
<td>7.2.1</td>
<td>Description</td>
<td>349</td>
</tr>
<tr>
<td>7.2.2</td>
<td>Age</td>
<td>352</td>
</tr>
<tr>
<td>7.3</td>
<td>KINTAP GRANITE</td>
<td>352</td>
</tr>
<tr>
<td>7.3.1</td>
<td>Description</td>
<td>352</td>
</tr>
<tr>
<td>7.3.2</td>
<td>Age</td>
<td>355</td>
</tr>
</tbody>
</table>

**CHAPTER VIII** DISCUSSION AND CONCLUSIONS

Geological and Tectonic Evolution of the Meratus Mountains

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1</td>
<td>INTRODUCTION</td>
<td>357</td>
</tr>
<tr>
<td>8.2</td>
<td>BERRIASIAN–EARLY Aptian: Shelf to Slope Sedimentation</td>
<td>359</td>
</tr>
<tr>
<td>8.3</td>
<td>LATE Aptian–Early Albian: Subduction and Ophiolite Emplacement</td>
<td>366</td>
</tr>
<tr>
<td>8.4</td>
<td>LATE Albian–Early Cenomanian: Volcanic Arc</td>
<td>373</td>
</tr>
<tr>
<td>8.5</td>
<td>LATE Cenomanian–Early Turonian: Arc– Continent Collision, Final Ophiolite Emplacement, Renewed Subduction– And Strike-Slip Movement</td>
<td>375</td>
</tr>
<tr>
<td>8.6</td>
<td>LATE Turonian–Early Danian: Pull-Apart Basin</td>
<td>380</td>
</tr>
</tbody>
</table>

CONCLUSIONS | 384
RECOMMENDATIONS FOR FUTURE RESEARCH | 387

**BIBLIOGRAPHY** | 390

**ENCLOSURE - Geological Map of the Banjarmasin Quadrangle**
<table>
<thead>
<tr>
<th>Fig.</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Map showing location of the area studied</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Regional Map of Western Indonesia</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Map of physiography</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>A Monthly Rainfall</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>B Average Temperature</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>Tectonic framework of the Indonesian Archipelago</td>
<td>14</td>
</tr>
<tr>
<td>6</td>
<td>Distribution of rock-units within the Meratus Ophiolite</td>
<td>18</td>
</tr>
<tr>
<td>7</td>
<td>Morphologic features of the Ophiolite in the Manjam Range</td>
<td>19</td>
</tr>
<tr>
<td>8</td>
<td>Morphologic features of the Ophiolite in the Ambungan Range</td>
<td>19</td>
</tr>
<tr>
<td>9</td>
<td>View of Dewa Point</td>
<td>20</td>
</tr>
<tr>
<td>10</td>
<td>Dewa Point showing typical foreshore exposure</td>
<td>20</td>
</tr>
<tr>
<td>11</td>
<td>Sungai Pudak Traverse</td>
<td>23</td>
</tr>
<tr>
<td>12</td>
<td>Geological traverse across the Manjam Range</td>
<td>24</td>
</tr>
<tr>
<td>13</td>
<td>Upper Satui Traverse</td>
<td>25</td>
</tr>
<tr>
<td>14</td>
<td>Geological traverse across the Bobaris Range</td>
<td>26</td>
</tr>
<tr>
<td>15</td>
<td>Paning-Paning Traverse</td>
<td>27</td>
</tr>
<tr>
<td>16</td>
<td>Structural and textural deformation of the Ultramafic rocks</td>
<td>30</td>
</tr>
<tr>
<td>17</td>
<td>Rhythmic layering in peridotite, Sungai Paau</td>
<td>30</td>
</tr>
<tr>
<td>18</td>
<td>OL-OPX-CPX triangular diagram</td>
<td>35</td>
</tr>
<tr>
<td>19</td>
<td>Photomicrograph of serpentinite showing mesh structure</td>
<td>36</td>
</tr>
<tr>
<td>20</td>
<td>Photomicrograph of serpentinised harzburgite, Sungai Satui</td>
<td>36</td>
</tr>
<tr>
<td>21</td>
<td>Photomicrograph of clinopyroxenite, Gunung Melati</td>
<td>37</td>
</tr>
<tr>
<td>22</td>
<td>Photomicrograph of Iherzolite, Manjam Range</td>
<td>37</td>
</tr>
<tr>
<td>23</td>
<td>Photomicrograph of chromite in harzburgite</td>
<td>38</td>
</tr>
<tr>
<td>24</td>
<td>Photomicrograph of pull-apart fractures in serpentinized peridotite</td>
<td>38</td>
</tr>
<tr>
<td>25</td>
<td>Layering in gabbro</td>
<td>42</td>
</tr>
<tr>
<td>26</td>
<td>Photomicrograph of allotriomorphic granular gabbro (layered)</td>
<td>44</td>
</tr>
<tr>
<td>27</td>
<td>Photomicrograph of hypidiomorphic granular gabbro (massive)</td>
<td>44</td>
</tr>
<tr>
<td>Fig.</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Photomicrograph of dolerite with ophitic texture</td>
<td>48</td>
</tr>
<tr>
<td>29</td>
<td>Photomicrograph of metadolerite</td>
<td>48</td>
</tr>
<tr>
<td>30</td>
<td>Columnar section of ophiolite in the Meratus Mountains, compared with other ophiolites</td>
<td>52</td>
</tr>
<tr>
<td>31</td>
<td>Map showing distribution of the Paniungan Formation and the Batununggal Formation</td>
<td>67</td>
</tr>
<tr>
<td>32</td>
<td>Section of the upper contact of the Paniungan Formation in the Sungai Satui</td>
<td>68</td>
</tr>
<tr>
<td>33</td>
<td>Geological traverse in the Sungai Paniungan</td>
<td>70</td>
</tr>
<tr>
<td>34</td>
<td>Parallel laminated mudstone of the Paniungan Formation</td>
<td>73</td>
</tr>
<tr>
<td>35</td>
<td>Slightly sheared sediments of the Paniungan Formation</td>
<td>73</td>
</tr>
<tr>
<td>36</td>
<td>Highly sheared mudstone of the Paniungan Formation</td>
<td>74</td>
</tr>
<tr>
<td>37</td>
<td>Limestone concretion in highly fractured mudstone</td>
<td>74</td>
</tr>
<tr>
<td>38</td>
<td>Thick sandstone beds in the mudstone</td>
<td>75</td>
</tr>
<tr>
<td>39</td>
<td>Close-up of the thickest sandstone bed in the mudstone</td>
<td>75</td>
</tr>
<tr>
<td>40</td>
<td>Outcrop of the Paniungan Formation at Sungai Naranin</td>
<td>76</td>
</tr>
<tr>
<td>41</td>
<td>Photomicrograph of calcareous laminated mudstone</td>
<td>79</td>
</tr>
<tr>
<td>42</td>
<td>Photomicrograph of calcareous siltstone</td>
<td>79</td>
</tr>
<tr>
<td>43</td>
<td>Photomicrograph of calcareous sandstone</td>
<td>82</td>
</tr>
<tr>
<td>44</td>
<td>Photomicrograph of calcareous sandstone</td>
<td>82</td>
</tr>
<tr>
<td>45</td>
<td>Geological traverse along Sungai Julung</td>
<td>85</td>
</tr>
<tr>
<td>46</td>
<td>Geological traverse along Sungai Tiwaang</td>
<td>86</td>
</tr>
<tr>
<td>47</td>
<td>Geological traverse in the Sungai Satui</td>
<td>88</td>
</tr>
<tr>
<td>48</td>
<td>Stratigraphic section of the Paniungan Formation</td>
<td>91</td>
</tr>
<tr>
<td>49</td>
<td>Photomicrograph of calcareous terrigenous sandstone intercalation</td>
<td>94</td>
</tr>
<tr>
<td>50</td>
<td>Photomicrograph of detrital grains of plutonic and volcanic rocks</td>
<td>94</td>
</tr>
<tr>
<td>51</td>
<td>Photomicrograph of porphyritic volcanic fragments</td>
<td>95</td>
</tr>
<tr>
<td>52</td>
<td>Photomicrograph of microlitic and felsitic grains in the sandstone</td>
<td>95</td>
</tr>
</tbody>
</table>
Fig.

53 Photomicrograph of pebble grade granodiorite in the Orbitolina-bearing limestone at Batununggal in the Sungai Kendihin 108

54 Photomicrograph of pebble grade granite occurring in the Orbitolina-bearing limestone 108

55 Photomicrograph of bryozoan-rich lime packstone-boundstone 111

56 Photomicrograph of *Orbitolina* wackestone 111

57 Geological traverse in the Sungai Kintap 115

58 Photomicrograph of echinoderm molluscan-rich lime packstone 116

59 Photomicrograph of fine-grained echinoderm molluscan-rich lime packstone 116

60 Photomicrograph of planktonic foraminiferid-rich lime mudstone 119

61 Photomicrograph of endolithic fungal borings in the neomorphosed bioclastic grains 119

62 *Costidiscus* sp. juv. from argillaceous limestone 120

63 Barremites sp. juv. from argillaceous limestone 120

64 Valdedorsella sp. juv. from argillaceous limestone 121

65 *Silisites* sp. juv. from argillaceous limestone 121

66 Photomicrograph of bioclastic peloidal wackestone clast in the lime mudstone 123

67 Photomicrograph of internal structure of a pebble grade coral fragment in the lime mudstone-wackestone 123

68 Folds and faults developed in argillaceous limestone and *Orbitolina*-bearing limestone 125

69 Extensional calcite veins in well indurated *Orbitolina*-bearing limestone 125

70 Photomicrograph of *Orbitolina* (*Mesorbitolina*) *parva* DOUGLAS in bioclastic wackestone-packstone 127

71 Photomicrograph of *Palorbitolina lenticularis* (BLUMENBACH) 127

72 Geological map showing location and position of Batununggul Formation in the Sungai Batubeguntur 133

73 Stratigraphic section of the Batununggul Formation in the Sungai Batubeguntur 134

74 Graded limestone turbidite 138
<table>
<thead>
<tr>
<th>Fig.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>Map showing distribution of the Pudak and Keramaian Formations of the Alino Group</td>
<td>155</td>
</tr>
<tr>
<td>76</td>
<td>Geological traverse in the Sungai Pudak</td>
<td>158</td>
</tr>
<tr>
<td>77</td>
<td>Geological traverse in the Sungai Satui</td>
<td>159</td>
</tr>
<tr>
<td>78</td>
<td>Geological map of the northeastern end of the Northern Belt</td>
<td>161</td>
</tr>
<tr>
<td>79</td>
<td>Photomicrograph of altered hornblende diorite</td>
<td>165</td>
</tr>
<tr>
<td>80</td>
<td>Photomicrograph of altered gabbro</td>
<td>165</td>
</tr>
<tr>
<td>81</td>
<td>Highly sheared matrix-supported polymictic conglomerate &quot;melange&quot; in the Sungai Pudak</td>
<td>166</td>
</tr>
<tr>
<td>82</td>
<td>Matrix of the polymictic breccia conglomerate &quot;melange&quot;</td>
<td>166</td>
</tr>
<tr>
<td>83</td>
<td>Close-up of cataclastic texture in the matrix of the melange</td>
<td>169</td>
</tr>
<tr>
<td>84</td>
<td>Photomicrograph showing an asymmetrical microfold</td>
<td>169</td>
</tr>
<tr>
<td>85</td>
<td>Block of <em>Orbitolina</em>-bearing limestone in the Sungai Pudak</td>
<td>171</td>
</tr>
<tr>
<td>86</td>
<td>Block of recrystallised <em>Orbitolina</em>-bearing limestone in the Sungai Satui</td>
<td>171</td>
</tr>
<tr>
<td>87</td>
<td>Photomicrograph of sponge spicular mudstone block</td>
<td>174</td>
</tr>
<tr>
<td>88</td>
<td>Photomicrograph of planktonic foraminiferid mudstone</td>
<td>174</td>
</tr>
<tr>
<td>89</td>
<td>Photomicrograph of nodular limestone</td>
<td>176</td>
</tr>
<tr>
<td>90</td>
<td>Photomicrograph of structural slicing in the nodules</td>
<td>176</td>
</tr>
<tr>
<td>91</td>
<td>Photomicrograph of typical plagioclase-bearing sandstone clast</td>
<td>180</td>
</tr>
<tr>
<td>92</td>
<td>Photomicrograph of seriate-textured basalt clast</td>
<td>180</td>
</tr>
<tr>
<td>93</td>
<td>Photomicrograph of augite-plagioclase-phyric basalt clast</td>
<td>181</td>
</tr>
<tr>
<td>94</td>
<td>Photomicrograph of foliated radiolarian chert clast</td>
<td>181</td>
</tr>
<tr>
<td>95</td>
<td>Volcanic breccia conglomerate in the Sungai Pudak</td>
<td>183</td>
</tr>
<tr>
<td>96</td>
<td>Volcanic breccia conglomerate in the Sungai Satui</td>
<td>183</td>
</tr>
<tr>
<td>97</td>
<td>Volcanic breccia conglomerate in the Northern Belt</td>
<td>185</td>
</tr>
<tr>
<td>98</td>
<td>Surface-cut view of volcanic breccia conglomerate</td>
<td>185</td>
</tr>
<tr>
<td>99</td>
<td>Photomicrograph of porphyritic andesite clast</td>
<td>188</td>
</tr>
<tr>
<td>100</td>
<td>Photomicrograph of trachytic microdiorite clast</td>
<td>188</td>
</tr>
<tr>
<td>Fig.</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>101</td>
<td>Polished section of sponge spicule-radiolarian mudstones</td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>Close-up of alternation of graded radiolarian terrigenous mudstone</td>
<td></td>
</tr>
<tr>
<td>103</td>
<td>Measured section of volcaniclastic turbidite</td>
<td></td>
</tr>
<tr>
<td>104</td>
<td>Photomicrograph of clinopyroxene in limestone clast</td>
<td></td>
</tr>
<tr>
<td>105</td>
<td>Photomicrograph of trondhjemite clast</td>
<td></td>
</tr>
<tr>
<td>106</td>
<td>Measured section of the limestone breccia conglomerate</td>
<td></td>
</tr>
<tr>
<td>107</td>
<td>Exposure of the limestone breccia conglomerate and associated rocks in Parang Ilang</td>
<td></td>
</tr>
<tr>
<td>108</td>
<td>Close-up of Fig. 107</td>
<td></td>
</tr>
<tr>
<td>109</td>
<td>Surface-cut view of the limestone breccia conglomerate</td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>Photomicrograph of limestone breccia conglomerate</td>
<td></td>
</tr>
<tr>
<td>111</td>
<td>Photomicrograph of upper part of limestone breccia conglomerate</td>
<td></td>
</tr>
<tr>
<td>112</td>
<td>Geological traverse along the road at the summit of Gunung Keramaian</td>
<td></td>
</tr>
<tr>
<td>113</td>
<td>Type section of Keramaian Formation</td>
<td></td>
</tr>
<tr>
<td>114</td>
<td>Thin-bedded to laminated mudstone and massive mudstone</td>
<td></td>
</tr>
<tr>
<td>115</td>
<td>Stratigraphic section of the Keramaian Formation</td>
<td></td>
</tr>
<tr>
<td>116</td>
<td>Geological map of the northeastern end of the Northern Belt showing distribution of the Keramaian Formation</td>
<td></td>
</tr>
<tr>
<td>117</td>
<td>Some stratigraphic sections of the Keramaian Formation in the Sungai Satui</td>
<td></td>
</tr>
<tr>
<td>118</td>
<td>View of the Keramaian Formation at Kuringkit</td>
<td></td>
</tr>
<tr>
<td>119</td>
<td>Close-up showing graded, parallel and rippled sandstones</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>View of well bedded volcanic sandstone turbidite in the Sungai Satui</td>
<td></td>
</tr>
<tr>
<td>121</td>
<td>Exposure of volcanic sandstone turbidite at Locality NS-613</td>
<td></td>
</tr>
<tr>
<td>122</td>
<td>Close-up of laminated volcanic mudstone</td>
<td></td>
</tr>
<tr>
<td>123</td>
<td>Close-view of radiolarian chert at Locality NS-859</td>
<td></td>
</tr>
</tbody>
</table>
| 124  | Photomicrographs of cherts of the Keramaian Formation  
A Chert with few radiolarians  
B Radiolarian chert |
<table>
<thead>
<tr>
<th>Fig.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>SEM photographs of radiolarians</td>
<td>228-30</td>
</tr>
<tr>
<td>126</td>
<td>Photomicrograph of CPX-PL bearing volcanic litharenite</td>
<td>232</td>
</tr>
<tr>
<td>127</td>
<td>Photomicrograph of lithic volcanic CPX-PL arenite</td>
<td>232</td>
</tr>
<tr>
<td>128</td>
<td>Photomicrograph of pure volcanic litharenite</td>
<td>233</td>
</tr>
<tr>
<td>129</td>
<td>Photomicrograph of lithic volcanic carbonate litharenite</td>
<td>233</td>
</tr>
<tr>
<td>130</td>
<td>Photomicrographs of lithic grain types in volcanic sandstones</td>
<td>242</td>
</tr>
<tr>
<td></td>
<td>A Stretched meta quartz</td>
<td>243</td>
</tr>
<tr>
<td></td>
<td>B Siltstone</td>
<td>243</td>
</tr>
<tr>
<td></td>
<td>C Gabbro</td>
<td>244</td>
</tr>
<tr>
<td></td>
<td>D Dolerite</td>
<td>244</td>
</tr>
<tr>
<td></td>
<td>E Trondhjemite</td>
<td>245</td>
</tr>
<tr>
<td></td>
<td>F Pyroxenite</td>
<td>245</td>
</tr>
<tr>
<td>131</td>
<td>Geological map showing distribution and subdivision of the Manunggul Group</td>
<td>253</td>
</tr>
<tr>
<td>132</td>
<td>Geological map along Sungai Pamali</td>
<td>260</td>
</tr>
<tr>
<td>133</td>
<td>View showing type section of the Pamali Formation</td>
<td>261</td>
</tr>
<tr>
<td>134</td>
<td>Close-view of ophiolitic pebbly conglomerate</td>
<td>261</td>
</tr>
<tr>
<td>135</td>
<td>Geological traverse along the upper course of the Sungai Paau</td>
<td>262</td>
</tr>
<tr>
<td>136</td>
<td>Stratigraphic section of the Pamali Formation</td>
<td>263</td>
</tr>
<tr>
<td>137</td>
<td>Thick bedded sandstone of the Pamali Formation</td>
<td>264</td>
</tr>
<tr>
<td>138</td>
<td>Typical feature of the pebble concentration in the sandstone</td>
<td>264</td>
</tr>
<tr>
<td>139</td>
<td>Geological traverse along Sungai Julung</td>
<td>267</td>
</tr>
<tr>
<td>140</td>
<td>Geological traverse along Sungai Tiwaang</td>
<td>268</td>
</tr>
<tr>
<td>141</td>
<td>Cylindrites sp.</td>
<td>270</td>
</tr>
<tr>
<td>142</td>
<td>Actaeonella/Cylindrites</td>
<td>270</td>
</tr>
<tr>
<td>143</td>
<td>Very coarse pebbly conglomerate</td>
<td>272</td>
</tr>
<tr>
<td>144</td>
<td>Crude graded pebbly conglomerate</td>
<td>272</td>
</tr>
<tr>
<td>145</td>
<td>Calcareous litharenite of the Pamali Formation</td>
<td>276</td>
</tr>
<tr>
<td>146</td>
<td>Photomicrograph showing transported Orbitolina fossil in the calcareous litharenite</td>
<td>276</td>
</tr>
<tr>
<td>147</td>
<td>Photomicrograph of arkosic plutarenite</td>
<td>277</td>
</tr>
<tr>
<td>148</td>
<td>Photomicrograph of oolitic terrigenous calcarenite</td>
<td>277</td>
</tr>
<tr>
<td>Fig.</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>149</td>
<td>Geological traverse in the upper Sungai Paning-Paning</td>
<td>283</td>
</tr>
<tr>
<td>150</td>
<td>Geological traverse in the Sungai Tambulihan</td>
<td>284</td>
</tr>
<tr>
<td>151</td>
<td>Exposure of sandstone in the Sungai Tambulihan</td>
<td>285</td>
</tr>
<tr>
<td>152</td>
<td>Finely laminated mudstone</td>
<td>285</td>
</tr>
<tr>
<td>153</td>
<td>Interbedded sandstone and mudstone of the Pamali Formation</td>
<td>287</td>
</tr>
<tr>
<td>154</td>
<td>Measured section of sandstone turbidite</td>
<td>288</td>
</tr>
<tr>
<td>155</td>
<td>Submarine fan facies terminology</td>
<td>290</td>
</tr>
<tr>
<td>156</td>
<td>Stratified conglomerate with intercalation of pebbly sandstone</td>
<td>293</td>
</tr>
<tr>
<td>157</td>
<td>Close-up of conglomerate showing texture and fabric</td>
<td>293</td>
</tr>
<tr>
<td>158</td>
<td>Geological map of the northeastern corner of the Banjarmasin Quadrangle</td>
<td>296</td>
</tr>
<tr>
<td>159</td>
<td>Geological traverse in Sungai Pitanak</td>
<td>297</td>
</tr>
<tr>
<td>160</td>
<td>Geological traverse along Sungai Hananai</td>
<td>298</td>
</tr>
<tr>
<td>161</td>
<td>Interbedded sandstone and mudstone of the Pamali Formation</td>
<td>300</td>
</tr>
<tr>
<td>162</td>
<td>Thin-bedded graded sandstone with intervening mudstones</td>
<td>300</td>
</tr>
<tr>
<td>163</td>
<td>Thick-medium bedded sandstones with intervening mudstone</td>
<td>301</td>
</tr>
<tr>
<td>164</td>
<td>Parallel laminated mudstone</td>
<td>301</td>
</tr>
<tr>
<td>165</td>
<td>Matrix to clast-supported conglomerate</td>
<td>302</td>
</tr>
<tr>
<td>166</td>
<td>Matrix to clast-supported conglomerate</td>
<td>302</td>
</tr>
<tr>
<td>167</td>
<td>Surface-cut view of calcareous ultramafarenite, Sungai Paning-Paning</td>
<td>307</td>
</tr>
<tr>
<td>168</td>
<td>Surface-cut view of calcareous ultramafarenite, Sungai Pitanak</td>
<td>307</td>
</tr>
<tr>
<td>169</td>
<td>Photomicrograph of calcareous ultramafarenite</td>
<td>308</td>
</tr>
<tr>
<td>170</td>
<td>Photomicrograph of schistose metagabbro clast</td>
<td>308</td>
</tr>
<tr>
<td>171</td>
<td>Photomicrograph of quartz-muscovite-chlorite-epidote-garnet schist clast</td>
<td>309</td>
</tr>
<tr>
<td>172</td>
<td>Photomicrograph of radiolarian micrite clast</td>
<td>309</td>
</tr>
<tr>
<td>173</td>
<td>Photomicrograph of terrigenous calcarenite</td>
<td>311</td>
</tr>
<tr>
<td>174</td>
<td>Photomicrograph of volcarenite</td>
<td>311</td>
</tr>
<tr>
<td>Fig.</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>------</td>
<td>------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>175</td>
<td>Photomicrograph of PL-PX phryic andesite clast</td>
<td>312</td>
</tr>
<tr>
<td>176</td>
<td>Photomicrograph of plagioclase-phyric andesite clast</td>
<td>312</td>
</tr>
<tr>
<td>177</td>
<td>Photomicrograph of lath-shaped plagioclase-bearing lava andesite clast</td>
<td>313</td>
</tr>
<tr>
<td>178</td>
<td>Photomicrograph of calcareous arkosic volcanenite</td>
<td>313</td>
</tr>
<tr>
<td>179</td>
<td>Photomicrograph of arkosic volcanenite, Sungai Tambulihin</td>
<td>316</td>
</tr>
<tr>
<td>180</td>
<td>Photomicrograph of arkosic volcanenite, Sungai Pitanak</td>
<td>316</td>
</tr>
<tr>
<td>181</td>
<td>Photomicrograph of arkosic volcanenite, Sungai Hananai</td>
<td>317</td>
</tr>
<tr>
<td>182</td>
<td>Photomicrograph of plagioclase andesite clast</td>
<td>317</td>
</tr>
<tr>
<td>183</td>
<td>Photomicrograph of pyroxene andesite clast</td>
<td>318</td>
</tr>
<tr>
<td>184</td>
<td>Photomicrograph of hornblende andesite clast</td>
<td>318</td>
</tr>
<tr>
<td>185</td>
<td>Schematic reconstruction of the depositional environment of the Pamali Formation in the Riam Kanan and Riam Kiwa Subbasins</td>
<td>323</td>
</tr>
<tr>
<td>186</td>
<td>Boulders of matrix-supported volcanic breccia of the Paau Volcanic Breccia</td>
<td>325</td>
</tr>
<tr>
<td>187</td>
<td>Stratified breccia tuff of the Paau Volcanic Breccia</td>
<td>325</td>
</tr>
<tr>
<td>188</td>
<td>Basaltic andesite lava in the Sungai Malinau</td>
<td>328</td>
</tr>
<tr>
<td>189</td>
<td>Type section of the Mandiangin Rhyolite</td>
<td>330</td>
</tr>
<tr>
<td>190</td>
<td>Exposure of rhyolite in the Sungai Paau</td>
<td>330</td>
</tr>
<tr>
<td>191</td>
<td>Geological traverse along Sungai Mihak</td>
<td>333</td>
</tr>
<tr>
<td>192</td>
<td>Poorly sorted, clast-supported to matrix-supported conglomerate in the Sungai Mihak</td>
<td>336</td>
</tr>
<tr>
<td>193</td>
<td>Pebbly conglomerate in the Sungai Paau</td>
<td>336</td>
</tr>
<tr>
<td>194</td>
<td>Imbricated pebbly conglomerate</td>
<td>337</td>
</tr>
<tr>
<td>195</td>
<td>Cross-bed sets in sandstone interbed of conglomerate deposit</td>
<td>337</td>
</tr>
<tr>
<td>196</td>
<td>Gunung Pahiyangan viewed from the Riam Kanan Reservoir</td>
<td>339</td>
</tr>
<tr>
<td>197</td>
<td>Close-view of the western flank of the Gunung Pahiyangan</td>
<td>339</td>
</tr>
<tr>
<td>198</td>
<td>Fresh outcrops of the Alimukim Agglomerate</td>
<td>346</td>
</tr>
<tr>
<td>199</td>
<td>Deeply weathered outcrops of the Alimukin Agglomerate</td>
<td>346</td>
</tr>
<tr>
<td>200</td>
<td>Map showing distribution of plutonic rocks</td>
<td>350</td>
</tr>
<tr>
<td>201</td>
<td>Exposure of metagabbro, metabolerite and ultramafics with granite intrusion in Sungai Hajawa</td>
<td>354</td>
</tr>
<tr>
<td>Fig.</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>202</td>
<td>Close-up of granite intrusion</td>
<td>354</td>
</tr>
<tr>
<td>203</td>
<td>Paleogeographical and tectonic sketches from Early Cretaceous to Paleocene</td>
<td>361</td>
</tr>
<tr>
<td>204</td>
<td>Series of diagrams showing tectonic evolution of SE Kalimantan</td>
<td>362</td>
</tr>
<tr>
<td>205</td>
<td>Facies model for the Paniungan and Batununggil Formations</td>
<td>365</td>
</tr>
<tr>
<td>206</td>
<td>Block diagrams showing the original emplacement of the Meratus Ophiolite</td>
<td>367</td>
</tr>
<tr>
<td>207</td>
<td>Block diagram showing the obduction of the Meratus Ophiolite</td>
<td>377</td>
</tr>
<tr>
<td>208</td>
<td>Paleogeographical and tectonic sketches showing evolution of SE Kalimantan and adjacent areas from Early Paleocene to Present Day.</td>
<td>383</td>
</tr>
<tr>
<td>Table</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Modal analysis of representative samples from ultramafic rocks</td>
<td>34</td>
</tr>
<tr>
<td>2</td>
<td>Mean framework modes of terrigenous grains of calcareous sandstone intercalations in the Paniungan Formation</td>
<td>81</td>
</tr>
<tr>
<td>3</td>
<td>Modal analysis of sandstones of the Keramaian Formation</td>
<td>235</td>
</tr>
<tr>
<td>4</td>
<td>Stratigraphic nomenclature of the Manunggul Group</td>
<td>252</td>
</tr>
<tr>
<td>5</td>
<td>Modal analysis of sandstones from the Riam Kanan Subbasin</td>
<td>275</td>
</tr>
<tr>
<td>6</td>
<td>Modal analysis of sandstones from the Riam Kiwa Subbasin</td>
<td>304</td>
</tr>
<tr>
<td>7</td>
<td>Summary of stratigraphic framework and geological evolution of the Meratus Mountains.</td>
<td>358</td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENTS

Arrangements for this study was made by Drs H M S Hartono, previously the Director of the Geological Research and Development Centre and Dr A J Barber of Chelsea College (now Royal Holloway and Bedford New College) of London University, to whom I would like first to extend my special acknowledgement and appreciation. I am indebted to the Technical Cooperation Training Department of the British Council, Great Britain, for supporting me to study in the University of London. Additional financial support was provided by the Asian Development Bank Loan Funds to the Project Implementation Office of the Indonesian Geological and Mineral Survey Project, and the Britoil ASEAN Scholarship made through the Indonesian Embassy in London. Many thanks for the help and encouragement from Mr Irawan Abidin, the former head of Information and Education Division of the Indonesian Embassy in London. This study, in one way or another, was also partly supported by University of London Consortium for Geological Research in South-East Asia. I wish to thank Dr A J Barber, Ir S Padmanagara and Drs H M S Hartono for guaranteeing a temporary loan from the Consortium/College and Miss Susie Morrow, Dra Mini Mustafa and Bapak Willy H G for all necessary administrative work.

Geological data for the study were obtained from South-East Kalimantan geological mapping activity in 1982 by the Geological Research and Development Centre. I am deeply grateful to Drs Rab Sukamto and Drs Sam Supriatna for their help from the early start of the field work until dispatching all samples needed to London. The prompt assistance from Bapak Soepardjo to dispatch samples to London is greatly appreciated. I thank all my friends and colleagues who were involved in the geological mapping activity in South-East Kalimantan, in particular R Heryanto, I Umar, K Hasan, P Sanyoto, Amiruddin, S Santoso and D Satria. Thanks also go to Messrs A H Osman and L T Blanchard Jr of P T Arutmin Indonesia who have kindly provided copies of Synthetic Aperture Radar (SAR) imagery of South-East Kalimantan.

I would like to thank my Supervisor, Dr A J Barber, who has given much guidance, direction, help, critical review and encouragement from the beginning to the completion of this thesis. Various assistance from members of the academic and technical staff of formerly Chelsea College; in particular Keith Stephens, Dr John Wright, Gerry Ingram, Neil Holloway and Kevin D'Souza; are greatly appreciated. To Professor M G Audley-Charles, S Tjokrosapoetro and Dr Robert Hall, many thanks for numerous helpful suggestions, stimulating discussions and encouragement. I also
wish to thank Professor M G Audley-Charles and the staff members of the UCL Department of Geological Sciences for providing me with a desk and Ron Dudman for technical assistance during the final stages of this thesis.

There are a number of people, with different kinds of speciality, who have contributed to this thesis. The invaluable assistance with paleontological identification from Dr H G Owen (ammonite), Dr C G Adams (foraminifera), Drs N J Morris and R Cleevely (gastropods and bivalves), all from the British Museum, is gratefully acknowledged. Thanks are due to Dr N F Hughes of the Department of Earth Sciences, University of Cambridge, for the most important identification of palynomorphs from the Paniungan Formation. I thank Dr Benita Murchey (USGS) for identifying radiolarians. Both the palynomorph slides and radiolarian residue were prepared by the generous help from Dr J K Wright. Radiometric dating was kindly helped by Dr N J Snelling and Mr David Bradly from the British Geological Survey (formerly the Institute of Geological Sciences). A number of selected and important carbonate samples were petrographically checked and briefly described by Dr Fiona Hyden. A special gratitude goes to Drs Graham and Fiona Hyden and their children Catherine and Michael who always ask when I would like to come for meal.

I wish to thank all fellow British and Indonesian postgraduate students for sharing various kinds of social activities during my study in London. To Martin Lailey, Marek Wajzer and Sarah Cook, thanks for stimulating and fruitful discussions. Many thanks go also to Tim Charlton, Susie Morrow and Steve Brindley, who have freely provided various kinds of assistance.

All the manuscript was stored into software by Miss Tania Crow, to whom I owe my sincere gratitude. Finally, I dedicate this thesis to Mapping Division of the Geological Research and Development Centre, where I had served for nearly 12 years before joining the Marine Geological Institute; and my parents, Nawawi Ramain and Alimar Ilyas, and my brothers and sisters, who have supported me morally and financially.
*Scientists still do not appear to understand sufficiently that all earth sciences must contribute evidence towards unveiling the state of our planet in earlier times, and the truth of the matter can only be reached by combining all the evidence.

A WEGENER, 1929

Translated by:
J BIRAN  1966
CHAPTER I

INTRODUCTION
1.1 LOCATION OF THE STUDY AREA

The study area for this project covers the major part of the Banjarmasin 1:250,000 Quadrangle, which lies between 3°00' - 4°15' south latitude and 114°00' - 115°30' east longitude (Fig. 1). The area is approximately 11,000 square kilometres, and is located at the southwestern end of the Meratus Mountains in the southeastern part of Kalimantan (formerly known as Borneo), the largest island in the Indonesian Archipelago and the third largest island in the world after Greenland and New Guinea. A large part of the area belongs to the administrative province of South Kalimantan, of which Banjarmasin (Lat. 3°20'S and Long. 114°35'E) is the capital city.

1.2 BACKGROUND TO PRESENT RESEARCH

Over the last eight years the Indonesian Geological Research and Development Centre (GRDC) has conducted a programme of geological mapping at 1:250,000 in South-East Kalimantan. So far 6 geological map sheets have been completed (Fig. 1). All of these geological maps, together with accompanying reports are now being reviewed and will be published shortly by the GRDC's Publication Section.

Despite the completion of these geological maps, the geology and tectonics of South-East Kalimantan as a whole still remains the centre of prolonged debate, especially regarding the nature of the Pre-Tertiary basement, on which the hydrocarbon-bearing Tertiary sedimentary strata of the Barito and Asem-Asem Basins were deposited. Because of this long-standing geological problem, and as the GRDC and Chelsea College's collaborative work continue to expand, a special arrangement was made by Drs. H.M.S. Hartono, previously the Director of the GRDC* and Dr. A.J. Barber of Chelsea College to permit the writer to study the matter at Chelsea College, University of London.

* The present Director of the GRDC is Dr. M. Untung, whilst Drs. H.M.S. Hartono is now acting as the Director of the newly formed Marine Geological Institute.
Fig. 1 Map showing location of the area studied (the Banjarmasin 1:250,000 Quadrangle, Sheet No. 1712) in South-East Kalimantan, Indonesia. Index Map (inset) showing the Indonesian Archipelago. Note: 1712 = Banjarmasin Quadrangle, 1713 = Amuntai Quadrangle, 1714 = Buntok Quadrangle, 1812 = Kotabaru Quadrangle, 1813 = Sampanahan Quadrangle and 1814 = Balikpapan Quadrangle.
The Banjarmasin 1 : 250,000 Quadrangle has recently been completed by Sikumbang et al (1982). This quadrangle proved to be significant to the understanding of the geology and tectonics of South-East Kalimantan because all the lithostratigraphical names of Mesozoic strata used in South-East Kalimantan were defined there. Therefore the Banjarmasin Quadrangle was chosen as the writer's project area.

The present study is based on descriptive geological data obtained during the CROC's geological mapping project, carried out between June-November 1981, in the Banjarmasin Quadrangle (Sikumbang et al 1982). In addition the writer spent three more months, from the middle of September to the middle of December 1982, studying a substantial number of critical sections in the map area.

As one would expect in the tropics, the outcrops in most river sections are intermittent and are not so well exposed. However, the river sections traversed during this study still yield a lot of valuable information because each outcrop was examined in detail, and the rivers were traversed during the peak of dry season. The most important river traverses are: the Pudak (Kintap) and Satui in the southeastern foothills of the Manjam Range; and the Paau, Pamali, Julung, Tiwaang, Mihak, Paniungan, Paning-Paning, Tambulihin, Pitanak and Hananai in the area between the Manjam and Tambak-Tamban Ranges (see Figs 3 and 131).

1.3 PREVIOUS WORK

In spite of the economic pre-eminence of South-East Kalimantan for the occurrence of diamonds in the sedimentary deposits of the Riam Kanan area (Koolhoven 1933 and 1935), Tertiary fuel resources in the Barito Basin (Koesoemadinata 1969; Koesomadinata et al 1978), and the tectonic interest of the so-called "Upper-Cretaceous Subduction Complex" in the Meratus Mountains (Katili 1971; 1973 and 1978;
Hamilton 1979; Asikin 1974; cf. Bemmelen 1949), the stratigraphic framework of the region, which is the basis of my geological and tectonic studies presented herein, is still in a state of chaos and has not yet been properly established. Therefore, in this present work, the confusion of naming stratigraphic units, together with their characteristics as outlined in the Indonesian Stratigraphic Code (Martodjojo 1975), and in the International Stratigraphic Guide (Hedberg 1976; see also Holland et al 1978), has to be clarified before the problems of the tectonic history of Meratus Mountains can satisfactorily be resolved.

Most previous research work was carried out between 1870 and 1935 (Verbeek 1871, 1874 and 1875; Martin 1889 a and b; Hooze 1893; Krol 1918, 1920 and 1925; Rutten 1926; and Koolhoven 1933 and 1935). They mainly dealt with reconnaissance geology (e.g. Verbeek 1875 and Krol 1918) and the occurrences of either diamonds (e.g. Koolhoven 1933 and 1935) or macrofossils (e.g. Martin 1889). These early geological investigations have been summarised and advanced by Bemmelen (1949) and Hashimoto and Koike (1973), and recently by Situmorang (1982) and Priyomarsono (1984). A métallogénie map of Indonesia (Sigit 1969), geological reports of Koolhoven (1935), Koesoemadinata (1969), Koesoemadinata et al (1978), Siregar (1975) and a report on "Iron and Steel - Project" (Anon. 1962) provide the basis for economic geological investigations.

Many attempts have been made to explain the tectonic evolution of the Meratus Mountains (Bemmelen 1949; Katili 1971, 1973, 1975 and 1978; Hamilton 1979; Suhaeli et al 1980; Situmorang 1982 and Priyomarsono 1984), but there is still disagreement about mechanism and timing of events and whether there has been a collision with obduction of the Meratus Ophiolite or whether the complex was formed by rifting (Audley-Charles 1978).
With present geological findings, obtained during the GRDC systematic geological mapping project in South-East Kalimantan, it became evident that the geology of the Banjarmasin Quadrangle is the key to answer most if not all the present geological and tectonic problems in the region.

1.4 THE AIM OF THE RESEARCH

The particular aims of this geological research are:

1. To refine the nomenclature of the Pre-Tertiary rocks, in the light of modern stratigraphic principles.
2. To establish the Pre-Tertiary stratigraphic framework of the Meratus Mountains with particular reference to the Banjarmasin 1:250,000 Quadrangle.
3. To study the relationship between Paniungan Formation and limestone strata.
4. To clarify the relationship between "ophiolite" and "submarine volcanioclastic cover" of Alino Formation and volcano-sedimentary sequence of Manunggul Formation.
5. To study the age, both paleontologically and radiometrically, sedimentology and petrography of the sedimentary, ophiolitic, metamorphic and volcanic rocks.
6. To interpret the depositional environment and provenance of each stratigraphic unit.
7. To determine the paleogeography of the Meratus Mountains.
8. To analyse the Pre-Tertiary sedimentation and tectonic patterns and the architecture of the basins.
9. To propose a more realistic tectonic model for the evolution of the Meratus Mountains.
10. To discuss how this model can be fitted in with the regional geology of Kalimantan and the surrounding islands.
In this thesis, an attempt has been made to separate the facts from the interpretations, with the hope that the geological history of the region can be firmly founded on what exists in the field.

1.5 BASE-MAP PREPARATION

Base-maps used for the mapping of the Banjarmasin Quadrangle (Sikumbang et al 1982) mostly on a scale of 1 : 50,000 (Department of Works of Indonesia and OTCA Japan, 1974), cover 70% of the mapping area. Topographic maps with a scale of 1 : 100,000 (Geological Survey of the Netherlands Indies, 1930) and 1 : 250,000 (U.S. Army Map Service, 1962) were used for the rest of the area studied.

Aerial photos are available for some parts of the Banjarmasin Quadrangle (see Sikumbang et al 1982 for the index map). They were used for refining the above topographic maps. LANDSAT already exists, but is not used because of poor quality over the area of interest. Good quality of the SAR (Synthetic Aperture Radar) imagery at scales of 1 : 100,000 and 1 : 250,000 covers a narrow area of the southern (Aero Service, 1979) and the central (Trend Energy Company 1981) portions of the Banjarmasin Quadrangle.

The results of recent field mapping as well as air photos and SAR interpretations have been put together in the form of a complete geological map at a scale of 1 : 250,000. This map is included in this thesis (see back pocket).
CHAPTER II

GEOLOGICAL AND TECTONIC SETTING
2.1 PHYSIOGRAPHY

South-East Kalimantan, which includes the islands of Pulau Laut and Sebuku to the southeast is now part of the Sunda Continent (Fig. 2). Kalimantan as a whole is separated from Sulawesi in the east by the Strait of Makassar and from Java in the south by the shallow continental shelf of the Java Sea. The Makassar Strait, which is up to 2,500 m deep and up to 250 km wide, marks the meeting of the Western or Sunda Continent and Eastern Indonesia.

South-East Kalimantan can be divided into four distinct physiographic terrains: the Meratus Mountains, the Barito Basin, Asem-Asem - Pasir Basin and Pulau Laut Ridge. These terrains continue southwestward, into the Karimun Jawa and Bawean Arches in the Java Sea, but die out westward towards the West Java and East Java Basins (Fig. 2).

The Meratus Mountains, with a J-shaped outline, form the backbone of South-East Kalimantan, surrounded by shallow to deep Tertiary basins, can be subdivided into three conspicuous northeast -trending mountain ranges (Fig. 3); Manjam in the southeast, and Bobaris and Tambak-Tamban in the northwest. These ranges are characterised by rugged topography, narrow and sharp ridges, with v-shaped valleys. The Manjam Range and the Bobaris Range converge in the southwest of the map area (Fig. 3).

The most rugged terrain is the Manjam Range, varying in height from a few hundred metres to more than 1,450 m, with the Mount Kahung being the highest point (1,456 m). The highest mountain in the Bobaris Range is Mount Melati (622 m). Furthermore, a southward continuation of the Bobaris Range is represented by two small ranges, the Dadaringan and Ambungan Ranges (see Fig. 6).

The area between the Manjam and the Bobaris - Tambak-Tamban Ranges is occupied by a graben-like basin, called the Manunggul Basin which is characterised by smooth ridges with moderate elevations,
Fig. 2. Map showing major physiographic and tectonic features of Western Indonesia (from Barber 1986). Present Pre-Tertiary outcrop (outline) in South-East Kalimantan and adjacent areas is indicated by number: 1=Meratus Mountains; 2=Pulau Laut Ridge; 3=South Sulawesi; 4=Karimun Java Arch; 5=Bawean Arch; 6=Luk-Olu and 7=Gileu. Tertiary sedimentary basins mentioned in the text: B=Barito, A=Asem-Asem-Pasir, K=Kutai, E=East Java and W=West Java.
Fig. 3. Map showing main divisions of physiography of the Banjarmasin Quadrangle. Important geographic names and type localities of the stratigraphic units are also shown on the map.
ranging from about 400 m to over 900 m (Fig. 3). The rivers and small streams that flow from the surrounding mountains drain into two main rivers, the Riam Kanan (Right River) and the Riam Kiwa (Left River). These rivers flow in a northeast-southwest direction, subparallel to the major structures of the mountain ranges (see Fig. 3).

The second terrain (Fig. 3) formed by rocks of Tertiary age, is characterised by typical hilly morphology with rounded tops, flanking the Meratus Mountains on the northwest and on the southeast. The northwestern flank is part of the Barito Basin, whereas the southeastern flank includes the northwestern margin of the Asem-Asem Basin.

The youngest terrain, which primarily consists of Pleistocene alluvial fan complexes and Holocene surficial deposits, forms a flat-lying area, occupying the western and southeastern margin of the Banjarmasin Quadrangle. The flat-lying plain of the western half (i.e. Barito Basin) is crossed by three large rivers, the Barito*, Murung and Kahayan (Fig. 3). These rivers flow in a north-south direction, in general parallel to the strike of the Meratus Mountains.

As the area studied is close to the equator, 3°0' to 4°15' south latitude, so the climate is characterised by uniformly high temperature and humidity; a typical tropical climate. The maximum temperatures range from 30°C to 33°C during November to June and 33°C to 35°C during July to October, whilst the minimum temperature is around 22°C to 24°C during November to June and 21°C to 23°C during July to October. The average temperature is shown in Fig. 4B, the temperature commonly falling to around 16°C to 22°C in mountainous areas. The humidity reaches 71-90%.

There are only two seasons. The dry and wet (rainy) seasons. The dryest months are May to October and the wettest months are November to April, with December and January having the heaviest rainfall (see Fig. 4A). As can be seen in Fig. 4A, rainfall varies
Fig. 4A Monthly rainfall in several places in the Banjarmasin 1:250,000 Sheet Area (data from the Meteorological and Geophysical Centre, Department of Communications, 1980)

Fig. 4A Average temperature in several places in the Banjarmasin 1:250,000 Sheet Area (data from the Meteorological and Geophysical Centre, Department of Communications, 1980)

Bm = Banjarmasin 03°20'LS 114°35'BT 20
Bb = Banjarbaru 03°28'LS 114°50'BT 12
Tt = Tatakan 03°03'LS 115°07'BT 15
from place to place, with yearly totals 1,860mm in the southern and 2,292mm in the northern parts of the map area.

Banjarmasin can be reached easily by three regular airlines, Garuda, Merpati and Bouraq 2 hours from Jakarta.

There are several flights per day from Jakarta and Surabaya, on the coast of East Java, to Banjarmasin. Sea transportation is also available to Banjarmasin, either from the port of Tanjung Perak in Surabaya or from Tanjung Priuk in Jakarta.

The road network is quite extensive throughout the area studied (see Fig. 3). Roads are either surfaced or unsurfaced. The surfaced road links the capital city of Banjarmasin and towns and important villages (i.e. rubber plantations and transmigration areas). Road access to the hinterland, that is to the area of the Manjam Range, the Bobaris Range and the Mannunggul Basin are mainly provided by unsurfaced timber roads which join the main towns of the districts or "kecamatan", to either main villages or to the site of timber camps.

In the southern part of the Banjarmasin Quadrangle there are two important unsurfaced roads leading toward the site of timber camps in the Manjam Range: P.T Sumpol Timber Camp in the upper Satui River (i.e. Tandui) and P.T Hutan Kintap Timber in the upper Kintap River.

From the surfaced roads, between Martapura and Binuang (see Fig. 3) there are two entrances to the central part of the Manunnggul Basin, as far as the villages near and around Paniungan River, the first from Danau Salak and the other is from Simpang Empat.

There is also a popular and most vital form of transport, which is locally called "kelotok" or in Indonesian is called the "perahu

* The Barito River is the second largest river, after the Kapuas River, in Kalimantan. This river flows approximately 900 km southward, from the Muller Mountains in Central Kalimantan.
motor", a speed-boat which ranges from ten to several hundreds Horse Power (HP). This is the main transport from coastal to inland areas.

South-East Kalimantan has a population of several million, of which more than half is concentrated in Banjarmasin and in main towns such as Pelaihari and Rantau. The population is predominantly the ethnic group of Banjar and Dayak which scattered throughout the area. Other racial groups originally come from Java and Sulawesi, and the most well-known are the Javanese, Madurese, Buginese and Makassarese.

2.2 GEOLOGICAL AND TECTONIC SETTING

The location of the Meratus Mountains with respect to the regional tectonic framework of the Indonesian Archipelagic system is shown in Fig. 5 (see also Fig. 2). The mountains form part of a northeast-southwest trending Upper Cretaceous orogenic belt which lie along the southeastern Sunda continental margin and are surrounding by four shallow to deep Tertiary basins, Kutai Basin in the north, Barito Basin in the west, and Asem-Asem and Pasir Basins in the south and east, respectively.

The Pre-Tertiary rocks of the Meratus Mountains extend south-westward as indicated by the Karimun Jawa and Bawean Arches in the Java Sea, Lok-Ulo and Ciletuh outcrops in Java and the Gumai Mountains in Sumatra; and northwards to the Suikerbrood High, just north of the Mangkalihat Peninsula and continue to northeast Kalimantan and the Philippines (Figs. 2 and 5). Similar topographical and geological characters also occur in nearby islands, Pulau Laut and Sebuku islands and a few scattered outcrops in the south arm of Sulawesi. All these Pre-Tertiary outcrops, prior to the opening of the Makassar Strait, may have formed an accretionary complex above a subduction zone formed during Upper Cretaceous time (e.g. Katili, 1971 and 1978; Hamilton, 1979 and Hartono, 1984).
FIG. 5. Tectonic framework of the Indonesian Archipelagic system, showing Cretaceous and Tertiary subduction zones and volcano-plutonic belts. Modified from Hamilton (1979), Katili (1975) and Silver and Moore (1978). Distribution of Pre-Tertiary outcrop in SE Kalimantan and adjacent areas is shown in Fig. 2.
Katili (1971) divided South-East Kalimantan into a northwestern belt of magmatic arc and a southeastern belt dominated by slices of subduction complex. Arc magmatism took place during the Upper Cretaceous and is commonly agreed to have resulted from southeast subduction (Katili 1971; Hamilton 1979 and Hartono 1984). However, Barber (pers. comm, 1985) believes that this subduction was from northwest. At the present time, and during much of the Late Tertiary and Quaternary, the Meratus Mountains have been uplifted relative to basins in either side.

2.3 STRATIGRAPHIC NOMENCLATURE

Problems regarding the usage of Pre-Tertiary stratigraphic nomenclature in the Meratus Mountains are studied and evaluated in accordance with the rules outlined in the Stratigraphic Code of Indonesia (Martodjojo 1975) and the Guide to the International Stratigraphic Code (Hedberg 1976 and Holland et al, 1978).

The new maps of South-East Kalimantan (in preparation) provide additional data to describe and interpret the complexities of stratigraphic subdivisions in the area studied. The results of recent mapping indicate that the previous stratigraphic nomenclature, which is still currently being employed by various people and organisations, should be reviewed and corrected.

The present writer has been able to review and revise all the stratigraphic names of Pre-Tertiary stratigraphic nomenclature in the Meratus Mountains (see below). This is the first attempt that has ever been made regarding the stratigraphy of the whole region in the light of modern geological concepts. The Banjarmasin Quadrangle offers an excellent opportunity to establish a reference of mapping units and as well to clear up the confusion of the existing stratigraphic nomenclature in the region.
The stratigraphy of the Meratus Mountains shown below has been prepared from the information of Krol (1920), Koolhoven (1933 and 1935) and Sikumbang et al (1982), combined with the results of recent field and laboratory observations. Fifteen mapping units are recognised. For the sake of clarity the stratigraphic subdivision are defined and placed in accordance with their presumed allochthonous or autochthonous characters. These consist of the following mapping units from bottom to top:

<table>
<thead>
<tr>
<th>AUTOCHTHONOUS</th>
<th>PARAUTOCHTHONOUS</th>
<th>ALLOCHTHONOUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEDIMENTARY/VOLCANIC</td>
<td>INTRUSIVE</td>
<td>TECTONIC</td>
</tr>
<tr>
<td>Kayujohara Volcanic Fm.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rantaulajung Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tabatan Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benuariam Volcanic Fm.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pamali Formation</td>
<td>Rimuh Plutonic Complex</td>
<td></td>
</tr>
<tr>
<td>Pitanak Volcanic Fm.</td>
<td>Kintap Granite</td>
<td></td>
</tr>
<tr>
<td>Keramaian Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pudak Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batununggal Formation</td>
<td>Paniungan Formation</td>
<td></td>
</tr>
<tr>
<td>Meratus Ophiolite</td>
<td>Pelaihari Phyllite</td>
<td></td>
</tr>
<tr>
<td>Hauran Schist</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The following chapters present the rock subdivision and descriptions of the formations comprising the Early Cretaceous to Early Tertiary rocks in the study area.
CHAPTER III

MERATUS OPHIOLITE
3.1 MERATUS OPHIOLITE

3.1.1 General Statement

Mafic - ultramafic rocks are exposed in a series of narrow strips in the Meratus Mountains, South-East Kalimantan. These rocks form two prominent northeast trending mountain ranges in the region. The main range is the Manjam (previously called Meratus*) Range, and the other is the Bobaris Range. These mountain ranges converge to the south-west of the Riam Kanan Reservoir (Fig. 6).

The study area covers the whole Bobaris Range and its southwest extension in the Dadaringan and Ambungan Ranges, and the southwestern part of the Manjam Range (Fig. 6, for detail see Geological Map). In addition, a number of mafic remnants, forming roof pendants within a complex of granitic rocks, are found in and around Rumu area in the Tamban Range, northeast of the Bobaris Range.

Most of these rocks form rugged mountainous terrain (Fig. 7) with deeply incised valleys covered by dense forest. In the Dadaringan and Ambungan Ranges the ultramafic rocks also form relatively smooth-topped hilly terrain (Fig. 8), with good outcrops restricted to the foreshore (Figs. 9 and 10).

3.1.2 Previous Work

Verbeek, Hooze and Krol (in Koolhoven, 1933) were the first to make sketch maps of the distribution of the mafic - ultramafic rocks in the area of Bobaris and Manjam Mountains. The most significant of the early geological reports concerning the occurrence of the mafic - ultramafic rocks was published by Koolhoven (1933 and 1935). These reports represent the latest publication dealing with purely descriptive geological work in the region.

* The name Meratus Mountains, as used throughout this thesis, encompasses all northeast trending mountain ranges (e.g. the Manjam and Bobaris Ranges) that occur within southeast Kalimantan, and including a hilly terrain between the Manjam and Bobaris-Tamban Ranges.
Fig. 6 . Distribution of rock-units within the complex of Meratus Ophiolite. Simplified from Sikumbang et al. 1982.
Fig. 7  Looking north towards the Manjam Range, showing the morphological features of the ophiolite. Road in foreground leads to a timber camp of P.T. Hutan Kintap in the upstream of Sungai Asem-Asem.

Fig. 8  Ambungan Range, Batakan, showing morphological features of ultramafics in the hilly terrain.
Fig. 9  View of Dewa Point at the southwestern end of the Ambungan Range (i.e. continuation of the Bobaris Range), near the village of Batakan, looking south toward Java Sea. Brecciated and locally sheared ultramafics are exposed intermittently along the foreshore (see photo below).

Fig. 10  Dewa Point, showing a foreshore exposure of brecciated and sheared ultramafics.
However, Koolhoven's work, like many others, was primarily concerned with the diamond occurrences, from which the name of Bobaris became well known for peridotite-breccia pipes, particularly the one claimed to intrude the Bobaris peridotite in the Pamali River.

The occurrence of the rocks mentioned above have actually long been regarded (e.g. by van Bemmelen 1949) as "ophiolite", and since then many attempts have been made to explain the tectonic evolution of the Meratus Mountains (Katili 1971 and 1973; Hutchinson 1975; Suhaeli et al 1980, Situmorang 1982 and Priyomarsono 1984). But the question still remains as to how this ophiolite can be explained satisfactorily in terms of its origin and time of emplacement.

3.1.3 Present Study

The following section presents the rock subdivision, description, distribution, stratigraphic position and possible age of the formation of the Meratus Ophiolite. The time of ophiolite emplacement in the study area can be determined from in situ sedimentary rocks of the Manunggul Group and also from volcaniclastic deposits of the Alino Group. This will be discussed after the above two groups have been described.

Though the ophiolitic rocks are now largely serpentinized, sheared, folded and faulted, "ophiolite stratigraphy" can still be reconstructed on the basis of two detailed geological traverses in the Kintap and Satui Rivers. These two traverses which are perpendicular to the main structural trend of the Meratus Ophiolite (Figs. 11, 12 and 13) provide the best and most continuous exposures, although they do not show a complete ophiolite section (i.e. incomplete or dismembered).
3.1.4 Name and Type Section

The name Meratus peridotites appears to have been first employed by Verbeek (1875) and Hooze (1893) and since then the name has become used traditionally (e.g. Koolhoven 1933; Bemmelen 1949; Hutchinson 1975).

As has been mentioned earlier van Bemmelen (1949) was the first to use the term "ophiolite" for the mafic - ultra mafic rocks in the Meratus Mountains. The writer retains the name, but in the sense of Penrose Field Conference (Anon. 1972), that is as a distinctive assemblage of mafic and ultramafic rocks with the characteristics described below.

The mafic - ultramafic rocks are classified and named in accordance with the principal minerals. The nomenclature recommended by the IUGS Sub-Commission on the Systematics of Igneous Rocks, as given by Streckeisen (1976), is used throughout this thesis.

The two sections mentioned above, i.e. in the Kintap River and in the Satui River, both located on the southern part of the Manjam Range, are designated type sections for the Meratus Ophiolite. These two sections are presented in Figs. 11, 12 and 13 showing the distribution of the ophiolite and associated rocks and the location of samples used in this study. Approximately 200 samples of ultramafics were collected. From these, 30 samples were cut and petrographically studied.

3.1.5 Lithological Characteristics

The ophiolite is divided into the following units:

1. Ultramafic rocks: serpentinized peridotite and dunite, with minor pyroxenite, ultramafic mylonite and schist.

2. Gabbroic rocks: layered and massive gabbros, with minor pegmatoidal gabbro. Some of the gabbroic rocks have been metamorphosed, to form metagabbro or amphibolite.
KEY TO SYMBOLS
- Upper Cretaceous Sediments (Manunggul Group)
- Pudak Formation
- Gabbros
- Ultramafics
- Sample locality

FIG. 11 GEOLOGICAL TRAVERSE, FROM SUNGAI PUDAK TO RIAM KANAN
FIG. 12 GEOLOGICAL TRAVERSE, from Sungai Batul to Sungai Paeu, across the Manjam Range. Showing relations between ophiolite and adjoining rock-units. Sample locality
Fig. 13 SATUI UPSTREAM TRAVERSE
See Fig. 12 for locality map

KEY TO SYMBOLS
- PUDAK FORMATION
- VOLCANIC BRECCIA (Exclude Ophiolite)
- DOLERITE
- GABBRO, WITH OCCASIONAL BASALT BANDS
- SERPENTINIZED PERIDOTITE
- HIGHLY SHEARDED PERIDOTITE

Sample locality

Lithological Boundaries
Layering in Peridotite

Dolerite, containing ultramafic xenolith
Highly brecciated
Highly brecciated
FIG. 14 GEOLOGICAL TRAVERSE ACROSS THE BOSARIS RANGE
It shows relationships between ophiolite and adjoining rocks, and sample localities

- Sample locality
FIG. 15 PANINGPANING TRAVERSE
Northern side of the Bobarla Range
See Fig. 14 for locality map

KEY TO SYMBOLS
- Upper Cretaceous Sediments (i.e., Manunggul Group)
- Basalt
- Ultramafic
- Sample locality

Weathered outcrop

0 200 m
N
3. Leucocratic rocks: diorite and trondhjemite ("plagiogranite"*).

Microdiorite, andesite and granite (adamellite); regarded as post-dating the ophiolite emplacement, are not considered as part of the ophiolite complex.

3.1.5.1 Description of Ultramafics

Field Occurrence

The ultramafic rocks which are confined in two major north-east - southwest trending belts in the area studied, i.e. the Manjam and Bobaris Ranges, occupy approximately 90% of the ophiolite complex. The distribution of these rocks and their relationships to surrounding rock-units can be seen in Fig. 6. A detailed geological map is deposited in the back pocket. A detailed list of mineral assemblages is tabulated in Table 1.

The ultramafics, particularly in the Manjam Mountains, e.g. in the lower Sungai Hamarau, due south of the village of Puliin, and in the main tributary of Sungai Paau (see geological map), also commonly contain tectonic slices or "inclusions" of metamorphic rocks (NS-577, NS-588 and IU-224). Radiolarian chert (NS-70), as found only in one locality in the upper Sungai Aritan (Fig. 12), is present perhaps as a tectonic slab within the complex of ultramafic rocks. The size of these inclusions varies from hundreds of metres to a few kilometres. In addition, poorly exposed ultrabasic mylonite (e.g. near Gunung Tandukan, Manjam Range) is also observed locally, commonly in and adjacent to fault zones (e.g. IU - 55A).

* Plagiogranite is a genetic term for K₂O-deficient granitic rocks that range from quartz diorite to albite granite (Coleman and Peterman 1975).
Although the ultramafic rocks are variably affected by low grade metamorphism (see below) and intense deformation, the original lithological characteristics can still be recognised. They are best seen in narrow passes through the mountains, along the narrow streams (i.e. mostly in the upstream parts of the rivers) and in road cuts. Megascopically, the ultramafics are mostly disrupted, crushed and serpentinized or even sheared to some extent (Fig. 16), and in many places nearly completely replaced by serpentine or in some degrees exhibit blocky or boudinage structures. The blocks vary in size, ranging from a few centimetres to over two metres, commonly elongate in shape with irregular and rather sharp edges. These blocks are set in a sheared and crushed matrix.

Fresh and relatively undeformed rocks, however, are still discernible in a number of places, for instance in the upper Sungai Satui (NS - 534) and in the upper Sungai Tabanio (RH - 88).

In some outcrops, e.g. in the upper Sungai Paau (NS - 586) and in the right tributary of Sungai Tabanio, the rocks show very conspicuous layering or cumulus texture (Fig. 17). Very frequently the layers are continuous for a few ten of metres along strike, and then pinch-out in one or both directions. Layering is commonly parallel or subparallel, defined by contrasting grain sizes and other aspects of texture that can be seen obviously on the rock-exposures.

In the upper Sungai Satui, in the southern foothills of the Manjam Range (see Fig. 13), the layering is intermittently exposed through a section of about 2.5 kilometres. Due to the limited areal exposure as well as the intense deformation within the ultramafics, the layers here can only be traced laterally for a few metres. The layers usually consist of dunite (olivine-rich layers) alternating with harzburgite or pyroxenite. The ultramafics in this particular section, and perhaps elsewhere too, consist of two varieties, massive
Fig. 16  Photograph showing structural and textural deformation of the ultramafic rocks. The original rocks have been severely sliced, crushed, serpentinized and sheared. Note segments of rodingite dykes (white weathering) surrounded by highly fractured and sheared serpentine.

Fig. 17  Rhythmic layering in peridotite, Paau River. Note some of the layers show fining upward (cf. graded-beds in sediments), with both gradational and sharp bases. The coarser grains, as can be seen on the lower part of the layers, are elongate in shape and these seem to be parallel to the compositional layering. The layers are made up of alternation of dunite (olivine-rich) and harzburgite or pyroxenite (pyroxene-rich).
and layered (cumulate) peridotites. These two varieties usually occur in the same outcrop (see Fig. 13), and sometimes the layered peridotite occurs as intercalations (60cm - 1m) within massive peridotite.

Individual thickness of the layers varies from just over a centimetre to usually less than ten centimetres. Most layered ultramafics occur as blocks within disrupted and crushed rocks. Loose blocks are also encountered in a few places. The layers observed are compositionally layered but may also be modified by deformation.

Most of the layers in the ultramafics have rather sharp bases, and rarely show conspicuous grading. However, in several localities (e.g. see Fig. 17), although the coarser mineral grains are seen to have been elongated due to the effect of deformation, a size grading is seen in the layers (Wager, Brown and Wadsworth 1960). The way-up direction of the layers mapped in the study area are indicated by this type of structural feature.

Petrography

In thin section the ultramafic rocks are mostly composed of very simple mineralogy, consisting of variable proportions of olivine (OL, 5-15%), orthopyroxene (OPX, 1-60%) and clinopyroxene (CPX, 1-100%). Brief descriptions of the ultramafics is given below, and is also summarised in Table 1.

The ultramafic rocks are classified as harzburgite, lherzolite and dunite, with minor olivine orthopyroxenite, olivine clinopyroxenite, wherlite, clinopyroxenite, websterite and ultramafic schist. Described as 'serpentinized' if serpentine <50%, but > 20%. In many places the rocks contain sufficient serpentine (> 50%) to be classified as serpentineite, e.g. NS-675 and NS-28.
Typical thin sections of serpentinized harzburgite, lherzolite, clinopyroxenite and serpentinite are shown in Figs. 19 to 22. Modal analyses for a number of selected samples are listed in Table 1, and plotted on an OL - OPX - CPX triangular diagram (Fig. 18).

Dunite

Though a reliable estimate is difficult, dunite usually less than 10% in most ophiolites. In hand specimen, they are dense and greyish olive (10 Y 4/2), dark greenish grey (5 GY 4/1) to greenish black (5 G 2/1) in colour.

Petrographic examination reveals that the dunite now consists almost entirely of fine-grained serpentine (Fig. 19) with a strongly developed mesh structure (i.e. mainly antigorite with occasional thin chrysotile veinlets). In some of the thin-sections observed (e.g. NS-2B), very rare aggregates of bastite are present within the dunites (now serpentinites). These are probably formed as a replacement of original pyroxene. Furthermore, MT and CR grains occur sparsely in some thin sections (e.g. NS-2B).

Harzburgite

Typically, harzburgite is a peridotite which is composed of olivine (OL) and orthopyroxene (OPX). In the area studied, the harzburgites (Fig. 20; Table 1) contain 15-55% of OL, 14-37% of OPX, Tr-2% of CR, and secondary minerals such as serpentine (SR), bastite (BA) and ilmenite (IM) make up respectively from 2-40%, 2-15% and 2-6% of the rock volume. Olivine, as the most conspicuous constituent in harzburgite, occurs highly fractured and dissected by veinlets of serpentine. The OL grains are generally replaced by serpentine. Small olivine remnants frequently float in a meshwork of grey (in XPL) birefringent serpentine.
The second major mineral in the serpentinized harzburgite is orthopyroxene, poikilitically enclosed within olivine. Some orthopyroxene contains OL inclusions. The orthopyroxene is to some extent replaced by bastite and in other cases this is further partially recrystallised to an indistinct cryptocrystalline aggregate. Talc and muscovite, and lamellae of exsolved clinopyroxene are also occasionally present in some orthopyroxenes. A small proportion of Clinopyroxene (CPX), typically diopside, 0.5–2 mm in size, occurs in several thin sections (e.g. NS – 63 and RH – 135). The CPX grains have been partially replaced by serpentine and talc.

Chromite (brown spinel) is a minor constituent in most samples observed (see Table 1), occurring as anhedral to subhedral grains, generally surrounded by, or in some cases tending to be included within the olivine (Fig. 23). The outer rims of chromite may sometimes be converted to opaque minerals, probably magnetite. Alteration is also present along the fractures or cracks in the grains. Most of the chromite grains observed are scattered throughout the area of the thin-section, so they do not form bands that could be regarded as the primary layering in the ultramafics.

Magnetite usually accompanies the serpentine as a replacement of olivine and pyroxene, variously occurring as discontinuous strings, small lenses, and small patches, following the pattern of the interstices of the olivine grains and as internal fractures in olivine (Fig. 24). All of these petrographic characteristics indicate that magnetite formed during the alteration of olivine into serpentine. Ilmenite grains are commonly present and show pull-apart fractures. These fractures were likely to have formed during serpentinisation of the peridotite (Fig. 24).
<table>
<thead>
<tr>
<th>Studied Sample No.</th>
<th>LOCATION</th>
<th>Petrographic Rock-Type</th>
<th>Grain size (mm)</th>
<th>PRIMARY MINERALS</th>
<th>SECONDARY MINERALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MANJAM RANGE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-586 Sungai Paau</td>
<td>Serpentinitized lherzolite</td>
<td>0.5-2</td>
<td>Tr 4 1 5</td>
<td>33 2 22 1 20 Tr 2 Tr 10</td>
<td></td>
</tr>
<tr>
<td>NS-529 Sungai Satul</td>
<td>Serpentinitized harzburgite</td>
<td>0.1-3</td>
<td>25 12 3 Tr 6 30 4 10 Tr 10 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-536 Ibid</td>
<td>Ultramafic (Magnebite) sch</td>
<td>1.5-4</td>
<td>- - 1 1 - 30 Tr - 63 Tr 5 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-62 Sungai Aritan</td>
<td>Websterite</td>
<td>1-6</td>
<td>- 60 20 2 Tr 15 3 Tr - -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-63 Sungai Aritan</td>
<td>Serpentinitized harzburgite</td>
<td>1.2-7</td>
<td>25 28 1 2 2 40 2 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-576E Sungai Haja</td>
<td>Websterite</td>
<td>2-6</td>
<td>- 20 65 - 4 6 - 4 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-28 Sungai Pudak</td>
<td>Serpentinite</td>
<td>0.2-1</td>
<td>Tr - Tr 1 98 Tr 1 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AM-91B Ibid</td>
<td>Serpentinitized lherzolite</td>
<td>2-4</td>
<td>5 24 20 2 Tr 50 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-331 Sungai Pudak</td>
<td>Ultramafic (Magnebite) sch</td>
<td>-</td>
<td>- - - 3 95 -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-217C Ibid</td>
<td>Clinopyroxenite</td>
<td>1-1.6</td>
<td>Tr 90 1 - - - 4 5 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RH-135 Sungai Kintap Besar</td>
<td>Serpentinitized harzburgite</td>
<td>1-3</td>
<td>15 36 1 2 4 40 2 Tr - - Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RH-142 Sungai Kintap Besar</td>
<td>Serpentinitized lherzolite</td>
<td>0.8-2.9</td>
<td>10 35 15 2 1 35 - 2 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KB-243 Sungai Iwakan</td>
<td>Altered Clinopyroxenite</td>
<td>1.5-8</td>
<td>- 1 75 - - Tr 10 14 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IU-95 Sungai Kalaan</td>
<td>Harzburgite</td>
<td>2-5</td>
<td>45 27 1 1 Tr 2 15 10 Tr - -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IU-96 Ibid</td>
<td>Harzburgite</td>
<td>1.5-5.5</td>
<td>42 37 Tr 3 12 6 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IU-100 Ibid</td>
<td>Serpentinitized lherzolite</td>
<td>0.1-0.2</td>
<td>- 8 Tr 1 85 6 Tr Tr Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IU-55A1 Ibid</td>
<td>Altered Clinopyroxenite</td>
<td>1-1.8</td>
<td>- Tr 45 - - Tr 55 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IU-55A2 Ibid</td>
<td>Ultramafic-mylonite</td>
<td>-</td>
<td>- - Tr 2 - 20 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IU-51 Gunung Tandukan</td>
<td>Harzburgite</td>
<td>1-6</td>
<td>55 14 - 13 15 1 - Tr Tr Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IU-53 Gunung Tandukan</td>
<td>Clinopyroxenite</td>
<td>0.4-1.6</td>
<td>- - 88 1 - 3 8 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RH-88 Sungai Tabanio</td>
<td>Olivine Clinopyroxenite</td>
<td>2-5</td>
<td>- - 88 Tr 2 10 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RH-90A Ibid</td>
<td>Olivine Clinopyroxenite</td>
<td>1-4.5</td>
<td>Tr 59 1 10 30 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BORARIS RANGE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IU-252 Gunung Pempurun</td>
<td>Wherelite</td>
<td>3-10</td>
<td>25 1 55 3 15 1 Tr Tr Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-852 Sungai Pamali</td>
<td>Olivine clinopyroxenite</td>
<td>2-5</td>
<td>20 74 6 - Tr Tr Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-852B Ibid</td>
<td>Clinopyroxenite</td>
<td>6-11</td>
<td>- - 100 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-675 Sungai Jalung</td>
<td>Serpentinite</td>
<td>0.2-3</td>
<td>5 1 - 1 4 83 2 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AM-133B Gunung Melati</td>
<td>Clinopyroxenite</td>
<td>2-4.5</td>
<td>- 1 98 Tr 1 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RH-106B Sungai Melahin</td>
<td>Lherzolite</td>
<td>1.5-5</td>
<td>35 22 25 Tr 10 1 2 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IU-29 Bukit Betagah</td>
<td>Olivine Clinopyroxenite</td>
<td>0.2-5</td>
<td>30 58 - 2 1 Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-191B Batakian</td>
<td>Websterite</td>
<td>1-5</td>
<td>- 20 57 1 2 15 Tr</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Modal analyses (volume %) of representative samples from ultramafics of the Manjam-Bobaris Ranges.

Note: Granulity: coarse = 5mm; Medium = 1-5mm; Fine = 1mm.

Fig. 18. Ultramafic composition: OL-OPX-CPX triangular diagram, showing modal composition of ultramafic rocks. Rock nomenclature from Streckeisen (1976).

Key to Symbols:

OL= Olivine, OPX= Orthopyroxene, CPX= Clinopyroxene. Samples from the Manjam Range are shown by open circles, whereas the samples from the Bobaris Range are shown by black circles.
Fig. 19: Portion of dunite (now serpentinite) showing typical mesh structure (i.e., antigorite) with thin chrysotile veinlets. Scale bar 0.2 mm.

Fig. 20: Portion of serpentinized harzburgite from an upper main occurrence of the Sungai Satui, Manjam Range. Sample NS-7. Scale bar 0.2 mm.
Fig. 19 Photomicrograph of dunite (now serpentinite) showing typical mesh structure (i.e. antigorite) with thin chrysotile veinlets. Sample NS-2B. XPL. Scale bar 0.2mm.

Fig. 20 Photomicrograph of serpentinized harzburgite from an upper main western tributary of the Sungai Satui, Manjam Range. Sample NS-63. XPL. Scale Bar 0.2mm.
Fig. 21 Photomicrograph of clinopyroxenite from Gunung Melati in the central part of the Bobarls Range. Note spinel intergrown with CPX (lower right corner). Sample AM-133B. XPL. Scale bar 0.2mm.

Fig. 22 Photomicrograph of interzolite from the Upper Sungai Satui in the southern part of the Manjam Range. Note spinel both in CPX and OPX. Sample NS-529. Scale bar 0.2mm.
Fig. 21 Photomicrograph of clinopyroxenite from Gunung Melati in the central part of the Bobaris Range. Note spinel intergrown with CPX (lower right corner). Sample AM-133B. XPL. Scale bar 0.2mm.

Fig. 22 Photomicrograph of lherzolite from the Upper Sungai Satui in the southeastern end of the Manjam Range. Note spinel both in CPX and OPX. Sample NS-529. Scale bar 0.2mm.
Fig. 23 Photomicrograph of chromite in harzburgite. Sample No. NS-63. PPL. Scale bar 0.3mm.

Fig. 24 Photomicrograph of pull-apart fractures in opaque iron oxide (ilmenite) grains, serpentinized peridotite, southern part of the Bobaris Range. Sample NS-675B. PPL. Scale bar 0.2mm. These fractures resulted from expansion of the rock because of serpentinisation.
Lherzolite

Lherzolite, composed essentially of the mineral assemblage olivine (OL), clinopyroxene (CPX) and orthopyroxene (OPX), with a significant amount of Fe-iron grains (ilmenite and/or magnetite) and minor green spinel (Table 1), is commonly found in the southern portion of the Manjam Range, e.g. in the Upper Sungai Satui and Pudak (Kintap). However, in two localities, i.e. in the Upper Sungai Paau in the northern foothills of the Manjam Range and in Gunung Melahin of the Bobaris Range, the serpentinised peridotite may also be included in the lherzolite category. The rock in the former locality is now largely altered to magnesite and haematite.

Distinction of the colour of spinel in the lherzolite is very important as it can be used to define the P and T conditions under which the mineral crystallised. Green spinel suggests high P, whilst brown spinel indicates lower P condition (Dr. Robert Hall, pers. comm., 1985).

Serpentinite

From the above petrographic evidence, the serpentinite has been derived from more than one ultramafic rock type. It may have been derived from dunite (e.g. NS-2B and NS-520), harzburgite (e.g. NS-675), and lherzolite.

As stated earlier, the serpentinite contains more than 50% of serpentine (SR). Most serpentine is antigorite. It occurs in a variety of habits, but mainly forming mesh structures replacing OL grains (Fig. 22).

The meshwork of serpentine is accompanied by very fine aggregates of opaque minerals (i.e. magnetite). Talc is occasionally found associated with serpentine, occurring as randomly oriented grains.
The serpentinite usually exhibits waxy lustre, sheared and slickensided, commonly occurring in veins or fractures and along the shear planes and major faults, e.g. on the northern foothills of Malihin Mountains in the Bobaris Range.

3.1.5.2 Description of Gabbroic Rocks

The gabbroic rocks are the most conspicuous rock type within the ultramafic assemblage and make up approximately 15% of the ophiolite complex in the study area (see Fig. 6). These rocks include gabbro, olivine gabbro, leucogabbro, and metagabbro; dolerite, meta dolerite and basalt. In the majority of exposures the gabbros are associated with dolerite and less commonly with basalt. The latter particularly occurs as dykes or sills in layered gabbro.

Judging from the pattern of outcrop and their distribution on the map, the gabbros consist of elongate bodies, ranging from a few hundred metres to approximately 14 km in length, and varying in width from approximately 100m to 8km.

The morphology of the gabbroic rocks with an elevation between 250 and 900m above sea-level can be observed clearly on both air photos and the Synthetic Aperture Radar (SAR) image. The rocks are sporadically exposed along the southern margin of the Manjam Range and also in a few places within the Bobaris Range. Mappable (1:250,000) gabbroic bodies in the Manjam Range are found in Gunung Paikat, Gunung Manjam, Gunung Condong, near Gunung Tarip Kinjangan, Gunung Batubegigi, south of Gunung Mungguanau and, in the upper Sungai Pudak and Hajawa (see geological map). Beside these, many other outcrops are present but they are too small to be represented on the geological map. The distribution pattern of these unmappable gabbroic rocks within the ultramafic host rock is represented by a detailed traverse in the upper Satui River (see Fig. 13). Mappable gabbroic rocks in
the Bobaris Range occur in Gunung Pempurun, Bukit Besar and Gunung Pancur.

The gabbros are either layered (Fig. 25) with allotriomorphic-granular textures or massive gabbros with hypidiomorphic-granular textures (Figs 26 and 27). In addition, pegmatitic gabbros are also present in several places. The best exposure is in the upstream part of the Sungai Pudak, in the southern foothills of the Manjam Mountains. Pegmatitic gabbros occur as small stocks and are commonly cut by dykes of diorite or dolerite.

Layered gabbro is intimately associated with basalt, serpentinite and serpentinized peridotite in the southeastern part of the Manjam Range (e.g. NS-335 and KH-222); whereas in the northwestern part of the range it occurs as isolated bodies, not layered, within the ultramafics, and is associated with dolerite rather than basalt, e.g. in the upper Sungai Satui and Kintap.

Based on the above field evidence where the layered gabbro generally occurs in the southeastern portion of the Manjam Range, together with marked increase in the number of small stocks and dykes of leucocratic gabbro, dolerite, diorite and trondhjemite toward the northwest (see Figs 11 and 13), it can be suggested that the southeastern portion of the range represents a lower stratigraphic level of the ophiolite sequence in the Meratus Mountains. This suggestion seems to be consistent with the common occurrence of Iherzolite (+ green spinel) towards the southeast in the upper Sungai Satui and Pudak.

The contact between the gabbro and the surrounding ultramafics is commonly obscured by intense serpentinisation and shearing. This clearly exhibits the effects of fault movements. Despite these structural and textural problems the thickness of the gabbro can still be estimated by assuming dip seen in layered gabbro and using
Fig. 25 Layered gabbro. Note layers are not always strictly parallel, but locally slightly wavy and occasionally cut by other sets of layers. Very fine-grained basalts are quite often seen in gabbro as dykes or sills. An isolated patch of basalt, as shown on upper-right hand side (in light greenish grey), is also present. These features indicate that the gabbro has undergone deformation, possibly shortly after or contemporaneously with its formation in oceanic environment.

Locality: Upper Sungai Pudak, Kintap, South-East Kalimantan.
the width of the outcrop. On the basis of these criteria, the thickness of individual lenses of the gabbro ranges from 100m to 1,400m. These figures are likely to be highly overestimated as the rock may have been repeated a number of times by thrusting.

Petrography

About one hundred samples of gabbroic rocks were collected from various localities throughout the study area. Megascopically, they are characteristically greyish black (N\text{2}2) with white or light grey (W\text{7}7) spots (if massive) or laminae (if layered). From these, fifteen samples were studied under the microscope.

The gabbroic rocks are classified in accordance with both modal analysis and the rock-nomenclature of Streckeinsen (1976). They include gabbro, olivine gabbro, leuco-gabbro, and metagabbro.

Most of the gabbros have a granular texture either allotriomorphic (i.e. in layered gabbro, Fig. 26) or hypidiomorphic (i.e. in massive gabbro, Fig. 27). However, poikilitic texture is also common. The gabbros consist mainly of plagioclase (PL) and clinopyroxene (CPX), with grain size varying from 0.5-6mm. Orthopyroxene is only present in very minor amounts in some of the thin sections observed (e.g AM-71). Secondary constituents in the gabbros include brown and green amphibole, saussurite, uralite, chlorite, epidote, magnetite, serpentine and minor amounts of prehnite, pumpellyite, sphene, apatite and iron oxides. Leucoxene also occurs as alteration of ilmenite.

Plagioclase is the most abundant constituent of the gabbros. The crystals are subhedral-anhedral, but most commonly subhedral with grains varying from 1-4mm long. In some of the layered gabbros, as in sample AM - 72, the long axis of the plagioclase is orientated sub-parallel to the long axis of other minerals (i.e. CPX, now largely altered to chlorite). Most of the plagioclase observed from un-or
**Fig. 26** Photograph of allotriomorphic granular texture in layered gneiss, or intermediate in CPX, wavy extinction in PL and intermediate crystal twinning and deformation lamellae (e.g. from the upper Sungai Pudak, southern foothills of the Marjum Range. XPL. Bar scale 0.2mm long.

**Fig. 27** Photograph of feridiororphic granular texture in massive gneiss, or intermediate from the upper Sungai Pudak but to the north of the...
Fig. 26 Photomicrograph of allotriomorphic granular texture in layered gabbro. Notice rupturing in CPX, wavy extinction in PL and intersection of crystal twinning and deformation lamella (e.g. lower centre). Sample from the upper Sungai Pudak, southern foothills of the Manjam Range. XPL. Bar scale 0.2mm long.

Fig. 27 Photomicrograph of hypidiomorphic granular texture in massive gabbro. Sample from the upper Sungai Pudak but to the north of the above sample.
less altered crystals do not show compositional zoning, but they do show albite and carlsbad twinning.

In several thin sections (e.g. IU - 251) plagioclase grains are fractured, commonly perpendicular or oblique to mineral cleavages. In other cases plagioclase is intimately intergrown with iron ore (possibly ilmenite) and augite crystals. The composition of plagioclase, from several measurements (Michel Levy's Method) indicates a labradorite (An 52 -55) composition.

The PL has variably been affected by saussuritization and deformation. Secondary minerals identified are saussurite, sericite, epidote, chlorite and occasionally prehnite, calcite and amphibole. Wavy extinction in the PL grains was observed in some thin sections (e.g. AM-81D, Fig. 26).

Clinopyroxene is the next most abundant constituent in the gabbroic rocks. The grains of clinopyroxene vary in size from less than 1mm-5mm, and commonly exhibit partial replacement by serpentine, brown amphibole, green amphibole (actinolite) or uralite and chlorite, in particular along the outer rims of the grains, and along fractures and mineral cleavages. Brown amphibole is partly altered to green amphibole or chlorite. In some thin sections (e.g. IU-251), clinopyroxene is intergrown with plagioclase, but are separated from the plagioclase by a very thin film of brownish green amphibole. Corona texture is also developed around some of the grains (e.g. NS-530). In some samples (e.g. NS-522 and NS-5768), the CPX grains are largely replaced by greenish brown to green amphibole. This suggests that the rocks should be regarded as metagabbro or amphibolite.

Olivine is only present in a few thin sections of gabbroic rocks. One sample, i.e. from Pempurun Mountain in the Bobaris Range, is classified as olivine gabbro (IU-251). As in the ultramafic rocks, the grains of olivine in the olivine gabbro tend to be rounded, though
they are now mostly fractured and the spaces filled in by serpentine. Note fracturing around olivine grains due to serpentinisation. Texturally, the olivine is set in between plagioclase and/or clinopyroxene crystals.

Dolerite

Dolerites ("microgabbros") are quite common, occurring as sills and dykes in the gabbros and as well as in the ultramafics, in particular in the central and northern parts of the Manjam Range. They are relatively easy to recognise in the field, although sometimes may be confused with microdiorite ("porphyrite"). Some dolerites contain ultramafic xenoliths.

Most of the dolerite outcrops are too small to be shown on the 1:250,000 geological map. However, the general outcrop pattern of these dykes and sills was observed in the upper Sungai Satui (Fig. 13). The width or thickness of the dykes and sills varies from several tens of centimetres to over two and half metres.

Petrography

Petrographically, these rocks are composed mainly of PL and CPX. The texture is either sub-ophitic (e.g. NS-34 and NS-522, Fig. 28) or intergranular (NS-576F, NS-576G1 and NS-576G2). In addition, one sample (NS-576D) shows trachytic texture, flow-orientation of plagioclase laths, thus, it can be called trachytic pyroxene dolerite (cf. MacKenzie et al 1982). This trachytic dolerite is dark grey (N33) with greyish black spots (N22) and is a fine-grained rock composed mainly of altered plagioclase, fresh clinopyroxene and magnetite. Clinopyroxene ranges from less than 0.2mm to 1.6mm, and it rarely exceeds 1.6mm in size. Some of the grains are now olive-green chlorite, possibly as replacements of pyroxenes.
Despite hydrothermal alteration which has variably affected part of the PL and CPX grains, the original texture of subophitic dolerite (e.g. NS-34, NS-75 and NS-522) is still well preserved (Fig. 28). Subophitic dolerites are composed largely of PL laths (55%), CPX (20%) and MT (10%), with significant amount of secondary minerals such as chlorite, saussurite and epidote. In contrast, the intergranular dolerite (e.g. NS-576F and NS-527) has been significantly metamorphosed. The CPX grains in the rock are largely converted to green hornblende and less commonly to brown hornblende. The latter may be relic of the earliest conversion of CPX grains. Since the hornblende is considered to have been produced from the pyroxene in the conversion of dolerite into amphibolite, the rock is called metadolerite.

The metadolerites (e.g. NS-527) are fine- to medium-grained (0.5mm - 5mm), with mineral constituents consisting of variable proportions of PL (55-65%), HB (25-35%) and MT (5%). They show heteroblastic texture, with plagioclase occurring as a granoblastic xenoblastic mineral and hornblende as nematoblastic and idioblastic (Fig. 29). Minor constituents include apatite and pyroxene. The latter is regarded as primary in origin. Secondary minerals such as epidote, sphene, sericite, quartz, chlorite and magnetite are also present in varying amounts. On the basis of both textures and the presence of HB and other secondary minerals, it is suggested that the dolerites have suffered low to medium grade metamorphism or recrystallization.

Some metadolerites found in the upper Satui River (e.g. NS-527) contain ultramafic xenoliths. The size of these xenoliths ranges from 0.5 to 10 cm in diameter and the shape is subangular to angular. They consist mostly of peridotite (no petrographic description available) and fine-grained hornblendite. One xenolith is of hornblendite, a fine-grained equigranular rock, composed of light brownish green
Fig. 2. Rie, showing heteroblastic texture, granoblastic or xenoblastic mineral plastic and idioblastic minerals. See XPL. Scale bar 0.2mm long. Sample NS-527.
Fig. 28 Photomicrograph of dolerite in the ultramafic rocks, showing subophitic texture and composition. XPL. Scale bar 0.2mm long. Sample NS-34.

Fig. 29 Photomicrograph of metadolerite, showing heteroblastic texture, with plagioclase occurring as granoblastic or xenoblastic mineral and hornblende as nematoblastic and idioblastic minerals. See text for minor constituents. XPL. Scale bar 0.2mm long. Sample NS-527.
hornblende, forming short needles as long as 1.5mm which occasionally contain inclusions of clinopyroxene. Small patches of strained quartz are also present in this hornblendite. No detailed work on these xenoliths was possible within the scope of the present study.

From the above descriptions, it can be suggested that both gabbros and dolerites have been affected by low to medium grade metamorphism.

3.1.5.3 Leucocratic Rocks

Leucocratic rocks which make up approximately 5% of the ophiolite complex, are by far the most conspicuous rock-unit. They usually form either as small stocks or as dykes and sills. Regional field observation, together with a detailed traverse in the upper Sungai Satui (see Fig. 13) indicate that there are two kinds of leucocratic rocks present within the ophiolite. The first includes an assemblage of rocks that belong to the "plagiogranite" of Coleman and Peterman (1975), and is composed of quartz diorite and trondhjemite (i.e. in the sense of Streckeisen 1976). These are closely associated with ultramafite, microgabbro (dolerite) and gabbro. Whereas the second type includes hornblende (porphyritic) microdiorite (previously called "porphyrite" by Koolhoven 1935; Bemmelen 1949; cf. Hatch et al. 1980) and andesite which are not considered to be related to the ophiolitic rocks, and postdate the emplacement of the ophiolite complex, as they are also found as dykes or sills within the Upper Cretaceous volcano-sedimentary rocks of the Manunggul Group (see geological map). Granite (i.e. "adamellite") which clearly intrudes the ophiolite is also included among the second type of leucocratic rocks.

The following section presents a brief account of the lithologic characteristics and petrographic descriptions of the plagiogranites.
Ophiolite Related Leucocratic Rocks (Plagiogranites)

These rocks occur as dykes or irregular bodies some of which are mappable on the 1:250,000 geological map. Good exposures of leucocratic rocks can be found in the following areas: in the upper course of Sungai Asem-Asem, due north of Gunung Tandukan (e.g. IU-48); Upper Sungai Nayah, east of Gunung Batumandi (e.g. IU-83) and Sungai Kalaan, west of Gunung Pamatang Bikat (e.g. IU-100). The pattern of the rock distribution is shown in Fig. 6.

Petrographic examination (IU-48, IU-83 and IU-100) reveals that most of the plagiogranites are fine- to medium-grained (0.6 - 4 mm) hypidiomorphic rocks, consisting predominantly of quartz (QZ, 18-35%), plagioclase (PL, 45-72%) and significant amounts of mafic minerals, primarily hornblende (HB, 2-25%). Magnetite is a common accessory mineral, ranging from 2-3% of the rock volume; whereas biotite only occurs in IU-48 (1%), sphene in IU-48 and IU-100, chlorite and epidote in NS-194. Plagioclase occurs as subhedral lath crystals, commonly 1-4 mm long, partially sericitized and in one sample (NS-100) is partly replaced by quartz with aggregates of epidote or chlorite. Quartz shows medium to high undulatory extinction, with occasional polygonal crystals, some of which show intergrowths of quartz and plagioclase. These intimate intergrowths of plagioclase and quartz, to some extent, resemble "graphic" and "granophyric" textures, thus suggesting they are produced by simultaneous crystallisation (Barker 1979). The presence of secondary minerals, e.g. chlorite and epidote, in some of the samples, together with other textural features such as quartz with undulatory extinction, all suggest that the ophiolitic leucocratic rocks have undergone hydrothermal metamorphism and slight deformation.
3.1.6 The Meratus Ophiolite as a fragment of oceanic lithosphere

As has already been described in the preceding sections, the mafics, the ultramafics and the leucocratic rocks constitute the main lithological units of the Meratus Ophiolite (see above for detail). Field and petrographic characteristics of these three units (see above) can be compared with and therefore qualify for the definition of ophiolite proposed at the Penrose Field Conference (Anon. 1972). A mafic sheeted dyke complex, pillow lavas and associated pelagic sediments (i.e. chert, shale and pelagic limestone) have not been found in the Meratus Ophiolite sequence. Therefore, the ophiolitic rocks in this area are classified as a "dismembered ophiolite" (cf. Anon., Penrose Field Conference 1972).

Overall, regardless of the repetition of one or more of the rock units above, on the basis of attitudes taken on layered ultramafic rocks and gabbros, together with regional pattern of distribution of the rock-types, the writer has established a very generalised diagrammatic section of the Meratus Ophiolite (Fig. 30).

These rock units can be compared to ophiolite sections exposed over several hundred kilometres in the Oman Mountains (e.g. Robertson and Woodcock, 1980; Graham, 1980) and Troodos in Cyprus (e.g. Gass and Smewing, 1973; Coleman, 1977). Thus suggest that the rock-subdivisions in the Meratus Mountains might also be identical, as they have similar characteristics, to those found in cross-sections of the oceanic crust.

3.1.7 Age of the Meratus Ophiolite

There are two aspects to the age of the ophiolitic rocks in the Meratus Mountains which are discussed on the basis of present field observation, petrographic, palaeontological and radiometric data. They are:
Fig. 30 Columnar section of ophiolite in the Meratus Mountains, compared to an idealized ophiolite sequence of oceanic crust and the Troodos Complex, Cyprus. Thickness of the rock units are not to scale.
1. age of formation of ocean floor, and

2. age of ophiolite emplacement in present position in the Meratus Mountains. This second aspect will be discussed after the evidence of age of the associated stratigraphic units has been described.

The age of the ophiolite formation can be determined directly by radiometric dating of rocks from the ophiolite itself, e.g. gabbro, dolerite, diorite or trondhjemite (i.e. plagiogranite), which usually contains easily separated (e.g. hornblende, biotite and zircon) datable minerals. These minerals can be dated by radiometric or isotopic methods. Where datable minerals are not sufficiently abundant in the rocks, powder from the whole rock sample can also be used for radiometric dating.

Samples of the ophiolite were collected with a view to radiometric dating at laboratories of Isotope Geology Unit of the British Geological Survey (BGS), Grays Inn Road, London.

Many thin sections from various localities were examined by the writer in Bandung, Indonesia, to select samples which were sufficiently fresh for dating. From these, only three samples of the ophiolite, one gabbro and the other two dolerite, were considered fresh enough for radiometric dating and were brought to England. Although these three samples appear to be fairly fresh in hand specimen and also at first sight under microscope, Dr. N. Snelling (BGS, 1984) considered only one sample (NS - 527) fresh enough for radiometric dating, as the other two have indications of deuteric alteration. The fresh sample is from a metadolerite dyke (NS - 527) exposed in the upper Sungai Satui. It gives the age of metamorphism (possibly in oceanic environment) at 116 Ma (Lower Aptian).
If the above dating can be accepted, and therefore, it can be suggested that the ophiolite in the area studied and probably in the Meratus Mountains as a whole, was formed in an oceanic environment during Lower Aptian (116 Ma) times.

3.1.8 Regional Correlations

On a broad scale, Katili (1971, 1973), Asikin (1974) and Hutchinson (1975) have shown that the Meratus Ophiolite can be correlated southwestward to the Luk-Ulo area in Central Java (Emmy Suparka, pers. comm.) and Ciletuh area in West Java (see Suhaeli et al 1977). In the Java Sea (Bishop 1980), exploration wells penetrated basement rocks which are made up of various kind of ophiolitic rock-types (e.g. gabbro, dolerite, basalt and serpentinite) and associated metamorphics (e.g. schist and phyllite). The slices of correlative Meratus Ophiolite there swing northwest toward the Barisan Mountains (cf. Page et al, 1979; Cameron and Djunuddin, 1980; Wajzer, 1986).

The present study also indicates that the mafic-ultramafic rocks in the Meratus Mountains (see description above) are lithologically and even structurally very similar to those described by Albrecht (1946) in Northern Kutai (i.e. Sungai Klinjau and Belayan), East Kalimantan. The rock assemblage there consists of mafics (e.g. gabbro, norite and dolerite), ultramafics (i.e. serpentinised harzburgite, wherlite, dunite, pyroxenite and hornblendite), which are closely associated with greenschist and amphibolite (cf. Hauran Schist), phyllite (cf. Pelaihari Phyllite) and submarine volcanioclastics and radiolarian cherts (cf. Alino Group). Similar rock-types and associated rocks have been reported in North Kalimantan (see Hutchinson, 1975). In addition, ophiolitic rocks which show similar characteristics to those of the Meratus Ophiolite are also found in the Western Divide Range of south arm of Sulawesi (see Sukamto, 1975 and Leeuwen, 1981).
They all show typical features of an ophiolite as defined by Penrose Field Conference (1972), and therefore they can be designated as slices of ophiolite that may be derived from an ancient oceanic lithosphere.

But when and how was the Meratus Ophiolite emplaced in its present geological and tectonic setting? This question, is whether or not the Meratus Ophiolite represents a part of the ancestral mantle and oceanic crust, will be discussed after the associated rock assemblages, have been described in the following chapters.
3.2 METAMORPHIC ROCKS

3.2.1 General Statement

Metamorphic rocks are exposed between the Manjam and Bobaris belts of the Meratus Ophiolite (see Fig. 6). Other outcrops occur to the south of Pelaihari. Similar rocks occur as tectonic inclusions within the Manjam Ophiolite Range. All of these metamorphic rocks, as well as the ophiolites are overlain unconformably by a volcano-sedimentary sequence of the Manunggul Group which occupies the central axis of the Meratus Mountains. In the southwestern part of the area studied, that is in the north of Pelaihari, these metamorphic rocks are partially overlain unconformably by a volcaniclastic deposit of the Alino Group.

3.2.2 Lithological Characteristics

The metamorphic rocks are divided into two main lithological units, the Hauran Schist and Pelaihari Phyllite. The former is a prominent unit exposed over wide areas, while the latter is exposed only intermittently to the south of Pelaihari (Fig. 6 and Geological Map).

The relationship between the Hauran Schist and Pelaihari Phyllite is uncertain, but they have a close spatial association.

3.2.2.1 Hauran Schist

The Hauran Schist was formally named the Damargusang Schist by Sikumbang et al. (1982). This is now called the Hauran Schist and is proposed to include all quartz-muscovite schist, micaceous meta-quartzite, biotite (now chlorite)-epidote schist and hornblende-epidote schist. Metagabbro (amphibolite) which occurs in several localities is included within the Hauran Schist.
The type section is in the upper Sungai Hauran, about 22 km south of Martapura. Other good and continuous exposures, perpendicular to the main structural trend of the Meratus Mountains, are found along the Sungai Banyumin and Aranio which both lie to the northeast of the Sungai Hauran (see Geological Map).

In many localities, the schists are well-foliated with foliations defined by the alignment of platy muscovite or prismatic hornblende, and enhanced by an elongation or compositional layering of epidote and quartz. Generally the foliation dips steeply (55°-80°) to the NW and SE, forming antiformal and synformal structures that are generally subparallel to the main structural trends of the Meratus Mountains. Locally, deviation of strikes and dips of the foliations are found, particularly adjacent to faults or intrusive outcrops.

Lamination (1-2mm) and layering (up to 12cm) are quite conspicuous in a number of places. The most widely developed lamination and layering occurs in quartz-muscovite schist and phyllite.

The Hauran Schist consists largely of layered and laminated quartz-muscovite schist with interbeds of muscovite metaquartzite and rarely hornblende-epidote schist. In other localities the situation is reversed, with hornblende-epidote schist forming the dominant rock type, while quartz-muscovite schist occurs as intercalations. Quartz veins, ranging from 2mm to 6cm in width, commonly occur in quartz-muscovite schist and hornblende schist. The veins are filled with an association of quartz and epidote, with lesser amounts of opaque minerals and chlorite (biotite).

Metagabbro or amphibolite in the schist complex is exposed in the upper Sungai Hauran (NS-366, NS-371 and NS-372) and Sungai Banyumin (IU-6 and IU-10). The contact between schist and metagabroic rocks, although not well exposed, appears to be discordant to the foliation,
suggesting a possible intrusive relationship. Furthermore, meta-
dolerite is occasionally present as dykes or sills within the complex
of metamorphic rocks.

Quartz-Muscovite Schist

Quartz-muscovite schist is the most conspicuous rock type and
makes up about 50% of the metamorphic complex. It consists of various
types of quartz-muscovite schist, including quartz-plagioclase-
muscovite-epidote schist, quartz-muscovite-garnet-epidote-biotite
schist, quartz-muscovite-epidote-plagioclase schist and muscovite-
quartz-epidote-chlorite schist.

The rocks are characteristically white to light grey, very fine
to coarse grained, consisting mainly of quartz and muscovite. These
two main constituents form metamorphic lamination and layering, which
is perhaps superimposed on the original sedimentary layering. Epidote,
plagioclase and garnet are present in appreciable amounts in some of
the quartz-muscovite schists observed (NS-362 and IU-9.1). Sub­
ordinate constituents include biotite (now chlorite), sphene and
magnetite.

Quartz

Quartz is the most abundant constituent in the quartz-muscovite
schist, making up more than 50% of the thin section. Quartz occurs as
a granoblastic mineral, made up of a number of microcrystals, i.e.
polycrystalline quartz. These polycrystalline quartz microcrystals
have an interlocking relationship, and all show moderate to highly
undulose extinction. The intermicrocrystal boundaries are commonly
sutured resembling that of stretched metamorphic quartz (produced by
Straight microcrystal boundaries are also present. Individual grains
range from less than 0.2 mm to 0.8 mm, are equant to elongate in shape
with their long axes parallel or subparallel to the trend of the foliation, defined by the alignment of platy muscovite minerals.

Quartz porphyroclasts with undulose extinction are common in some thin sections (e.g. NS-577 B). They are elongate in shape, up to 4 mm long, and are set in an interlocking granoblastic polycrystalline quartz aggregate. They tend to be parallel to the foliation. The porphyroclasts have been partially recrystallised on their margins and contain inclusions of epidote and muscovite. The contact between the porphyroclasts and surrounding matrix is sharp, with irregular boundaries against the foliation.

Muscovite

The muscovite, as a lepidoblastic mineral, is the second most abundant constituent, forming less than 10% of a micaceous metaquartzite, to greater than 10% in quartz-muscovite schist. It occurs within the rock as colourless platy grains, forming discontinuous shreds, less than 1 mm to over 2 mm long, which conspicuously defined the foliation. In some cases, muscovite flakes lie at an angle to the foliation, where they cross-cut the quartz grains or coincidentally occur in between microcrystal boundaries of the granoblastic quartz. They are commonly intergrown with epidote and magnetite.

Plagioclase

Plagioclase occurs as one of the main constituents after quartz and muscovite. The size varies from <0.2 mm to 1 mm. They are commonly elongated, with their long axes parallel to the foliation. The majority of the plagioclase grains are untwinned. Twinned plagioclase, mainly Carlsbad Law, is rare and is present only in a few samples (NS-577; IU-13). Determinations by both the central and oblique illumination methods give an albite composition.
Epidote

Epidote is present in all thin sections, as accessory or one of the main constituents. Occasionally it is found together with quartz in veins. There are two kinds of epidote present:

1. epidote, yellowish green, pleochroic, intergrown either with muscovite or plagioclase and/or quartz; and
2. clinozoisite, colourless to light grey (iron-poor epidote), lack of pleochroism, and occurring as inclusions.

The latter is only present in trace amounts. The epidote varies in proportion, making up about 5% to 15% of the thin section. It normally occurs as an elongated form and lies parallel to the foliation. As mentioned above, the epidote grains are commonly intergrown with quartz, plagioclase or muscovite.

Garnet

Garnet, for example in NS-362, equant and up to 0.2 mm in size, commonly occurs as four or six-sided sections, but also as aggregates which are intergrown with epidote and opaque minerals. It is probably almandine. However, a possibility of manganese-bearing garnet or spessartite composition is not ruled out. Electron Microprobe study is needed for the exact determination of this garnet species.

Hornblende Schist

Hornblende schist occurs mainly in the northern part of the main metamorphic belt and in a tectonic inclusion near the watershed of Sungai Hajawa (NS-577 A) in the Manjam Range. Other outcrops are near Kalaan (e.g. KH-273 and KH-274) in the southern Riam Kanan Reservoir. Well exposed fresh rocks are found in the Sungai Aranio (NS-857), where they were petrographically studied and radiometrically dated.
Megascopically, the hornblende schist is recognised as fine to medium grained, with bands or segregations of quartz and feldspar. The foliation is normally well-developed, striking ENE to NNE and steeply dipping southeastward (40°-55°). Sometimes the foliation is microfolded or faulted. Quartz veins up to 4cm in width are present, cutting the foliation.

In thin section (e.g. NS-857), this rock shows a strong nematoblastic texture with oriented crystals of idioblastic and subidioblastic hornblende. Other constituents include epidote, quartz and plagioclase, with lesser amounts of muscovite, sphene and biotite (chlorite). The hornblende crystals are bluish green in colour, less than 0.02mm - 1mm long, euhedral in plagioclase and quartz. They are also seen as aggregates and fine needles within plagioclase and quartz grains, many of them lying parallel to the foliation. These hornblendes are intimately intergrown with epidote or rarely biotite (now chlorite). The bluish green hornblende crystals occur in parallel growth with biotite flakes. They all are elongated in the foliation direction.

Quartz-epidote-biotite-hornblende-garnet schist is occasionally found within the hornblende schist. In another locality (e.g. KH-273) the hornblende schist in turn forms laminae (up to 3mm) in quartz-epidote-biotite-hornblende-garnet schist. Quartz in the quartz-epidote-biotite-hornblende-garnet schist usually occurs as bands which are discontinuously interlaminated with epidote, hornblende and muscovite. Biotite and plagioclase are present in places. Muscovite is either parallel or oblique to foliation. The hornblende schist laminae within this rock type are composed of hornblende, epidote, biotite (now chlorite), muscovite, haematite, quartz and minor magnetite and pale pink garnet (almandine) and sphene. Garnet normally occurs as single grains, ranging from less than 0.1 to 0.2mm.
Biotite (Chlorite)-Epidote Schist

Biotite (chlorite)-epidote schist is exposed south of the quartz-muscovite schist and hornblende-epidote schist outcrops in the Sungai Banyumin (e.g. IU-7; NS-374), within the main metamorphic belt. This rock is characterised by the occurrence of minerals chlorite, epidote, plagioclase, quartz, muscovite, with minor sphene, clinozoisite and calcite. It is cross-cut by many fractures and microfaults. Adjacent to this chlorite schist, hornblende-epidote-quartz-chlorite schist (IU-92) is exposed. The rock is similar in texture and composition to that of the Aranio outcrops (NS-857).

The chlorite occurs as fine-grained aggregates, probably replacing a mafic mineral. In other cases, the chlorite is intergrown with some of the quartz bands. Preferential growth direction of the chlorite normally follows the trend of foliation.

Metagabbro

Metagabbro and associated metaigneous rocks occur in the core of the main metamorphic belt, e.g. IU-6. This rock is medium grained (0.2-3mm), and to a large extent still preserves its igneous texture. It has hypidiomorphic texture, consisting mainly of plagioclase and hornblende, with grain size varying from 0.2-3mm. Epidote is present in appreciable amounts. Quartz occurs as subordinate constituents, whereas magnetite and muscovite are present in minor amounts. Quartz makes up about 1%, slight to medium undulose extinction, granular texture, intergrown with plagioclase, or hornblende plus epidote.

Plagioclase only shows simple twinning, thus composition can only be determined by the central and/or oblique illumination methods. The plagioclase composition lies in the oligoclase category. Epidote, as granular to prismatic grains, occurs both between and within the hornblende and plagioclase.
3.2.2.2 Pelaihari Phyllite

The Pelaihari Phyllite was formally named by Sikumbang et al (1982). The rocks are exposed in scattered places just south of the town of Pelaihari. They occur to the southwest of the Hauran Schist. Although in general the rocks are poorly exposed, due to the low-hilly to flat-lying morphology with deep soil profiles, some small exposures still can be seen, in particular in road cuts or along small streams. These metamorphic rocks are fault bounded, both to the east and west, against tectonic slices of the Meratus Ophiolite. Fault contact against the volcaniclastic deposit of the Alino Group is also found in the southeast. No good section for the type locality of the phyllite has been found. The rocks are thought to pass by gradation into the Hauran Schist.

Observations from a number of small outcrops show that the Pelaihari Phyllite is a fine-grained, medium-light green to brown coloured rock, with a slight gloss on the surface due to the presence of chlorite and platy minerals. The rocks are very well cleaved although often folded and crenulated. Numerous quartz bands and veins are commonly found in these rocks. They contain gold, pyrite and other associated ore minerals. The native people are prospecting gold from these bands and veins (see Geological Map for gold pit localities).

Due to weathering and the difficulty of impregnating the fresher samples, petrographic examination was not possible.

3.2.3 Possible Origin of Metamorphic Rocks

On the basis of textural and compositional characteristics present in the metamorphic rocks, at least four parental rocks of the metamorphics may be recognised:
1. The phyllites suggest that they may be originally flysch-type sediments. If so, these rocks are the oldest flysch-type sediments in the Meratus Mountains.

2. Quartz-muscovite schist — from quartzose sandstones with argillaceous interbeds/cherts.

3. Hornblende-epidote schist — from dolerite or basalt, intrusions or lava flows.

4. Amphibolite — metabasic igneous rocks: gabbro or dolerite.

3.2.4 Grade of Metamorphism

The occurrence of the diagnostic minerals albite, oligoclase, almandine and hornblende, accompanied by combinations of epidote and biotite in the quartz-muscovite schist and hornblende-epidote schist of the Hauran Schist, are indicative of metamorphism at greenschist to amphibolite facies (low T and moderate P to moderate T and P). These types of metamorphic facies are characteristic of regional metamorphism which are considered to be related to orogenic movement in the Meratus Mountains, South-East Kalimantan.

3.2.5 Age of Metamorphism

The Hauran Schist and Pelaihari Phyllite are considered to have been deformed and metamorphosed at the same time, although differed in grade of metamorphism. The age of this metamorphism which forms the metamorphic complex of the Meratus Mountains was determined to be 108.4 Ma falling within Lower Albian (determination by Dr N J Snelling, British Geological Survey, using K/Ar dating on whole rock). Metagabbro which cut the metamorphic rocks in the Sungai Banyumin is also thought to have been affected by this metamorphism event, most probably at the same time. Other evidence which supports an Early
Albian (108.4 Ma) age is that the fragments of schist and undulose extinction quartz grains are found in the Albian-Cenomanian Alino Group (see Chapter V).

Metamorphic rocks which also have similar stratigraphic position (i.e. unconformably overlain by a sequence of radiolarian chert with sandstone interbeds, resembling the Alino Group) and geological setting have been reported to occur in south arm of Sulawesi (Sukamto, 1975). These rocks include glaucophane schist, garnet schist and albite-orthoclase gneiss. They have been dated, on muscovite, as 111 Ma or Early Cretaceous by Sukamto (1975).
CHAPTER IV

1. PANIUNGAN FORMATION: MUDSTONE WITH OCCASIONAL SANDSTONE AND LIMESTONE INTERCALATIONS

2. BATUNUNGGAL FORMATION: LIMESTONE STRATA

3. PITANAK FORMATION: PL-PHYRIC LAVA FLOWS
4.1. PANIUNGAN FORMATION

4.1.1 Introduction

Calcareous sandstones and mudstones which are intermittently exposed along the Sungai Paniungan have been known as Paniungan Formation for over 50 years (Koolhoven 1933). The age of this formation, based on the occurrence of Cylindrites sp., was regarded by Koolhoven (1933) as of probable Late Jurassic - Early Cretaceous age. Further, Koolhoven (1933) also considered that the formation was older than the mafic-ultramafic rocks because he found the serpentinite was intrusive into rocks of the Paniungan Formation.

As the Paniungan Formation has regional stratigraphic importance in the Pre-Tertiary geology and tectonic history of SE Kalimantan, detailed field (e.g. lithology and sedimentary structures) and laboratory studies (e.g. petrographic analyses) were carried out in the Sungai Paniungan and in other critical geological traverses throughout the study area where rocks may be correlated with the Paniungan Formation.

4.1.2 Definition

The name Paniungan Formation (Koolhoven 1935), is retained for the fine grained calcareous clastic unit. The type locality of the formation is in the Sungai Paniungan, 40 km ENE of Martapura (Fig. 31). Other important localities which can be satisfactorily compared with that of Sungai Paniungan are at Sungai Julung, Sungai Tiwaang, Sungai Manuit and Sungai Satui (Figs. 33, 45 and 46).

The formation is herein defined as one of the rock units which are overlain by the Manunggul Group. The base of the formation is not exposed, but it is considered to be overlying a continental basement unconformably (see evidence below).
A conformable stratigraphic contact between the Paniungan Formation and the overlying Batununggal Limestone was found for the first time during this study in the upper Sungai Satui (Fig. 32).

Fig. 32 Schematic vertical section of the upper contact of the Paniungan Formation at Sungai Satui, showing lithological transition into the overlying limestones of the Batununggal Formation.

4.1.3 Occurrence

The Paniungan Formation occurs in two discontinuous sedimentary belts, here called the Northwestern and the Southeastern Provinces (Fig. 31). The Northwestern Province extends from the upper Sungai Julung to the Sungai Paniungan, and then reappears at Sungai Manuit and Naranin, tributaries of the Sungai Melanau NE of the Sungai Paniungan. This area forms a narrow belt which extends for about 35km and the rocks here are in tectonic contact with ophiolite of the Bobaris Range. A very small outcrop of the Paniungan Formation occurs in the Sungai Paringin, a tributary of the Sungai Mangkauk, about 25 km N of Sungai Paniungan.
The fine clastic sediments which underlie the limestones of the Batununggal Formation in the upper Sungai Satui, in the southern foothills of the Manjam Range, represent the Southeastern Province of the Paniungan Formation (see Fig. 47). Although the sedimentary strata in this area show similar lithological, sedimentological and faunal characteristics with those found in the Sungai Paniungan, they have never been recorded or even mentioned in earlier geological reports. This new locality is very important as it can be used for establishing both the stratigraphic position of the Paniungan Formation and the Mesozoic stratigraphic framework of SE Kalimantan.

As sediments of the Paniungan Formation in the upper Sungai Satui have been affected by folding and faulting and, to some extent, tectonic shearing, the true thickness of the formation is difficult to determine. However, judging from both the areal extent of the formation and distribution of the strike and dip of the sedimentary strata, the thickness of the formation here is not less than 750 m.

4.1.4 Field Description

Detailed field descriptions and discussion of the formation in each province are given below. Representative stratigraphic sections of the formation are also shown, and each of the stratigraphic sections are subdivided into units or lithofacies.

4.1.4.1 Northwestern Province: Julung-Paniungan

In the Northwestern Province the Paniungan Formation (Fig. 31) is in fault contact on the west with the Bobaris Ophiolite but it is unconformably overlain by sedimentary strata of the Manunggul Group to the north and east. In addition, the sedimentary strata of the Paniungan Formation have been tectonically mixed with serpentinite of the Bobaris Ophiolite (e.g. at Sungai Paniungan as shown in Fig. 33). In other places such as at Sungai Julung and Tiwaang they have been intruded by microdiorite (Fig. 45).
FIG. 33 Geological traverse in the Sungai Paniungan, showing general characteristics of the Paniungan Formation. Traverse A is near the confluence of the Sungai Paniungan and the Sungai Pinang, whereas Traverse B is in the upper course of the Sungai Paniungan.
Geological traverses in this province are the Paniungan Traverse and Julung and Tiwaang Traverses.

A. Paniungan Traverse and Adjacent Area

The Paniungan Traverse is in the Sungai Paniungan from which the name of the formation is derived. Sungai Paniungan flows parallel to the trend of the Bobaris Range, i.e. northeast-southwest. It drains into the Sungai Pinang which then flows into the Sungai Riam Kiwa, the second biggest river in the central portion of the Meratus Mountains. The outcrops of the Paniungan Formation are intermittently exposed from the lower to upper course of the Sungai Paniungan (Fig. 33).

Description of Lithology

The formation consists predominantly of olive black (10 Y 2/2)* mudstones, with occasional sandstone intercalations. The mudstones are often laminated (Fig. 34), however, in many outcrops they have been highly disrupted, sheared and dissected by later faults (Figs. 35 and 36). These mudstones are composed of 17% calcium carbonate and 83% insoluble fraction (e.g. NS-740), thus they cannot be classified as marl (cf. Koolhoven 1935; Marks 1961). In a few places, such as in location NS-745 the mudstone is interbedded with light olive grey (5 Y 6/1) to olive grey (5 Y 4/1) fine grained calcirudite.

Dusky yellowish brown (10 YR 2/2) to olive black (5 Y 2/1) calcilutite concretions with numerous calcite veins, up to 20x30cm in size, are commonly present in the mudstone (Fig. 37). Some of the concretions contain bivalves and gastropods.

The sandstone beds are mostly olive grey (5 Y 4/1) to dark grey (N33), ine-medium grained, and frequently poorly to very poorly sorted. These sandstones can be classified as calcareous sandstone

* Colours in this thesis are specified according to the Rock-Color Chart prepared by the Rock-Color Chart Committee (Geological Society of America, 1980)
(<50% CaCO₃) and calcarenite (>50% CaCO₃) categories. In general, throughout the vertical section, as can be seen in Fig. 33, the sandstones show a marked increase in bed thickness (i.e. up to 50cm thick) toward the base of the section, e.g. in NS-747 and NS-748 (Figs. 38 and 39).

In addition, thin beds of pebbly sandstone (10-20cm thick) are present near the confluence of Sungai Paniungan and Sungai Aih (NS-270). They are commonly graded and become more common but thinner towards the top of the section. In the uppermost exposed section the formation fines upwards, i.e. in the lower Sungai Aih, where mudstones predominate. The calcareous mudstones in the Sungai Aih are strikingly similar to those of the Sungai Paniungan, where they are rather dense, highly fractured, sheared in places, and contain thin layers of either calcareous sandstone or calcarenite. As at Sungai Paniungan, laminations are the only sedimentary structures found in the mudstones. Fragments of bryozoa and bivalves are also occasionally present in the mudstone at Sungai Aih (e.g. NS-754).

Sediments of the Paniungan Formation are also found in a small exposure in the Sungai Manuit and Naranin (Fig. 40), about 15km NE of the Sungai Paniungan. The formation in these two small rivers (e.g. KH-145, KH-149 to 154, KH-156 to 164) consists mostly of calcareous mudstone with occasional intercalations of calcareous sandstone. Similar calcareous mudstone, but with many macrofossils (i.e. bivalves) and intercalations of limestone (4-8cm thick, NS-455) is also found in a small exposure in the lower Sungai Paringin, near Sungai Mangkauk.

From their lithological and sedimentological characteristics, the sediments exposed in the Sungai Manuit and Naranin, and also in the Sungai Paringin can be correlated with those exposed in the Sungai Paniungan and Aih. Therefore, the exposure of the Paniungan Formation
Fig. 34 Parallel laminated mudstone of the Paniungan Formation in the Sungai Paniungan (NS-752). Note that primary structures are still well preserved in this locality (i.e. unaffected by deformation).

Fig. 35 Slightly sheared sediments of the Paniungan Formation. Note foliation is defined by calcite segregations. The primary structures (i.e. laminations) are still retained, though the rocks have been involved in deformation. Laminations are intersected by surfaces of shear (e.g. see centre).
Fig. 36 Highly sheared mudstone of the Paniungan Formation, Sungai Paniungan. Calcite veins are another characteristic of the mudstone, filling either shearing planes or fractures. Veins which fill the shear planes are now contorted or folded.

Fig. 37 Limestone concretion in the highly fractured mudstone of the Paniungan Formation, Sungai Paniungan. Tensional fractures are filled by calcite. Notice post-sedimentation deformation around the concretion. The deformation of this sort resembles those seen in shale diapirs.
Fig. 38 A view showing thick sandstone beds in the mudstone, lower section of the Paniungan Formation. Exposed in the upper course of Sungai Paniungan. Locality: NS-747.

Fig. 39 Close-up of the right bottom corner of Fig. 38, showing the thickest sandstone bed. The thickness of the bed increases toward the north (i.e. upper centre).
Fig. 40 Outcrop of the Paniungan Formation (i.e. mudstone) at Sungai Naranin. The mudstone is indistinctly bedded (i.e. due to severe brecciation or fracturing) and poorly laminated.

in the three rivers above can be regarded as the northwestern continuation of the Paniungan Formation. Strike and dip of the sedimentary strata in those areas (except in the Sungai Paringin), which all dip steeply to the southeast (65° to 82°), support this interpretation.

Other important characteristics of the sediments of the Paniungan Formation are cone-in-cone structure developed in micrite or mudstone layers. This sedimentary structure is also found in the following rivers: Paniungan (NS-743, Naranin (KH-164) and Satui (NS-622).
Petrography

Representative samples from the Paniungan Formation have been examined under the microscope in order to document the petrographic characteristics of the samples.

There are three main lithologies present in the Paniungan Formation, mudstone, sandstone and limestone. As has been stated earlier, mudstone is the dominant lithology and makes up approximately 80% of the exposed section of the formation (see Fig. 33), whilst the sandstone and limestone constitute about 19.5% and 0.5% of the total thickness of the section respectively. The latter usually forms as nodules or concretions and rarely occurs as layers.

Representative samples from each lithological unit were selected for petrographic analysis, and the results are tabulated in Table 2. Sample localities can be seen in Fig. 33. Typical photomicrographs of mudstone and sandstone are displayed in Figs. 41 to 44.

Mudstone The mudstone is pale yellowish orange (10 YR 8/6) in thin section (i.e. under PPL), and is characteristically finely laminated, mostly parallel or slightly undulating (see Fig. 34). Individual laminae range from 1.5mm to about 2mm in thickness and are composed mainly of terrigenous and carbonate mud with significant amounts of micritised bioclasts (unidentified) and very fine sand to silt-sized grains of quartz (i.e. predominantly monocrystalline), plagioclase and muscovite. The proportion of very fine sand to silt-sized terrigenous grains is about 5-10% of the thin section.

By dissolving limestone in dilute HCL, the bulk composition of the mudstone was found to be 17% CaCO₃ (i.e. micrite and silt-sized carbonate grains) and 83% terrigenous very fine sand to silt-sized grains and mud. Carbonate analysis allows the mudstone to be classified as calcareous mudstone rather than marl.
Graded layering is commonly observable in the mudstone (e.g. NS-742). The base of the graded layers is characterised by an admixture of carbonate grains and very fine sand to silt-sized terrigenous grains consisting of quartz and plagioclase, with minor amounts of muscovite and epidote. Iron oxide as a cement and calcite veins are also fairly common in the mudstone. Furthermore, the terrigenous mud has been analysed by XRD which indicates that it consists largely of quartz (3.33 Å), albite (3.18 Å) and kaolinite (7.05 Å).

Some samples of the mudstone (e.g. NS-750 and NS-754) have also been analysed for foraminifers, but so far there does not seem to be a single foram present in the mudstone. The calcareous mudstones of the Paniungan Formation are evidently unfossiliferous (i.e. foraminifera). However, Ter Bruggen (in Koolhoven 1935) found some foraminifers (i.e. Quinqueloculina) in the mudstone, but they cannot be used for age determination (Bemmelen 1949).

Despite the scarcity of calcareous fossils in the deposit the writer has found palynomorphs in the mudstones of both the Northeastern (e.g. NS-754) and Southeastern (e.g. NS-622) Belts.

Sandstone Sandstone intercalations in the Paniungan Formation are fine to medium grained, grain-supported and poorly sorted, with framework grains forming approximately 90% of the thin section. The rest which forms approximately 10%, is matrix or micritised cement. The framework grains are generally angular to very angular in shape, with QZ (36-45%) and PL (27-29%) the most abundant constituents (Table 2).

QZ grains vary from equant to elongate and exhibit slightly undulose extinction. The rims of QZ grains are generally corroded or etched and partially replaced by calcite. Qm grains comprise approximately 35%, whilst Qp grains vary from 1.5 to 10%.
Fig. 41 Photomicrograph of calcareous laminated mudstone, showing texture and very fine sand - silt sized terrigenous detritus (i.e. quartz, plagioclase and muscovite). Sample No: NS-742, Sungai Paniungan. Scale bar 0.1mm.

Fig. 42 Photomicrograph of calcareous terrigenous siltstone, showing texture and composition. Sample: NS-13B, Sungai Paniungan. XPL. Scale bar 0.1mm.
There are two kinds of Qm present, one with slightly undulose extinction and another with moderately high undulose extinction; the former is predominant.

Grains of Qp quartz consist mostly of more than four microcrystals, showing pronounced undulose extinction. The boundaries of the intermicrocrystals are usually clearly defined. Sutured boundaries are predominant, but straight boundaries are also observed in some samples. Cryptopolycrystalline quartz has been included here in the Qp category but may be regarded as chert. The boundaries between cryptocrystals are too small to be identified. The grains of microcrystals of quartz are typically equant, varying from a few ten microns to over a hundred microns in diameter.

Feldspar grains are predominantly PL, with some Kf. The grains are generally clear, untwinned and simply twinned albite. In some samples (e.g. NS-743) grains of zoned PL were also recognised. In most cases the grains of PL are relatively unaltered but minor alteration was observed, particularly around the rims of the grains and along cleavages. The grains of Kf usually have been sericitized, thus they are frequently difficult to identify.

Lithic detritus is mainly plutonic and volcanic fragments which are made up of medium to fine-grained granite and andesite-like fragments (e.g. NS-743 and NS-751B). These lithic fragments are subrounded to rounded and make up 2% to 5% of the rock volume respectively. The size of granitic grains usually more than 0.3mm in diameter, and some clearly showing granophyric texture.

Coralline algae account for the bulk of the bioclastic constituents, which form approximately 12% of the thin section. The size of coralline algae vary from less than 0.2mm to over 0.4mm. Bryozoan and shell fragments are present in minor amounts. Other types of bioclastic grains are too difficult to identify as they are now completely recrystallised.
Table 2: Mean framework modes of terrigenous grains (Quartz, Q, Feldspar, F and Lithic, L) from calcareous sandstone intercalations of the Paniungan Formation, Northwestern (Sungai Paniungan) and South-eastern (Sungai Satui) Provinces, SE Kalimantan.

<table>
<thead>
<tr>
<th>AREAS</th>
<th>SUNGAI PANIUNGAN</th>
<th>SUNGAI SATUI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NS-743</td>
<td>NS-747</td>
</tr>
<tr>
<td>Monocrystalline quartz (Qm)</td>
<td>55</td>
<td>40</td>
</tr>
<tr>
<td>Plagioclase (PL)</td>
<td>43</td>
<td>26</td>
</tr>
<tr>
<td>K. Feldspar (Kf)</td>
<td>Tr</td>
<td>1</td>
</tr>
<tr>
<td>Polycrystalline quartz (Qp)</td>
<td>02</td>
<td>13</td>
</tr>
<tr>
<td>Volcanic rock fragments (Lv)</td>
<td>Tr</td>
<td>20</td>
</tr>
<tr>
<td>Granitic rock fragments (Gr)</td>
<td>Tr</td>
<td>Tr</td>
</tr>
<tr>
<td>Carbonate grains</td>
<td>12</td>
<td>30</td>
</tr>
<tr>
<td>Interstitial matrix and cement</td>
<td>10</td>
<td>18</td>
</tr>
</tbody>
</table>

Abbreviations: Qz=Quartz, Qm=Monocrystalline quartz, Qp=Polycrystalline quartz, PL=Plagioclase, Kf=Potassium feldspar, Lv=Volcanic rock fragments, Gr=Granite rock fragments and PX=Pyroxene.

Note: Percentages for sand carbonate grains and interstitial matrix and cement are based on point counts of all framework grains, interstitial, and cement.

* Explosive volcanic material, i.e. included in tuffaceous source (unreworked).

Chlorite, epidote, biotite, muscovite, pyroxene, sphene and magnetite occur as minor constituents scattered throughout the thin section. A single planktonic foraminifera is present in NS-743.
Fig. 43 Calcereous terrigenous sandstone from the Paniungan Formation. Photograph shows moderately well sorted texture and framework constituents set in micrite cement. Sample NS-748, Sungai Paniungan. XPL. Scale bar 0.5mm.

Fig. 44 Another photograph of calcereous terrigenous sandstone, taken under XPL illumination. Sample NS-743, Sungai Paniungan. XPL.
Fig. 43 Calcareous terrigenous sandstone from the Paniungan Formation. Photomicrograph shows moderately well sorted texture and framework constituents set in micrite cement. Sample NS-748, Sungai Paniungan. XPL. Scale bar 0.5mm.

Fig. 44 Another photomicrograph of calcareous terrigenous sandstone, taken under high magnification. Sample NS-743, Sungai Paniungan. XPL. Scale bar 0.2mm.
The matrix is composed either of terrigenous mud (i.e. in lithic arkose, e.g. NS-751B) or carbonate mud or micrite (i.e. in calcareous lithic arkose, e.g. NS-743). Clear sparry calcite is not apparent in the sandstones. Very frequently the recrystallised carbonate grains and matrix are very difficult to discriminate from the calcite cement.

**Limestone**  As mentioned earlier, the limestone occurs either concretions or intercalations in the mudstone of the Paniungan Formation. The former is far more common.

Limestone concretions occur mostly in the Sungai Paniungan, particularly in the middle (NS-744) and upper (Fig. 33, NS-741) parts of the formation. These concretions are hard, round to oval, and sometimes exhibit irregular shapes, ranging in diameter from a few cm to approximately 30 cm. Most of the concretions are composed of calcilutite, dusky yellowish brown (10 YR 2/2), olive grey (5 Y 4/1) to olive black (5 Y 2/1), are usually dense and some have been fractured. Moreover, the mudstone lamination around concretions is now curved and in places shows tension fractures (e.g. Fig. 37) which are infilled with calcite. In a few cases the original position of concretions has been modified by diapiric intrusion of the shales.

In the Sungai Satui the concretions are not as well developed as those found in Sungai Paniungan. The concretions here are not obvious, but polished surfaces reveal concretion-like fabric. They are composed of sandy mudstone, light olive grey (5 Y 6/1) to olive grey (5 Y 4/1), and contain bivalves and gastropods. The concretions have irregular outlines, and the contact with the surrounding masses is usually gradational on all sides.

The limestone concretions in the Paniungan Formation closely resemble those described and interpreted by Weeks (1957) in Lower Cretaceous shales of the Magdalena Valley of Colombia, South America. It is considered that the concretions are syngentic or early
diagenetic in origin, formed immediately after deposition. The occurrence of deformed lamination around the concretion is in line with this suggestion.

There are two kinds of limestone intercalations present in the mudstone. One is characterised by calcilutite or micrite, containing thin layers of cone-in-cone structure, and another is bioclastic calcarenite and fine calcirudite. The former is commonly found in the middle part of the section, whereas the latter is in the upper portion of the Paniungan Formation. The calcilutite or micrite (e.g. NS-623) is olive grey (5 Y 4/1) to yellowish grey (5 Y 8/1) in colour and occurs in the following rivers, Paniungan, Naranin and Satui. Whilst the bioclastic limestones (e.g. NS-745 A, NS-457), forming continuous or discontinuous layers, are found in the Sungai Paniungan and Paringin. Fine calcirudite is light grey (5 Y 6/1) to olive grey (5 Y 4/1), with greyish black (N₂2) spots. These particular limestones are the upper part of the Paniungan Formation, and can be regarded as the commencement of carbonate deposition of the Batununggal Formation, at least in and around the Sungai Paniungan area (see below).

B Julung and Tiwaang Traverses

The Julung and Tiwaang river traverses are located on the southern side of the Bobaris Range. These two rivers flow in a NNW direction, perpendicular to the Bobaris Range, and drain into the Sungai Malinau and eventually enter the Riam Kanan Reservoir (see Fig. 33).

Outcrops of the Paniungan Formation here are confined to the upper course of the rivers (Figs. 45 and 46). In the west the formation is cut by a high angle fault, against the Bobaris Ophiolite, while downstream in the east it has been intruded by microdiorite.
FIG. 45 Geological traverse along Sungai Julung, in the southern foothills of the Bobaris Range. Outcrops of the Paniungan Formation and their relationships with other units are shown in the figure.

KEY TO SYMBOLS

- Microdiorite
- Andesitic lavas and breccias
- Sandstone
- Paniungan Formation
- Meratus Ophiolite
- Fault
- Tributary

NS-660 Sample Locality

JAVAN SEA
FIG. 46 Geological traverse along Sungai Tiwang, in the southern foothills of the Jokan Range. Outcrops of the Paniungu Formation and their relationships with other units are shown in the figure.

KEY TO SYMBOLS
- Microdiorite
- Andesitic lavas and breccias
- Sandstone
- Paniungu Formation
- Meratus Ophiolite
- Lithological boundary
- Fault
- Sample Locality
As the rocks have been cut by faults and, to some extent, intruded by microdiorite, the true thickness of the formation here is unknown. But the minimum thickness can be crudely estimated as greater than 600m.

**Description of Lithology and Petrography**

The Paniungan sediments in both the Sungai Julung and Tiwaang are homogeneous and consist entirely of dark grey (N₃₃) mudstones. The mudstones are slightly calcareous, massive, hard and, to some extent fractured and brecciated, rarely displaying bedding.

However, some sedimentary structures are still preserved in a few outcrops, particularly laminations which can be seen at the downstream end of the Sungai Julung (NS-668) and in the Sungai Tiwaang (NS-690). The laminations are very thin (1-2mm thick) and they are frequently parallel or very slightly undulating with <1mm relief.

In thin section the mudstone is poorly sorted with significant amount of subangular to angular terrigenous grains. On the basis of petrographic examination (e.g. NS-673, NS-674, NS-690 and PR-16), silt to very fine sand-sized detrital grains are dominantly composed of Qm, PL and muscovite with subordinate chlorite and epidote. Other constituents include opaque minerals and clear calcite grains.

**4.1.4.2 Southeastern Province:** Sungai Satui, in the southern foothills of the Manjam Range.

As has been mentioned earlier the fine clastic sediments at Sungai Satui (Fig. 47) show striking similarities to those exposed in the type locality of the Paniungan Formation in the Sungai Paniungan. The sedimentary belt in the Southeastern Province is now separated from the Northwestern Province (see Fig. 37) by the outcrop of the Meratus Ophiolite and the Alino and Manunggul Groups.
FIG. 47 Geological traverse in the Sungai Satui showing outcrop pattern of the Paniungan and Batununggal Formations and adjacent rock-units.
This is the southernmost exposure of the Paniungan Formation in the study area and also for SE Kalimantan. The formation is unconformably overlain by quartz sandstone of Eocene age in the S, whereas in the N the formation is conformably overlain by the Batununggal Formation.

The original extent of the Paniungan Formation has been reduced by tectonic compression and, to some extent, by faulting. The base of the formation is not exposed. On the basis of present geological observation along Sungai Satui, the sediments of the Paniungan Formation here can be generalised as follows.

Description of Lithology and Petrography

This section describes the lithology and petrography of representative samples of the Paniungan Formation in the Sungai Satui, and is intended as a comparison with that of the Sungai Paniungan. Thus it should be read in conjunction with sub-section 4.1.4.1.

Localities mentioned in the text are shown in Fig. 47, and the position of the specimens collected is indicated on both the geological traverse and the generalised stratigraphic column (Fig. 48).

The rocks in the Sungai Satui are poorly exposed, thus they cannot easily be subdivided stratigraphically. However, on the basis of lithology and sedimentary structures, they can be divided into lower, middle and upper units (Fig. 48).

Unit A Undeformed mudstone with calcareous sandstone intercalations (NS-624 A and B and NS-623).

This is the basal unit of the formation, exposed from the confluence of Sungai Satui and Meweh to the Satui-Jelamu junction (Fig. 48). It is about 450m thick and the sediments consist of olive black (5 Y 2/1) mudstone, fine-grained olive grey (5 Y 4/1), calcareous sandstone and minor yellowish grey (5 Y 8/1) limestone. The mudstone makes up 95% of the lower unit, whereas the calcareous sandstone and limestone form approximately 4% and 1% respectively.
The lower part of Unit A is represented by undeformed mudstone (Fig. 48), normally laminated, with intercalations of calcareous sandstone. Beds of the sandstone generally range from 6-12 cm. However, the thickest calcareous sandstone intercalation (60 cm thick) is found between NS-623 and NS-624. The rocks in the middle part of the lower unit are characterised by thick bedded mudstone with faint lamination, moderately hard, and contain a few micrite layers which typically display cone-in-cone structure (i.e. NS-623). In the upper part of the lower unit, apart from the laminated mudstone, a bioturbated mudstone is also present, exposed south of the junction of Sungai Satui and Jelamu.

The mottles in the bioturbated mudstone are recognisable by spots or areas of different colours, olive grey with light grey mottles. These mottles are irregular, showing neither horizontal nor vertical orientations. Furthermore, the mottled mudstones have been burrowed or churned up by either filter or deposit feeder faunas (i.e. in soft muddy-silty bottoms), as molluscan fossils occur higher in the section, and the burrows themselves are infilled with sandy mudstones. In addition, calcareous sandstone intercalations are also occasionally present in this part of the section.

The mudstone contains significant amounts of coarse silt to very fine sand grade terrigenous detrital grains (30-40%), of which Qm, PL and muscovite are the commonest. Some patches and stringers of pyrite were also observed, and comprise 2-4% of the thin section area. The coarse silt to very fine sand grains are all set in a brown calcareous mud matrix (up to 90%).

The calcareous sandstones are moderately well sorted, fine to medium sand grade, with framework grains forming more than 85%. The rest, which forms between 10-15% is essentially a mixture of calcium carbonate and clay matrix. Sedimentologically, the sandstone, as
Volcaniclastic turbidite

Bioclastic micrite and calcareous, mainly bedded to interlaminated mudstone and sandstone

Mudstone, olive grey (5 Y 4/1), with some gastropods and bivalves and concretions/nodules

Cleaved mudstone, with calcareous sandstone intercalations. The rocks seem to have been folded in place (see Fig. and the text).

Mudstone, olive grey (5 Y 4/1), calcareous, faintly laminated, undeformed in the lower part, and occasionally intercalated with calcareous sandstone (5 Y 4/1) and rarely with limestone (5 Y 8/1). A bioturbated mudstone occurs in the upper part.

FIG. 48 Stratigraphic section of the Paniungan Formation in the Southern Province (i.e. Sungai Satui). Sample locations are shown by black dots.
terrigenous detritus of the Paniungan Formation elsewhere, is made up of Qz (mainly Qm, with uniform extinction or only slightly undulose), PL potassium Kf, granite fragment, occasionally with granophyric texture, rare biotite, and microlitic volcanic detritus, with minor chlorite (possibly after biotite) and micritized skeletal fragments. Other subordinate constituents are muscovite and radiolaria (very rare).

Cone-in-cone structure (NS-623B) is made up of nested cones of fibrous calcite analogous to fibrous gypsum. These fibrous crystals probably grew under stress (Blatt, 1982).

**Unit B:** Cleaved mudstone with intercalations of calcareous sandstones and siltstones (NS-622, NS-619B, NS619A and NS-618).

The rocks of Unit B extend from the confluence of Sungai Satui and Jelamu to Lokpadi (NS-616, see Fig. 47). They are clearly laminated, though they have been strongly cleaved, and contain a number of thin intercalations of calcareous sandstone, with bed thicknesses generally ranging from 2-4cm. In general, this unit has clearly been affected by tectonic compression as the mudstones show "slaty cleavage". The cleaved mudstone, with an overall dip to the NW, is commonly cross-cut by quartz veins, particularly in the central part of the unit (i.e. NS-619 to NS-622).

The cleavage is parallel to the bedding. Several sandstone layers, located at NS-619 and NS-622, clearly follow the cleavage of the surrounding mudstones. The sandstone intercalations are well cemented by calcium carbonate, thus they frequently form beds resistant to weathering or erosion. In the upper part of the middle section (NS-616), the mudstones become massive, and in places contain concentrations of molluscan fossils. The fossiliferous mudstones are as concretion-like, with gradual or irregular boundaries. The sediments in the concretions are slightly more calcareous, silty or
sandy than surrounding sediment. The fossils and their skeletal debris show no preferred orientation.

Specimens for petrographic description were taken from either semilithified or well indurated siltstone and sandstone.

Petrographically, the siltstone of Unit B falls into sandy silty lime mudstone category. It consists of coarse silt to very fine sand grade terrigenous constituents (30-40% of the rock volume), mostly Qz, with some fresh PL, set in a calcareous mud matrix. Other constituents present include pyrite aggregates, muscovite, glauconite, phosphate and biotite (NS-618 and NS-619A). Planktonic foraminifera were also found in NS-619A.

The Qz grains are largely of monocrystalline type with uniform or slightly undulose extinction. Polycrystalline quartz grains, however, are also present but in very small quantity. Feldspar is mainly PL with very minor amounts of Kf.

The main constituents of the clay fraction in the mudstone of Unit B (e.g. NS-622) consist of quartz, albite, illite and kaolinite. Kf was detected in trace amounts. This indicates that the composition of the clay fraction is similar to those in the Sungai Paniungan.

The sandstone is fine-medium grained (0.15-0.4mm), calcareous sandstone, moderately well sorted. Composition and texture of the sandstone is shown in Figs. 49 and 50. The most abundant constituent is volcanic fragments (35% of the rock volume). The volcanic fragments present include porphyritic (Fig. 51), microlitic and felsitic (Fig. 52) grains, but the former and second are dominant. Microlitic grains are characterised by visible microlites or laths of plagioclase arranged in a disoriented fabric. Felsite grains display fine-grained mosaics of quartz and feldspar which are sometimes difficult to distinguish from chert.
Fig. 49 Photomicrograph of calcareous terrigenous sandstone intercalation showing texture and composition. Note granite clast in the centre (1mm in diameter) and volcanic detritus just above plagioclase grain (i.e. upper centre). Sample: NS-622, Sungai Satui. XPL. Scale bar 0.4mm.

Fig. 50 Photomicrograph of the same sample as the above photo, showing detrital grains of plutonic (e.g. diorite and quartz) and microlitic volcanic rocks. XPL. Scale bar 0.25mm.
phyritic volcanic fragments (e.g., terrigenous sandstone of Unit B, Fig. XFL. Scale bar 0.25mm.

Fig. Microlitic (lower left corner) and inclusions in the calcareous terrigenous sandstone of Unit B, sample no-ozz, Sungai Satui. XFL. Scale bar 0.25mm.
Fig. 51 Photomicrograph showing porphyritic volcanic fragments (e.g. upper centre) in the calcareous terrigenous sandstone of Unit B, Sungai Satui. Sample: NS-622. XPL. Scale bar 0.25mm.

Fig. 52 Photomicrograph showing both microlitic (lower left corner) and felsitic (upper centre) grains in the calcareous terrigenous sandstone of Unit B. Sample: NS-622, Sungai Satui. XPL. Scale bar 0.25mm.
Subordinate constituents include chlorite, oolitic grains, echinoderm fragments and glauconite. Coralline algae and magnetite, i.e. as individual grains or aggregates, make up 4% and 5% of the thin section. Other carbonate grains which form about 5% of the rock volume are difficult to determine as they have been completely micritized.

**Unit C**: Bedded and laminated calcareous mudstone and calcareous sandstone NS-615 A, B, C and D.

This is the upper part of the formation, exposed in a small area in the upper Sungai Satui (Fig. 48, it can only be seen if the water level is very low), and it has an exposed (minimum) thickness of 8m. The lower boundary of this upper section is not exposed, but it has a sharp contact, with a strongly cleaved mudstone zone at the top, separating it from the overlying Batununggal Formation. The contact is thought to be conformable because of the parallelism of the bedding planes in these two rock-units.

The rocks in this unit are characterised by very thin bedding, ranging from 1-4cm, and strongly interlaminated calcareous sandstone and slightly calcareous mudstone or claystone (Fig. 48).

The sandstone is greenish grey (5 GY 6/1) to olive grey (5 Y 4/1), highly indurated and displaying parallel lamination, but commonly with wavy layering in the upper part of the bed. The top of the sandstone bed is sharp and commonly has an undulatory boundary.

The mudstones are variable in colour and range from light olive grey (5 Y 6/1), olive grey (5 Y 4/1) and greyish black (N2.2). Another general characteristic of the mudstones is the finer and more homogeneous the grain size, the less sand or silt the lighter the colour of the mudstone. The thickness of individual laminae in the mudstone is not uniform, varying from <1mm to >6mm, and consists of alternating light olive grey (5 Y 6/1) or olive grey (5 Y 4/1) and greyish
black (N_2^2). These laminae are normally parallel, to slightly wavy or undulatory, but some also display small-scale flame structures.

Most of the primary structures in the upper section are very well preserved, although the rocks have been squeezed, cleaved, fractured and displaced in places.

In thin section sand grains include: Qm, PL (An 42-56, andesine-labradorite), PX, fine-grained lava and carbonate grains and crystal tuff with microlitic PL and PX. Qp with sutured crystal boundaries is rarely present in the rock. The grains of Qm usually have very slight undulatory extinction.

An echinoderm plate (2.2mm in size) and a few forams are also recognisable. Most of the carbonate grains have been recrystallised. Some grains of coralline algae were also observed. In general, micritized carbonate grains form discontinuous layering and they are parallel/subparallel to pressure solution seams or stylolites. Glauconite is also present in very small amounts. Calcite veins usually cross-cut bedding planes obliquely. PL is up to 400 microns in size, and typically displays albite twinning. A few grains of zoned plagioclase were observed in thin section. Lithic detrital grains, usually porphyritic volcanic fragments, showing drop-structures.

4.1.5 Age and Correlation

The fine clastic sediments of the Paniungan Formation have been dated by a number of previous workers. Koolhoven (1935) was the first to report the occurrence of molluscan fossils, i.e. Cylindrites sp., from the exposure of the mudstones at Sungai Pamali, and suggested the species may correlate with Cylindrites sp. in Europe. This species was regarded by Koolhoven (1935) as of probable Upper Jurassic - Lower Cretaceous age. And since then, an Upper Jurassic - Lower Cretaceous
age for the Paniungan Formation has become formally and informally used by many workers.

From a stratigraphic point of view lithological and paleontological evidence, together with the relationship between the Paniungan Formation and the adjacent rock-units as observed in the Sungai Satui, the Paniungan, the Pamali and the Tiwaang, there are two points which should be taken into account. One is that the presence of Cylindrites sp. alone, cannot be used as a time indicator for the Paniungan Formation. This is because species of Cylindrites have a wide time range and furthermore the rock-unit where fossil Cylindrites was found by previous workers such as in the Sungai Pamali and Tiwaang, are actually lithologically and stratigraphically identical with the basal part of the Manunggul Group, and are not considered to form part of the Paniungan Formation.

This suggestion is clearly in line with the new finding of the basal unit of the Manunggul Group in the watershed of Sungai Pamali where the unit is represented by ophiolite-rich sediments, similar to the rock-type (ophiolitic clastics) and fauna (i.e. Cylindrites sp., Turonian age) found by the writer in the Sungai Paau, i.e. in northern foothills of the Manjam Range. From these new findings, it becomes clear that the fine clastic sediments which contain Cylindrites sp. in the Sungai Pamali and Tiwaang are not part of the Paniungan Formation (cf. Koolhoven, 1935; Hashimoto and Koike, 1973) but rather they are the basal unit of the Manunggul Group (see Chapter VI).

A recent attempt to date the Paniungan Formation, based on palynological analysis, was reported by Situmorang (1982). According to Situmorang (1982) any palynomorphs which were once present in the samples have been completely destroyed, therefore no age could be given for the Paniungan Formation. A further attempt was undertaken by the writer to obtain foraminifers and palynomorphs. Separations
were carried out by Dr. J. Wright at Chelsea College. The result indicates that the samples from Sungai Paniungan (i.e. NS-750 and NS-754) and Satui (e.g. NS-622) contain no foraminifers but do contain identifiable palynomorphs. The palynomorphs were identified by Dr. N.F. Hughes of Cambridge University. They include types of Cicatricosisporites, accompanied by specimens of:

**Coronatispora**
**Klukisporites**
**Leptolepidites**
**Verrucosisporites**
**Cyanthidites**
**Classopolli**
**Eucommiidites**

According to Dr. Hughes these palynomorphs are most likely to be of Early Cretaceous, Berriasian to Barremian age.

As the samples from Sungai Paniungan and Satui yield the same palynomorph species, the upper part of the Paniungan Formation in the area studied must interfinger with and grade laterally into, and is therefore equivalent in age to, the lower portion of the Batununggal Formation.

In summary, the present writer, on the basis of new stratigraphic framework which is controlled by new age data, considers that the Paniungan Formation is the oldest sedimentary unit in the area studied and in South-East Kalimantan. The age of the formation ranges from Berriasian to Barremian.
4.1.6 Environment of Deposition

The lithology of the formation in the Northwestern Province (e.g. Sungai Paniungan) and Southern Province (e.g. Sungai Satui) is mainly mudstone or "mud rock" (cf. Blatt 1982) but contains intercalations of calcareous sandstone and minor limestone. Parts of the mudstone also contain limestone concretions and a molluscan fauna.

It has always been difficult to determine the environment of deposition for mudstone, particularly when the rock contains very sparse fossils (see Blatt 1982). This is the case in the sediments of the Paniungan Formation. However, the depositional environment can still be interpreted from the lithology and primary sedimentary structures. Other sedimentary features which are used herein for inferring the depositional environment of the Paniungan Formation include microscopic textures, colours, and to some extent, the presence of authigenic minerals such as glauconite and phosphate.

The lack of burrowing infauna (except in the upper part of Unit A in the Sungai Satui), together with finely laminated character, dark-grey to black colour which may be caused by a relatively high content of either unoxidised organic matter or iron sulphide, and combined with a sparse population of benthic fossils found in the mudstone suggest that the Paniungan sediments were deposited in an aerobic environment (cf. Byers 1977).

The moderately well to poor sorting of the sediments as shown by the high proportion of muds among the coarse silt to very fine sand grade terrigenous detritus (see above) is typical of a relatively low energy (quiet) environment with very little current activity.

The presence of coarse siltstone to very fine grained calcareous sandstone (calcarenite) intercalations in the mudstone combined with occasional graded sandstone layers indicate that the low energy environment was interrupted by occasional incursions of relatively
strong tidal or storm wave currents (cf. Blatt 1982). Such currents were responsible for transporting bioclastic grains (e.g. bryozoa, bivalve and coralline algae) and terrigenous grains to the site of deposition of the dark-grey to black coloured mudstone.

The occurrence of limestone concretions in the middle part (Unit B) of the formation, both in the Sungai Paniungan (NS-741 and NS744) and in the Sungai Satui, suggests that they were found in a deeper stagnant (quiet) water environment in which oxygen was depleted (see Weeks 1957). However, it can be argued that these limestone concretions may also form in a continental shelf environment such as found in the lower Tertiary (Oligocene - Miocene) shelf deposits (i.e. Binuang Formation) in the area studied (see Sikumbang 1982).

Good preservation of the original depositional structure of the sediments in the middle and upper parts of the formation, i.e. simple parallel lamination both in northern and southern sedimentary provinces, suggests that the sedimentation was taking place, from suspension, on a rather flat basin floor, probably in a stable mid to outer shelf environment. The presence of glauconite (e.g. in Unit B in the Sungai Satui) and phosphate is also suggestive of quiet water conditions or slow sedimentation in shelf environment under which calcium carbonate can be replaced by collophane (e.g. Manheim et al 1975; Parker 1975).

It is suggested that the mudstone was deposited in an oxygen depleted environment, probably in a deeper part of an extensive shallow-marine shelf environment, where deposition took place in an area undergoing slow sedimentation in which the normal processes of oxygenation have ceased to operate (see Byers 1977).
The vertical variation in the thickness of sandstone beds throughout the mudstone section, grain size and composition with calcium carbonate content would indicate that the sedimentation gradually changed, perhaps as a result of a gradual increase in water depth toward the top of the Paniungan Formation, that is probably from the shallow-marine shelf to the deeper part of shelf environments. This formation therefore represents a transgressive phase.

4.1.7 Source Areas

Field observation and petrographic data suggest that the sediments of the Paniungan Formation were derived from three main sources:

1. terrigenous material (i.e. mud, silt and sand sized grains), derived from land outside the site of deposition.
2. calcium carbonate material (i.e. bioclastic grains and cement), derived from in or adjacent to the site of deposition.
3. tuffaceous material (i.e. ash, crystal grains and small fragments of lava), derived either from erosion of land area or from explosive volcanic eruptions and gravitational settling simultaneously with terrigenous mud, silt and sand, and carbonate sedimentation.

4.1.7.1 Terrigenous Source

Petrographic data, as shown in Table 2, indicate that the terrigenous detritus of the Paniungan calcareous sandstones are dominated by the following constituents: 1. non to slightly undulose Qm, 2. PL and 3. volcanic rock fragments (i.e. felsite and microlite).

Small amounts of K-feldspar (Kf) and plutonic/granitic rock fragments with granophyric texture, are locally present. Accessory minerals include pyroxene, biotite (i.e. now nearly all altered to chlorite), hornblende, epidote and sphene. No ophiolite fragments
have been found in terrigenous detritus of the Paniungan Formation. This would imply that the Meratus Ophiolite was not an area of provenance at the time of the Paniungan deposition.

On the basis of these framework grains, together with their accessory minerals, the bulk of terrigenous detritus of the Paniungan Formation was probably derived from the erosion of an emergent region of the Sunda Shield, the "continental block" category in the sense of Dickinson and Suczek (1979) and Dickinson et al (1983). The terrigenous detritus was probably derived from uplifted diorite or granodioritic rocks that were on the W and NW margin of the Meratus Mountains.

Furthermore, the occurrence of microlitic and felsic grains indicates that volcanism also contributed to the sediments of the Paniungan Formation. They are thought to have been derived from ash fall tuffs which were erupted before the deposition of the calcareous volcaniclastic arkose intercalation in the middle part of the formation (NS-622). This evidence implies a pre-Barremian episode of volcanism in South-East Kalimantan.

4.1.7.2 Calcium Carbonate Source

Petrographic examination reveals that the calcium carbonate material (i.e. bioclastic grains and cement) in the Paniungan Formation is most likely derived from the disintegration of shallow-marine organisms, e.g. molluscans, bryozoans and echinoderms. It is also suggested that some carbonate grains were abraded or degraded into carbonate mud (micrite) by more resistant terrigenous material such as quartz and feldspar during transport.

Other sources considered for the derivation of calcium carbonate includes micritization of the carbonate grains, organic erosion by microboring as indicated by the presence of endolithic algae, and
pressure solution during compaction which dissolved calcium carbonate for use as cement of the sediment.

4.1.7.3 Tuffaceous Source

Tuffaceous material in the form of ash, crystal grains (e.g. feldspar and pyroxene) and small fragments of fine-grained lava are common in the uppermost part of the Paniungan Formation. They occur either as matrix or as coarse silt to sand-sized grains which are intermixed with other detritus, such as quartz and carbonate grains. The occurrence of upward fining ("grading") and dropped structures suggest that the layers accumulated by gravitational settling of tuffaceous material. In other words, the tuffaceous material could result from a volcanic shower simultaneous with calcareous terrigenous sedimentation on an open shelf environment. However, the geographic location of volcanic source is not known.
4.2 BATUNUNGGA FORMATION

4.2.1 Introduction

The occurrence of limestones or "Orbitolina-bearing sediments" in South-East Kalimantan was first reported by Krol (1918), though their stratigraphic position and type section were not clearly defined.

Present geological findings suggest that the Orbitolina-bearing limestones in the study area (and also elsewhere in Kalimantan?) occur in three different tectonostratigraphic units:

1. Autochthonous Unit: The Orbitolina-bearing limestones are still intact, e.g. in the Sungai Paringin and the Satui. They are not disrupted and redeposited, and do not show deformational features.

2. Parautochthonous Unit: The limestones are intermediate in tectonic character between autochthonous and allochthonous, forming thrust sheets, some of which are separated from each other by a highly sheared matrix-supported polymictic breccia interpreted as diapiric (cf. Barber et al., in press) or tectonic melange. Lithological and sedimentological characteristics as well as fossil content are still well preserved in these limestone thrust sheets.

3. Allochthonous Unit: The limestones occur as clasts or exotic blocks in a chaotic assemblage of polymictic breccia conglomerate of the Pudak Formation (Alino Group) interpreted as "sedimentary melange" or "olistostrome" that has now been tectonically disrupted, sliced and sheared. They have the following characteristics: cleaved, sliced, fractured, sheared and show very conspicuous pressure solution ("stylolitic structures") and are cut by numerous veins of either calcite or quartz, or combination of both.
This chapter is only concerned with description and interpretation of the autochthonous and parautochthonous units which are here included in the Batununggal Formation.

4.2.2 Definition

The name Batununggal derives from a village on the Sungai Kendihin in the Amuntai Quadrangle (i.e. north of the area studied). Here the unit, though it partly has been faulted and obscured by volcanic strata, is exposed in the upstream part of the river (Heryanto et al., in prep.).

A type section for the Batununggal Formation has not yet been established in the Amuntai Quadrangle, thus, it will be defined in future work.

The Batununggal Formation consists of ammonite-bearing argillaceous limestone, Orbitolina-bearing limestone, sponge spicular limestone and bioclastic limestone of various compositions (see below).

4.2.3 Occurrence

The Batununggal Formation in the study area occurs in two main provinces, in the northwestern and southeastern parts of the Meratus Mountain. In the former, the rocks of this formation, autochthonous, are now largely covered by in situ and undeformed amygdaloidal PL-phyric lava flows of the Pitanak Formation (Fig. 31), and are also intruded by intermediate to acid igneous rocks, e.g. diorite and granite (see Chapter VII). Whilst in the southeastern Meratus Mountains the limestones are thrusted and overlain unconformably by deformed volcaniclastic deposits of the Alino Group (Chapter V).
Northwestern Province

The limestones are observable as small isolated limestone hills which range from a few hundred to several kilometres long, commonly surrounded by volcanics. They occur in two discontinuous belts:

1. on the eastern flank of the Tambak Range, and
2. on the western flank of the Tamban Range.

These two discontinuous limestone belts trend in a NNE-SSW direction, parallel to the adjacent structural trend but form at about 20° to the major structures of the Meratus Mountain ranges. The area between the first and second belts, about 2.5 km in distance, is occupied by a well preserved Tertiary sedimentary belt which is consisting of the Tanjung and Berai Formations (see Geological Map).

No other limestone outcrops were observed elsewhere on the Tambak and Tamban Ranges although they may well exist in other locations but they are now concealed beneath a cover of either volcanic rocks of Tambak-Tamban or Barito Tertiary sedimentary strata.

The base of the formation is not exposed. However, on the basis of the presence of granodiorite and granite detritus in the basal part of the Orbitolina-bearing limestones at Batununggal in the Sungai Kendihin, north of the area studied, it is suggested that the formation was deposited unconformably on the Sunda continental basement, of which northern edge of the Meratus Range formed a small part.

In the lower Sungai Paringin, on the western flank of the Tamban Range, the limestone occurs as intercalations (4-8cm thick) in mudstone which probably belongs to the uppermost part of the Paniungan Formation. If this is correct, the Batununggal Formation, particularly in the lower part, interfingers with the upper part of the Paniungan Formation.
BIOCLASTIC LIMESTONE

Calcite cement

GRANODIORITE PEBBLE

Fig. 4. Calcite pebble in the Sungai Jerai, north of the study area.

Fig. 5. A pebble of granite from Orbitolina-bearing limestone is the same as above.
Fig. 53 Photomicrograph of the margin of a granodiorite pebble in the Orbitolina-bearing limestone at Batununggal in the Sungai Kendihin (i.e. in the Amuntai Quadrangle, north of the study area).

Fig. 54 Photomicrograph of a pebble of granite from Orbitolina-bearing limestone. Location is the same as above.
As all isolated limestone hills in the Tambak and Tamban Ranges are completely surrounded by either volcanics or Tertiary sedimentary strata, and do not show internal sedimentary structures the determination of the thickness is difficult.

Southeastern Province

As the limestones of the Batununggal Formation are poorly exposed in the Northwestern Province, it is not possible to study the vertical variation of the limestone section in that area in detail. However, there are two well-exposed sections of the Batununggal Formation in the Southeastern Province, one in the Sungai Kintap and another in the Batubeguntur. These two areas are of particular interest for the following reasons:

1. They have the thickest and most complete limestone sections for SE Kalimantan, approximately 400m thick in the Sungai Kintap.

2. There is lithological and paleontological evidence to indicate that this carbonate section has vertical variation.

3. The stratigraphic relationships of the limestone section to adjacent rock-units in those two areas provides evidence for interpreting geological and tectonic events during Lower Cretaceous time, in particular prior to and shortly after deposition of the limestone strata.
4.2.4 Description of Lithology and Petrography

4.2.4.1 Northwestern Province: Tambak and Tamban Area

Megascopically, the carbonates in the Tambak and Tamban Ranges are monotonous and consist of yellowish grey (5 Y 8/1) to slightly grey (N7) bioclastic limestones (e.g. NS-454, NS-457, NS-249A, RH-160, RH-169, IU-130 and KH-136). Orbitolina is present in the limestones. The limestones here are massive, hard and do not show any signs of deformation.

Petrography

Petrographic examination indicates that the limestones consist of at least two lithofacies, pure bryozoan-rich lime packstone-boundstone (RH-04) and mud-supported Orbitolina wackestone (NS-457). The relationship between these two lithofacies is not clear, but on the basis of rock distribution and morphology, the bryozoan-rich lime packstone-boundstone occurs relatively lower in the stratigraphic section than the Orbitolina wackestone.

Bryozoan Lime Packstone-Boundstone

The bryozoan-rich lime packstone-boundstone (RH-04) contains no terrigenous detritus. It is similar in character to the pure limestone in the SE of Binuang (NS-257, KH-129 and KH-136) and in some respect with the limestone in the thrust sheets in the Sungai Kintap. Bioclasts in this lithofacies are dominated by cellular colonial organisms (probably cheilostome bryozoan) and scattered echinoderm plates, and whole bivalves which have been geopetally filled with carbonate mud and calcite cement or sparry calcite (Fig. 55). Clear calcite spar also fills the zooecial cavities of the cellular colonial bryozoan. Individual zooecia are between 50 and 300 microns across, and are neomorphically replaced by dusty micrite and clear microsparite similar to that which fills the zooecial cavities.
Fig. 55 Photomicrograph of bryozoan-rich lime packstone-boundstone, showing texture and composition. Bryozoan debris (upper right) showing very rounded chambers (zooecia) with relatively thick fibrous wall structure. Sample RH-04, Sungai Paringin, western flank of the Tamban Range. XPL. Scale bar 0.25mm.

Fig. 56 Photomicrograph of wackestone, showing tests of Orbitolina in a micritic matrix. Sample NS-457, Sungai Paringin, western flank of the Tamban Range. XPL. Scale bar 0.25mm.
Echinoderm and mollusc fragments are also common in this lithofacies. Some of the bioclasts are completely recrystallized and are now replaced by clear calcite. Echinoderm grains commonly have extensive syntaxial overgrowth, with the original pattern only represented by dusty pyrite "ghosts".

The type of porosities in the bryozoan-rich lime packstone include interparticle and intraparticle pores, channel, vug and fracture (cf. Choquette and Pray, 1970). Interparticle and intraparticle pores are frequently hidden by rhombic calcite. Some parts of the thin section contain numerous post diagenetic veins, commonly less than 0.2 mm and rarely exceeding 0.4 mm in width, and filled with clear sparite. The limestone does not show pressure solution and overpacked texture, nor any of the deformational features seen in the limestone thrust sheets or blocks (i.e. cleaved and stylolitic limestones) in the sedimentary melange of the Pudak Formation.

**Mud-supported Orbitolina-wackestone**

Similar to the above lithofacies, the mud-supported *Orbitolina* wackestone (Fig. 56) is not affected by pressure solution, and contained no terrigenous detritus. However, this lithofacies can be differentiated from the previous lithofacies by primary texture and to some extent by the difference in the main skeletal constituents. Bioclasts in this lithofacies are set in a micritic matrix and are composed largely of mollusc (i.e. gastropod), bryozoan, echinoderm debris and whole fossils of *Orbitolina*. This limestone is very poorly sorted, with the size of skeletal grains ranging from a few hundred microns to over 1 cm across. Nearly all bioclastic grains are neomorphically replaced, and internal cavities have a micro-clear sparite cement similar to the bryozoan-rich lime packstone-boundstone lithofacies. The type of porosity in this limestone is simple, that is only interparticle pore and small vugs. Unlike the bryozoan
packstone, this rock only contains a few post diagenetic veins, i.e. less than 0.2 mm wide.

4.2.4.2 Southeastern Province: Sungai Kintap and Batubeguntur

These are the parautochthonous limestone units occurring in two main areas along the southeastern flank of the Manjam Range, in the upper Sungai Kintap and in the upper Sungai Batubeguntur.

The reasons for including these limestones in this section have been mentioned earlier. The limestone sections both in the Sungai Kintap and Sungai Batubeguntur provide lithological and paleontological characteristics, and also add important information about the lateral variation of the carbonate sedimentation.

Stratigraphic sections from each area are given in Figs. 57 and 75. Positions of individual samples from these sections are included on a stratigraphic column.

A. Sungai Kintap

From the geological traverse in the Sungai Kintap, as shown in Fig. 57, five lithofacies can be recognised, each is characterised by its lithology, internal characteristics (i.e. sedimentary structures), and fossils. These lithofacies have been given descriptive names as follows (from the bottom up):

E. Sponge-spicular limestone (mudstone)
D. Orbitolina-bearing limestone (bioclastic lime mudstone)
C. Massive limestone (wackestone and packstone)
B. Planktonic-ammonite-bearing limestone (terrigenous mudstone)
A. Echinoderm, molluscan and coral-rich limestone (packstone).
A.1 Bioclastic Limestone (Packstone) Lithofacies

This lithofacies has an exposed thickness of 12 m. The base is coincidentally the same as the sole of the limestone thrust sheet. The upper boundary of lithofacies is arbitrarily placed at the bottom of the Planktonic foraminiferid-ammonite-bearing limestone lithofacies which is the second lithofacies of the limestone section. The underlying rocks are represented by a highly deformed matrix-supported limestone-clay assemblage which is herein included in thrust fault related melange (Fig. 57).

It is characterized by massive to thick bedded, medium dark grey (N4.4) to dusky yellowish brown (10 YR 2/2), fine to medium grained bioclastic calcarenite. In thin section, this lithofacies (e.g. NS-308) is remarkably uniform and is composed mainly of conspicuous echinoderm plates (with poorly developed syntaxial rim cements) and spines, and fragments of bivalve, bryozoans (some recrystallized), coral and micritic peloids in sparse micritic matrix. Some foraminifers (including large forms) were also observed. Other constituents include several phosphatic grains and pyrite. Replacement by chalcedony was observed in bioclastic grains and it occurs frequently in the central part of the grains. Some bioclasts are now completely replaced by chalcedony. Stylolites and cross-cutting calcite filled microfractures are also present in the sample.

On the basis of the texture and bioclastic constituents the bioclastic calcarenites from this lithofacies are classified as echinoderm molluscan (bivalve) - rich lime packstone (NS-308A, Figs. 58 and 59) and recrystallised coral lime packstone (NS-309). Specimen NS-308B is essentially similar to that of NS-308A, that is echinoderm bivalve-rich lime packstone, except the former is slightly coarser grained (up to 4.5 mm in diameter), and contains coralline algal fragments and sparse planktonic foraminifers (i.e. whole fossils) as
FIG. 57 Geological traverse in the Sungai Kintap, showing the outcrop patterns of the Batununggal Formation and its relationship to the adjacent rock-units.
Fig. 58 Photomicrograph of NS-308B. This is similar to that of the above photo except NS-308B is finer grained. Note replacement by chalcedony in the centre. Scale bar 0.4mm.

Fig. 59 Photomicrograph of NS-308B. This is similar to that of the above photo except NS-308B is finer grained. Note replacement by chalcedony in the centre. Scale bar 0.4mm.
Fig. 58 Photomicrograph of echinoderm molluscan (bivalve)-rich lime packstone, showing texture and composition of microstructures (i.e. calcite veins and stylolites). Note large bryozoan with good preservation of zooecia (infilled by clear calcite) also occurs in the packstone. Sample NS-308A, Sungai Kintap. XPL. Scale bar 0.4mm.

Fig. 59 Photomicrograph of NS-308B. This is similar to that of the above photo except NS-308B is finer grained. Note replacement by chalcedony in the centre. Scale bar 0.4mm.
well as bryozoans. One specimen of biserial benthic foraminifers (cf. mid-Cretaceous Textularian foraminifers from Texas, see Loeblich and Tappan, 1982) is present in specimen NS-308B.

The characters of the skeletal grains and a few whole planktonic foraminifers in specimen NS-309 have been extensively affected by recrystallisation. Though difficult, due to extensive recrystallisation, the limestone of NS-309 can still be classified as bioclastic calcarenite or packstone which is made up largely of coral debris, with minor amounts of recrystallised echinoderm and molluscan fragments. As in NS-308 A&B, this rock is cross-cut by numerous post diagenetic veins which are all infilled with clear calcite microsparite. The rock is devoid of terrigenous detritus.

The type of porosity in the echinoderm bivalve-rich packstone includes interparticle and intraparticle pores, vugs and fractures. All the pores are now filled with clear calcite cement. Whilst in the coral lime packstone, the type of porosity is of larger pores of fracture and vug shapes.

The lithofacies is overlain conformably by planktonic-foraminiferid-ammonite-bearing limestone lithofacies.

A.2 Ammonite foraminiferid-bearing limestone lithofacies

Only 10m of this lithofacies is exposed, but the actual thickness is probably more than 40 m. The stratigraphic position of this lithofacies is clearly shown in Fig. 57.

It is homogeneous and consists of greyish black (N₂2) to brownish black (5 YR 2/1), thin to thickly bedded argillaceous limestone. Some intercalations of laminated argillaceous limestone occur in the lower part of the section. The layers range from a few cm to less than 30 cm, and these layers are normally horizontal. Most of the primary stratification in this lithofacies is still preserved, although it has been destroyed in places by bioturbation. The rocks contain scattered
pyrite, occurring either as small patches or as fossil replacement (i.e. ammonite or more commonly planktonic foraminifera).

Ammonites are quite conspicuous in the outcrop as they are replaced by pyrite and as well as being more resistant to weathering and erosion than the host rock. Species of ammonites were identified by Dr H G Owen of the British Museum as follows:

- Barremites sp. juv.
- cf. Valdedorsella sp. juv.
- ? Silesites sp. juv.
- cf. Costidiscus sp. juv.

Petrographic observation reveals that the argillaceous limestone which forms the lithofacies can be classified as planktonic foraminiferid-rich mudstone (Fig. 60). The coarsest grains (i.e. bioclasts and foraminifers) are mostly less than 100 microns. Planktonic foraminifers, which are the most conspicuous framework grains, make up more than 20% of the thin section. Nearly all planktonic foraminiferid chambers are now infilled with pyrite. Their tests are essentially calcite, with occasional traces of ferroan calcite.

Bioclastic fragments are scattered throughout and form about 15% of the rock volume. Most of them have suffered degrading neomorphism thus contributing to the micrite. Bivalve debris is the only identifiable type of bioclastic fragments in this lithofacies. Other fragments have been completely recrystallised.

Apart from filling foraminiferal chambers, pyrite also occurs as small patches (50-150 microns) and micro veins. Very small framboids (20-30 microns) occur within borings in bioclastic grains, e.g. echinoderm plates and bivalves (Fig. 61). This is probably related to endolithic fungal borings, before transport and deposition of grain (cf. Kobluk and Risk, 1977).
Fig. 60 Photomicrograph of planktonic foraminiferid-rich lime mudstone. Nearly all foraminifers are now filled with pyrite (framboidal pyrite). Pyrite can also be seen as small patches and as endolithic fungal borings in neomorphosed bioclastic grains as shown on overlay. Sample NS-307, Sungai Kintap. XPL. Scale bar 0.15mm.

Fig. 61 Photomicrograph shows endolithic fungal borings in the neomorphosed bioclastic grains (see overlay). Sample NS-307, Sungai Kintap. XPL. Scale bar 0.1mm.
Fig. 60 Photomicrograph of planktonic foraminiferid-rich lime mudstone. Nearly all foraminifers are now filled with pyrite (framboidal pyrite). Pyrite can also be seen as small patches and as endolithic fungal borings in neomorphosed bioclastic grains as shown on overlay. Sample NS-307, Sungai Kintap. XPL. Scale bar 0.15mm.

Fig. 61 Photomicrograph shows endolithic fungal borings in the neomorphosed bioclastic grains (see overlay). Sample NS-307, Sungai Kintap. XPL. Scale bar 0.1mm.
Fig. 62 Costidiscus sp. juv. from argillaceous limestone of the Batununggal Formation in the Sungai Kintap, southern foothills of the Manjam Range. Sample NS-307.

Fig. 63 Barremites sp. juv. from argillaceous limestone of the Batununggal Formation in the Sungai Kintap, southern foothills of the Manjam Range. Sample NS-307.
Fig. 64  *Valdedorsella* sp. juv. from argillaceous limestone of the Batununggal Formation in the Sungai Kintap, southern foothills of the Manjam Range. Sample NS-307.

Fig. 65  *Silesites* sp. juv. from argillaceous limestone of the Batununggal Formation in the Sungai Kintap, southern foothills of the Manjam Range. Sample NS-307.
Terrigenous mud is widely distributed in the ammonite-
foraminiferid-bearing limestone, dusty brown in thin section (i.e.
under PPL), and accounts for more than 25% of the rock. (e.g. NS-307).
The lower and upper contacts of this limestone lithofacies are
not exposed, but it changes abruptly to bioclastic calcarenite and
massive calcarenite in the underlying and overlying lithofacies
respectively.

A.3 Massive Limestone (Wackestone and Packstone) Lithofacies
This lithofacies is poorly exposed. It was therefore not
possible to undertake a detailed study in the field. The thickness of
this lithofacies (unit) is approximately 260 m.

It consists of homogeneous bioclastic limestone, with no apparent
sedimentary structures. The colour of the rocks is very light grey
\((N_g8)\) with light grey \((N_77)\) mottles, hence the massive limestone
lithofacies is distinctly different from the underlying rock-units
where they are very much darker, i.e. medium dark grey \((N_44)\) to
greyish black \((N_22)\).

In thin section, the rocks are classified as bioclastic lime
mudstone-wackestone and bioclastic peloidal lime packstone-grainstone
(Fig. 66). The fabric is rather random due to an irregular contact
between mudstone-wackestone and packstone-grainstone. The latter
possibly forming burrow fills or may also occurring as clasts in
mudstone-wackestone. The coarsest grains in the mudstone-wackestone
range from coarse silt to fine sand grade, and are composed of
bioclastic debris. No silt-sand terrigenous detritus was found in
thin section. The packstone-grainstone is mostly medium sand to
pebble grade peloids and bioclasts with very rare pebble (up to
1x1.2 cm in size) grade coral fragment (Fig. 67).
Fig. 66 Photomicrograph of bioclastic peloidal wackestone clast in the lime mudstone. Note syntaxial rim in the echinoderm plate in the upper centre. Sample NS-306, Sungai Kintap. XPL. Scale bar 0.75mm.

Fig. 67 Photomicrograph of internal structure of a pebble grade coral fragment in the lime mudstone-wackestone. Sample NS-306, Sungai Kintap. XPL. Scale bar 0.75mm.
Bioclasts are dominated by micritised echinoderm and molluscan debris. Bryozoan and foraminiferid fragments are also common. As in the previous lithofacies most bioclasts are neomorphically degraded and replaced by micrite. Bioclasts which have internal cavities (i.e. coral) are now infilled with a microspar-clear sparite cement similar to the intergranular cement (Fig. 67).

A.4 Argillaceous Limestone (Lime Mudstone) and Orbitolina bearing bioclastic limestone (Wackestone and packstone) Lithofacies

This lithofacies is in the upstream part of the Sungai Kintap. It has an exposed thickness of 260 m. Though the lower contact is not exposed, as it is obscured by a melange zone (see Fig. 57), the lithofacies is considered to have been originally conformably overlying the massive lime mudstone-wackestone lithofacies.

This lithofacies is marked by thickly bedded, medium dark grey (N₄⁴) to dark grey (N₃³), poorly sorted argillaceous (lime mudstone) and bioclastic limestone. This rock corresponds with the Orbitolina-bearing limestone found elsewhere in the area studied, and particularly closely resembles (in terms of lithology, sedimentary structures and paleontology) that found at Sungai Batubeguntur (see below). Similar lithofacies are also found in the downstream part of the Sungai Kintap (i.e. NS-0337 to NS-0341). The rocks there are bounded by a fault against sponge spicular limestone lithofacies in the north, and to the south is separated from the Kintap Granite by a melange zone.

Folds and faults (Fig. 68) together with fractures and quartz or calcite veins (Fig. 69) affect in the bioclastic Orbitolina-bearing limestone lithofacies, particularly in Locality NS-301. Identical Orbitolina-bearing limestone, which occasionally shows such structures, is also found as exotic blocks or olistoliths in the over-
Fig. 68 Folds and faults developed in argillaceous limestone (less indurated) and Orbitolina-bearing limestone (indurated). These were probably caused by thrust tectonics or strike-slip faulting, or a combination of both. The blocky appearance of the rocks with fractures, stylolites and veins suggest that deformation took place in a brittle environment.

Fig. 69 Extensional calcite veins in well indurated Orbitolina-bearing limestone.
lying sedimentary melange of the Pudak Formation (i.e. basal unit of the Alino Group).

From the brief description above, two important features exist in outcrops, the lime mudstone (less indurated) and Orbitolina-bearing bioclastic limestone (well indurated or cemented). Each of these lithological units may have been deposited in different environments. The well-cemented Orbitolina-bearing bioclastic limestone is classified as wackestone or packstone of Dunham (1962). Components of this cemented limestone are commonly present in less indurated argillaceous limestone/lime mudstone.

Orbitolina fossils were taken from the well indurated bioclastic limestone of this lithofacies. They were identified by Prof. R. Schroeder (pers. comm. to Dr C G Adams) as follows (Figs. 70 and 71):

Palorbitolina lenticularis (BLUMBENBACH)
Orbitolina (Mesorbitolina) parva DOUGLAS

These species indicate that the lithofacies of Orbitolina-limestone is early Late Aptian age.

In thin section the lime-mudstone (i.e. NS-301 and NS-302) contains scattered granule grade bioclastic debris, including pelagic bivalves, pyritised bioclasts, phosphate, and small foraminifers infilled with calcite and pyrite. Pockets of shallow water debris-micritic peloids, micritised echinoderms and forams (packstone-grainstone) occur in Sample NS-302. This rock has been extensively multifractured (calcite-filled) and stylolitised, and to a certain extent, shows some recrystallisation of original fabric. NS-301 is faintly laminated micrite with scattered silt-granule grade bioclasts, and shows abundant replacive pyrite in the matrix. As in the rocks of the previous lithofacies, this mudstone is free of silt-sand grade terrigenous clasts.
Fig. 70  Photomicrograph of *Orbitolina* (Mesorbitolina) parva DOUGLAS in bioclastic wackestone-packstone. The species indicates Late Aptian age. XPL.

Fig. 71  Photomicrograph of *Palorbitolina lenticularis* (BLUMENBACH) in bioclastic wackestone. The species indicates basal Late Aptian age. XPL.
A.5 Sponge Spicular Limestone Lithofacies

The sponge spicular limestone lithofacies occurs in the lower Sungai Kintap, about 1 km due N of Riam Adungan (see Fig. 57). The rocks are poorly exposed. Observations on a number of small outcrops along the river (NS-0329 to NS-0336B) indicate that the lithofacies is characterised by at least 100 m of thick to thin bedded, olive grey (5 Y 3/2) to medium dark grey (N44), fine to coarse grained clastic limestones. In some localities (e.g. NS-0329A) the grain size is up to 8 mm in diameter. Rocks of this lithofacies are also found as blocks within the Pudak Volcaniclastic Formation (see Chapter V).

In the N the lithofacies is cut by a thrust fault against the Tertiary sedimentary sequence, while to the S it is separated by a thin zone of melange from the Orbitolina-bearing limestone lithofacies (Fig. 57). Although the contact with the underlying lithofacies is not exposed, the sponge spicular limestone lithofacies is considered to be the uppermost lithofacies of the Batununggal Formation in the Sungai Kintap. This suggestion is based on the disappearance of Orbitolina fossils which occur only rarely in the lower part of lithofacies, and more importantly the first appearance of volcanic material, in the form of crystals (i.e. PL, CPX and HB), volcanic lithic grains (i.e. microlitic and porphyritic volcanics) and ash material (see below). Therefore it is quite probable that this lithofacies is depositionally underlain by Orbitolina-bearing limestone lithofacies.

As the rocks of the sponge spicular limestone lithofacies are now cut and disrupted by faults, it is difficult to describe them in terms of the original stratigraphic order. In hand specimen, these rocks are uniform and are composed mainly of fossiliferous well-cemented calcarenites. However, on the basis of petrographic observations, the lithofacies is made up of six rock types:
1. graded pebbly grainstone (with sponge spicules);
2. sponge spicular packstone-mudstone;
3. graded PL-bearing pebbly grainstone (with sponge spicules);
4. sponge spicular PL-bearing bioclastic packstone;
5. mottled sponge spicular PL-bearing packstone-mudstone;

and

6. sponge spicular plagioclasarenite.

Graded divisions (cf. Bouma AE, 1962) and mottled sponge spicular PL-bearing fine-grained grainstone-mudstone are important and will be described herein. The grading is best seen in NS-0329A and NS-0329C (see Fig. 57), where the Bouma A division is made up of various kinds of limestone and bioclastic clasts. They are normally grain-supported (NS-0329A and NS-0329B), angular poorly to very poorly sorted, with the size ranging from 0.2 mm - 8 mm, and consisting of: 1. bryozoan limestone; 2. heterogeneous bioclastic (bivalves, echinoderm, bryozoan and coralline algae); 3. peloidal limestone; 4. algal limestone; 5. molluscan (mainly gastropods) limestone; and 6. Orbitolina-bearing limestone or mudstone (NS-0329C).

Most of these clasts are elongate with their long axes parallel to bedding, and rimmed by a thin film of iron oxide. The carbonate clasts are intimately intermixed with euhedral to subhedral PL and CPX and HB crystals, and minor microlitic or porphyritic lithic volcanic fragments. The total proportion of terrigenous grains ranging from 20 to 30% of the rock volume. PL (An 42-54, andesine-labradorite) is predominant over CPX with minor HB and volcanic lithic fragments. All of these volcanic grains together with sponge spicules and sand-sized bioclastic grains (limestones) act as the matrix of the graded pebbly grainstone. They are well-cemented by clear micrite.
Crystal grains (i.e. PL, CPX and HB) are normally fractured and filled with micrite. These fractures are both perpendicular or oblique to the crystal cleavages. PL crystals are partially replaced by small patches of clear calcite or less commonly opaque or haematite aggregates, while CPX and HB grains are replaced by opaque minerals.

Both the size and proportion of the carbonate clasts as well as terrigenous grains decreases toward the top of the Bouma A division but in turn the carbonate mud or micrite increases. Stylolitic structures are present, and they are cut by microfaults which are oblique to the general trend of the stylolites.

The mottled sponge spicular PL-bearing limestone (NS-03365) is massive in character. It is light grey in colour with mottles of greyish black. Light grey limestone is dominant, and is made up largely of sponge spicular PL-bearing fine-grained packstone/grainstone, whereas the greyish black mottles are occupied by sandy sponge spicular mudstone. Radiolarians and planktonic foraminifers are present in small numbers. In contrast, terrigenous (PL and PX) grains (cf. NS-0330) are rarely present.

The sponge spicular packstone-mudstone is the commonest rock type found in the lithofacies (e.g. NS-0329B and NS-0334). As is clear from the name this rock is made up largely of sponge spicules and subordinate terrigenous grains, mainly altered PL. Most of these spicules show characteristic canal and spicule shape, with the diameter ranging from a few tens of microns to 250 microns. The longest axis of spicules exceeds 3 mm. The spicules have thick walls and a central canal, and therefore, many of them were originally composed of opaline silica (Black, 1970). However, calcareous spicules are also common. These spicules have no preferred orientation. In addition small patches and discontinuous strings of chert are common in the rock. Recrystallised shell fragments are
found in small amounts. Stylolitic structures with a thin film forming solution seams are fairly well developed. The matrix is partially altered to iron oxide. Microfaults normally cut the general orientation of the stylolitic structures. Rare radiolarians and planktonic foraminifers are found.

The other important rock type of the sponge spicular limestone lithofacies is sponge spicular plagioclasearenite (NS-0336B). The rock is greenish grey (5 GY 6/1) with dusky yellowish brown (10 YR 2/2) elongated or discontinuous laminae parallel to bedding. The mineral grains are poorly sorted, angular to very angular (i.e. euhedral to subhedral PL and CPX), 0.2 mm - 1.2 mm, and set in an altered tuffaceous matrix. The rock is composed of PL (65%), spicules (10%), CPX (5%), magnetite (5%) and mud matrix (15%). In addition the rock commonly contains wispy-shaped patches of PL sponge spicular mudstone (5%), which are interpreted to have been derived from the underlying or adjacent unconsolidated sediments. Many of the CPX grains are partially altered to chlorite and magnetite, whereas PL grains are in part altered to secondary sericite, chlorite and magnetite. Composition of PL ranges from An 32-36 (Andesine).

The terrigenous detritus present in this lithofacies is essentially of volcanic origin, i.e. PL, CPX and HB crystals, and volcanic lithic fragments. None of the terrigenous detritus was derived from a continental land area, except a few grains of light green deformed/folded mica, probably phengite (e.g. NS-330 and NS-0336A). The greatest proportion of volcanic grains occurs in sample NS-0336B, a sponge spicular plagioclasearenite. The geographic position of the sample together with distribution of strikes and dips suggests that the sponge spicular plagioclasearenite is the uppermost unit of the Batununggal Formation and presages the termination of carbonate deposition.
B. Batubeguntur Area

Bioclastic limestones with *Orbitolina* fossils are exposed in a restricted area in the upper Sungai Batubeguntur. The rocks there are commonly thick bedded (with beds up to 120 cm thick) and dipping 35° towards the W (Figs. 72 and 73). The best and most complete exposures (unbroken) can be seen on the southern side of the Sungai Batubeguntur where the limestone section shows lithological variation, sedimentary structure and contain fossils. The total thickness of this section is estimated at about 25m. Elsewhere the limestones have been disrupted and are now scattered throughout the Batubeguntur area, occurring together with blocks of marble and ironstone ("magnetite"). Disruption may be the result of volcanic eruptions.

The base of the limestone strata is unexposed, but it is quite probable that all the limestones in the Batubeguntur area occur as a roof-pendants in the basaltic andesite (Fig. 72). The rocks closely resemble the *Orbitolina*-bearing limestone lithofacies of the Batununggal Formation in the Sungai Kintap (see above).

The limestone strata (Fig. 73) in this area exhibit three distinct sublithofacies (in ascending order):

1. Massive Limestone : Bioclastic lime mudstone and lime wackestone
2. Bedded Orbitolina-bearing Limestone : Mudstone with minor wackestone
3. Graded Limestone : Lime wackestone-packstone

B.1 Massive Limestone Sublithofacies

This is the lower part of the limestone section, and is approximately 10 m thick. Though the lower contact is not exposed, the massive limestone is considered to be in contact with the basic intermediate volcanic intrusion as it is affected by metamorphism and must lie in the metamorphic aureole.
FIG. 72 Geological map showing location and position of the Batununggal Formation and adjacent rock-units in the Sungai Batubeguntur area, Bajuin.
**Graded line wackestone-packstone, dark grey (K₃) to greyish black (Ng₂)**

**Molluscan lime wackestone-packstone, greyish black (Ng₂)**

**Orbitolina wackestone, containing corals and bivalves**

**Bioclastic lime wackestone-packstone, greyish black (Ng₂) to black (Ng₁), containing limestone clasts**

**Orbitolina wackestone**

**Pyritised mudstone**

**Bioclastic lime wackestone-packstone**

**Orbitolina mudstone, dark grey (K₃)**

**Pyritised mudstone, greyish black (Ng₂)**

**Orbitolina mudstone**

**Orbitolina mudstone, dark grey (Ng₂)**

**Pyrite-rich bioclastic lime mudstone, greyish black (Ng₂)**

**Laminated silty mudstone, greyish black (Ng₂)**

**Pyroxene-andesite**
It is characterised by its massive character and displays no obvious bedding and is homogeneous throughout the section. The rocks are very fine-grained, greyish black ($N_2$), mud-supported bioclastic or mudstone of Dunham (1962) in the lower part (NS-835A) and bioclastic lime wackestone in the upper part (NS-835A). In thin section, the rocks are very poorly sorted, and contain a large proportion of pyritised calcium carbonate mud admixed with terrigenous clay.

Bioclastic fragments form about 10-20% of the rock volume and consist mostly of bivalves and corals. Epidote is the dominant (15%) metamorphic secondary mineral (e.g. NS-835A), and usually occurs as yellowish green bladed minerals, pseudohexagonal in cross-section. Dolomite which is closely associated with epidote is also very common in the rock, forming about 15% of the thin section. It occurs as grains, microveins and as a replacement of calcium carbonate.

Pyrite which forms about 10-20% of the rock volume occurs both as grains and as microveins or discontinuous laminae and some fill internal structures in the bioclastic fragments. Small frambooids also occur within borings in bioclastic grains, e.g. molluscs shell fragments and is probably related to endolithic fungal borings (cf. Kobluk and Risk, 1977).

B.2 Bedded Orbitolina-bearing Limestone Sublithofacies

Bedded Orbitolina-bearing limestone has a thickness of 14 m. Though the base is not exposed, this sublithofacies probably overlies the massive limestone conformably. The upper boundary is placed at the base of graded bioclastic lime wackestone-packstone sublithofacies which is the uppermost part of the limestone section (see below). The rocks are commonly thickly bedded lime mudstone/wackestone, ranging from 40 cm - 120 cm, and occasionally intercalated with very thin layers (9 - 20 cm thick) of pyrite-rich lime mudstone (see Fig. 73). The lime mudstone (e.g. NS-835D) forms about 80% of the sublitho-
facies, dark grey ($N_3$) in colour, and typically containing abundant (25%) *Orbitolina* fossils. In thin section the lime mudstone is cut by numerous calcite veins, either perpendicular or parallel to bedding.

Bioclastic fragments are present in small amounts, mostly echinoderm plates and spines. A few grains of terrigenous detritus (i.e. granodiorite and plagioclase) are also present in the mudstone (see NS-835D). The terrigenous fragments are up to 1.4 mm in diameter, subrounded- to rounded texture, and in most cases, individual crystals particularly plagioclase have been altered and are replaced by clear calcium carbonate cement.

In addition, one of the samples studied from the bedded *Orbitolina*-bearing limestone falls into wackestone category (i.e. NS-835B). The wackestone occurs in the lower part of the section showing a clastic fabric, and contains abundant (20%) *Orbitolina* fossils. Bioclastic fragments comprise about 12% of the rock and are dominantly coarse silt to medium sand grade bivalve (10%) and coral (2%) fragments. The wackestone also contains minor amounts of terrigenous clasts, forming about 1% of the rock volume. Terrigenous clasts are mainly quartz grains, mostly monocrystalline with uniform extinction, and a few grains of calcium carbonate cemented quartz, feldspathic sandstone. Pyrite commonly occurs as matrix, and some as veins or lensoidal laminae.

Sample NS-835C represents thin layers of pyrite-rich mudstone, as intercalations in the *Orbitolina* mudstone. This microfacies forms about 5% of the sublithofacies section. It is made up of a complete intergrowth of micrite-calcite, pyrite and clay. No detrital grains were observed. In addition, iron oxide is also present along fractures.
B.3 Graded Limestone Sublithofacies

This sublithofacies is the uppermost part of the limestone section, 7.6 m thick, thickly bedded, dark grey (N33), greyish black (N22) to black (N11) lime wackestone. The lower limit of the sublithofacies, 1 m thick, is thinly bedded bioclastic lime wackestone and Orbitolina wackestone with an intercalation of pyritised mudstone.

The next 4.6 m of the succession, i.e. middle part of the section, is thickly bedded, ranging from 60 cm to over 2 m thick, being mainly composed of bioclastic lime wackestone and packstone with a graded Orbitolina wackestone intercalation (see Fig. 73). Several sets of simple graded beds (Bouma, AE), as shown in Fig. 74, occur in the sublithofacies. Grain size of the limestone clasts at the base of graded beds commonly ranges from very coarse sand to pebble grade.

In the upper 2 m of the graded limestone sublithofacies, (see Fig. 73), the rocks are coarser carbonate sediments ("redeposited carbonates", cf. breccia beds of Krause and Oldershaw 1979) than the underlying sublithofacies. Graded beds in this part of sublithofacies are commonly poorly sorted, and are composed of matrix-supported granular to pebbly limestone (e.g. NS-835I and NS-835II, Fig. 73). The coarsest redeposited limestone bed occurs in the uppermost exposed section of the sublithofacies. The clasts of this breccia bed are several cm to over 20 cm in size and angular- to subrounded in shape. These are all set in a muddy-sandy matrix. Lithology of the clasts is dominated by shelf derived clasts consisting of bioclastic lime packstone, grainstone and boundstone. Fragments of coral are also commonly found. The clasts in the breccia bed are completely disorganised and chaotically oriented fabrics (cf. disorganised bed of Walker 1975 and 1976).
Fig. 74 Graded limestone turbidite. This represents the upper part of limestone section of the Batununggal Formation in the Sungai Batubeguntur, 3.5 km east of Bajuin Village, Manjam Mountains.

4.2.5 Age and Correlation

The present study attempts to refine the age of the Batununggal Formation, mainly on the basis of ammonites (examined by Dr. H G Owen of the British Museum, London) and species of Orbitolina fossils (examined by Dr C G Adams of the British Museum, London and Prof. R Schroeder of Geologisch-Palaeontologisches Institut, West Germany), and to some extent controlled by potassium argon dating from granite plutons (i.e. adamellite). The accuracy of this age determination is extremely important for both dating and understanding the carbonate sedimentation itself, and for deducing the age of the underlying sedimentary unit comprising the Paniungan Formation which is now proved to be the oldest sedimentary strata lying on the Sunda Shield.
The samples dated from the Batununggal Formation were taken from the lower and upper parts of the most complete stratigraphic section found along the upper Sungai Kintap in the southern foothills of the Meratus Mountains (see Fig. 57). The sample localities are shown in the stratigraphic column.

The specimens of ammonites were taken from the lower part of the formation (see above). The ammonite species described for age determination have been listed above. The assemblage, according to Dr H G Owen, is consistent with a Barremian age. He further commented that "if the nuclei identified as cf. Costidiscus prove to belong to that genus, an upper Barremian age is more precise" (pers. comm., 20 September 1983). If this is the case the ammonite-bearing limestones, i.e. Barremian (Lower Cretaceous) age, are the oldest carbonate rocks of the Batununggal Formation. This is a new finding and also the first locality of Lower Cretaceous ammonites for SE Kalimantan.

The limestones which contain ammonites, exposed in the Sungai Kintap, are conformably overlain by the Orbitolina-bearing limestones. These form a continuation of the same period of carbonate sedimentation. The rocks contain abundant Orbitolina fossils, including Palorbitolina lenticularis (BLUMENBACH) and Orbitolina (Mesorbitolina) parva DOUGLAS, which are indicative of a basal Late Aptian age (i.e. based on personal communication between Dr C G Adams and Prof R Schroeder, 4 September 1984).

It is important to note here that the Cenomanian age of the "Orbitolina-bearing limestones" based on the occurrence of Orbitolina concava LAMARCK (described by Martin, 1889, in Krol 1918) can be ruled out (see Yabe and Hanzawa, 1931, in Hashimoto and Koike 1973). In relation to this Hashimoto and Koike (1973) studied the Orbitolina limestone from Hantakan, E of Barabai (i.e. N of the study area). From this study, he concluded that the species of Orbitolina from
Hantakan Limestone is not concava (for reasons see Hashimoto and Koike 1973).

Furthermore, Hashimoto (1975) stated that the Orbitolina concava LAMARCK as found in Kalimantan, Java and Sumatra has been identified as Orbitolina scutum Fritsch in Japan. This Orbitolina species occurs in association with Upper Aptian ammonites. On the basis of this evidence, together with the presence of Pseudocyclammina and Nautiloculina in the Hantakan Limestone, Hashimoto and Koike (1973) came to the conclusion that the "Orbitolina-bearing sediments" in South-East Kalimantan, and elsewhere too, such as in the Sungai Lok Ulo in Central Java, is Upper Aptian or not younger than Lower Albian.

Similarly Orbitolina cf. oculata, Orbitolina sp. and Orbitolina sp primitiv (described by Dr H Pringgoprawiro), Suhaeli et al. (1980), Situmorang (1982) and Sikumbang et al (1982) confirm that the age of the "Orbitolina-bearing sediments" range from Aptian-Albian or late Lower Cretaceous.

A radiometric date from a granite, intrusive into the limestones of the Batununggal Formation at Riam Adungan in the Sungai Kintap, gives 95.3 Ma or Lower Cenomanian age (K/Ar dating on whole rock, determined by Dr N J Snelling of BGS), which is reasonably consistent with paleontological data as presented above.

In summary, on the basis of both paleontological (i.e. ammonite and Orbitolina) and radiometric dating, it is suggested that the age of the Batununggal Formation ranges from Barremian to Late Aptian. One of the most important things to bear in mind is that the oldest unit of the Batununggal Formation is only present on the southeast of the Meratus Mountains. Whilst in the northwestern flank of the mountains, the Orbitolina-bearing limestones which lie immediately on the Sunda Shield basement are late Aptian or not younger than Lower Albian in age. This implies that the formation is younging towards the core of the Sunda Shield.
4.2.6 Depositional Environments

Field, petrographic and paleontological studies indicate that the limestones of the Batununggal Formation, as now exposed discontinuously in the northwestern (Northwestern Province) and southeastern (Southeastern Province) foothills of the Meratus Mountains, accumulated in various depositional environments in the Lower Cretaceous (Barremian-Late Aptian). Depositional environments were interpreted on the basis of the abundance of skeletal debris (e.g. bryozoans, echinoderms, bivalves and corals); whole fossil content (e.g. benthic and planktonic foraminifers); and sedimentary structures.

Northwestern Province

At least two lithofacies can be recognised in the Northern Province, i.e. in the Tambak-Tamban area (in ascending order): bryozoan-rich lime packstone-boundstone and Orbitolina wackestone. They are interpreted as a carbonate deposit which accumulated in a shelf setting. The common occurrence of Orbitolina fossils in wackestone may reflects a decrease in energy up the section from medium to low energy conditions. The abundance of skeletal debris together with the homogeneity of these rocks suggest deposition under aerobic conditions in a subtidal shelf environment (Byers, 1977).

In addition, the Orbitolina limestone in the Batununggal area, N of the study area, is inferred to have been deposited in a nearshore environment. The common occurrence of terrigenous detritus (granite, quartz, plagioclase and granodiorite) in the lower section of the limestone there implies that the Batununggal limestone was very close to and most likely deposited immediately on the granitic basement complex of the Sunda Shield. High energy conditions of deposition are indicated by grain size, i.e. very coarse sand grade to granule,
absence of bioturbation and sedimentary structures, and the lack of micrite between the grains. Moreover, the sparry calcite cement suggests currents strong enough to winnow lime and terrigenous muds (see Folk, 1962) while depositing terrigenous grains and reworked fossils.

Southeastern Province

In this province, in the SE of the Meratus Mountains, the Batununggal Formation crops out in the Sungai Kintap and Batubeguntur. Five lithofacies have been recognised in the Sungai Kintap, whereas in the Batubeguntur there are only two lithofacies present (see above). Each of these lithofacies is interpreted below.

Sungai Kintap

Bioclastic Limestone Lithofacies

The abundance of transported shelf and reef debris (see Scholle et al 1983) as well as lithologic (i.e. packstone) and petrographic evidence, coupled with the absence of terrigenous grains in the carbonate sediments, strongly suggests that the environment of deposition of this bioclastic limestone facies was relatively far from the shore, probably in an outer shelf or even in close proximity to a slope setting.

This interpretation is supported by the presence of planktonic foraminiferids in the packstone. Moreover, the water depth of the bioclastic limestone lithofacies can also be estimated on the basis of the occurrence of well preserved (unreworked) Textularia. The benthic foraminifera of this kind, as shown by Parker (1948) and Murray (1973), indicates approximate depth of water from middle shelf to bathyal, with a probable depth range from 50-640 m.
However, the absence of indicative shallow marine shelf of benthonic foraminifera such as Quinqueloculina together with the scarcity of planktonic foraminifers, suggests that the water depth was most likely shallower than outer shelf.

The fine-to medium sand grade, the absence of bioturbation or typical shallow-water burrows of trace fossils such as Thallassinoideas (Fursich, 1973) and Ophiomorpha (see Scholle, 1983) and sedimentary structures, together with localized occurrence of sparry calcite cement, suggest moderately high energy conditions of deposition. The current was not strong enough to completely winnow away lime (micrite) and terrigenous mud allowing sparry calcite cement to grow between the grains. The colour from medium dark grey (N₄4) to dusky yellowish brown (10 YR 2/2) also corresponds to the middle shelf environment (Scholle et al., 1983). This colour, together with the absence of burrows, is indicative of deposition under dysaerobic conditions (Byers, 1977).

Furthermore, the massive character of lime packstone was most likely formed under the influence of high gravitational energy with rapid deposition from suspension, preventing the formation of any primary sedimentary structures.

In conclusion, it is considered that the bioclastic limestone facies is a carbonate mass flow that represents a resedimentation episode, probably in an outer shelf to slope setting. This carbonate facies was succeeded by argillaceous lime mudstones relatively rich in ammonite juveniles and planktonic foraminiferids, indicating deepening of the area of deposition (see below).

Ammonite Foraminiferid-bearing Limestone Lithofacies

An outer shelf environment for this lithofacies is interpreted from the occurrence of fine-grained transported shallow-water fossil fragments (e.g. bivalves) and more importantly by the abundance of
planktonic foraminiferids which are usually indicative of outer shelf and deep-water marine facies of both modern and ancient sediments.

As mentioned earlier, the sediments are homogeneous, thin to thickly bedded argillaceous fossiliferous limestone, petrographically described as planktonic foraminiferid-rich mudstone. The homogeneous lithology of the sediments suggests a basinal setting (deep-water carbonate mudstone) relatively far from the source terrain or from the ancient shore line of the Sunda Shield.

The presence of numerous juvenile ammonites indicate that the sediments were deposited in a muddy, pelagic, quiet water, and open-marine environment. The occurrence of horizontal laminations in some beds are interpreted as products of a pelagic suspension settling in a basinal environment.

Another criterion generally used in recognizing the environment of deposition is the absence of benthic foraminiferids in the sediments. This clearly corresponds to the suggested basinal or deep-sea environment as has been pointed out above.

Furthermore, the prevalence of dark (i.e. greyish black, N₂2) lime mudstone, the presence of horizontal laminations and the lack of bioturbation, together with the absence of benthic fossils are all indicative of deposition in a quiet and anoxic environment (see Byers, 1977). Anoxic bottom conditions have been reported for rocks in various parts of the world such as along continental margin off the coast of southern California (Hartman and Barnard, 1958 in Byers, 1977) and in the New Albany Shale Group of the Illinois Basin, Indiana, United States of America (Cluff et al., 1981). According to Byers (1977), a fully anoxic condition may be established in water depth greater than 150 m.
The common occurrence of pyrite in the lithofacies also suggests deposition in reducing environment below an oxygen-minimum zone (Byers, 1977).

**Massive Limestone Lithofacies**

The environmental interpretation of this lithofacies can be made on the basis of the occurrence of transported shallow-water indicators such as coral fragments and bioclastic peloidal lime packstone-grainstone clasts.

According to Bathurst (1971), on the basis of studies of recent carbonate sediments in the Bahamas and Persian Gulf, peloidal grains commonly occur in a lagoonal environment. By analogy to the Bathurst's work above, it is probable that the peloidal lime packstone-grainstone which now occurs as clasts in the lime mudstone-wackestone lithofacies were originally deposited in lagoonal setting. Such transported lagoonal clasts are interspersed with coral fragments interpreted to have been derived from a shelf-edge or fore-reef slope setting.

The above evidence together with the massiveness (structurelessness) of the calcarenite correspond to the thick massive sandstone in a mass flow deposit (Middleton and Hampton, 1973). They were probably deposited by one or two mechanical processes, involving fluidization and/or grain flow of the sediments. However, more data are needed to find out the true mechanism for the deposition of this lithofacies.

**Lime Mudstone and Orbitolina-wackestone-packstone Lithofacies**

Lime mudstone and Orbitolina-bearing wackestone and packstone lithofacies is interpreted to have accumulated in fore slope and slope settings. This interpretation is indicated by black lime mudstone and bioclastic debris, and by sedimentary structures and fabrics. The
presence of various types of shallow to outer shelf clasts, such as micritic peloids and echinoderms, pyritised bioclasts, pelagic bivalves and small foraminifers, show that fine-grained debris was transported by downslope debris flows (cf. Walker and Mutti 1973; Enos and Moore 1983).

**Sponge Spicular Limestone Lithofacies**

This lithofacies which consists of massive and graded pebbly grainstone-packstone and sponge spicular mudstone may represent carbonate sedimentation in a lower slope to basinal setting. The predominance of sponge spicules indicates an open marine environment, in water depths less than 100 m for calcareous spicules but range down into abyssal depths for siliceous spicules (Black, 1970). The presence of carbonate turbidite within the sponge spicular limestone lithofacies, together with the absence of continentally derived terrigenous constituents such as quartz, plutonic and metamorphic detritus (i.e. except light platy green mica) corresponds with a slope to basinal environmental setting. This interpretation is also supported by the presence of radiolarians and planktonic foraminifers. Limestone clasts, e.g. peloid, bryozoan, algal and coralline algae, indicate derivation from the shelf edge or fore-reef slope.

Mottles in some beds of the sponge spicular mudstone are interpreted as the result of burrowing activity in a low energy environment. The mudstone was deposited from pelagic suspension. This indicates that turbidity current sedimentation was alternating with pelagic suspension.

In this lithofacies crystal grains (i.e. PL, CPX and HB) and volcanic lithic fragments (i.e. microlitic and porphyritic volcanics) are the secondmost distinctive component after sponge spicules. All of the crystal grains are considered to be of volcanic origin. The occurrence of volcanic material suggests that the deposition of the
sponge spicular limestone was contemporaneous with the onset of volcanic activity. Similar volcanic grains are the main constituents of the Alino Volcaniclastic Group (see Chapter V).

It is interesting to note here that the occurrence of sponge spicules is closely associated with the incoming of volcanic material. This evidence could support Alexandrowicz's (1973) suggestion that there is a close relationship between the abundance of sponge spicules and volcanic activity.

**Sungai Batubeguntur**

As mentioned earlier, the limestone strata here exhibit three distinct sublithofacies (see above). These sublithofacies can be correlated with the Orbitolina-limestone lithofacies of the Sungai Kintap.

**Massive lime mudstone-wackestone sublithofacies**

Metamorphism and recrystallisation has obliterated the detail of textures and sedimentary structures, thus, preventing precise interpretation of depositional environment of this sublithofacies. However, on the basis of the occurrence of transported reef and shelf debris (platform source), as well as lithologic (e.g. black coloured lime mudstones) and petrographic evidence, the rocks of massive limestone are interpreted as having been deposited in a fore-slope setting where they formed a thick unit, together with bedded fossiliferous lime mudstone and wackestone and graded lime wackestone-packstone. These rocks are similar to fore-slope carbonates described in detail by Scholle et al. (1983). This type of depositional environment possibly occurs around reef complexes and basinward of a platform-margin along a topographic high on a stable continental margin.
Bedded Orbitolina-bearing Mudstone (and Wackestone) Sublithofacies

A fore-slope setting for the bedded Orbitolina-bearing limestone sublithofacies is suggested by lithological association of dark grey (black) lime mudstone (80% of the sublithofacies) with abundant (20-25%) Orbitolina fossils and minor Orbitolina-bearing wackestone. The occurrence of a mixture of transported coarse silt to medium sand sized bioclastic grains, e.g. bivalves, echinoderms and corals, floating in a lime mud matrix of the mudstone and wackestone indicates derivation from a reef and shelf setting. Turbidity current transport of these shallow water bioclastic grains as well as terrigenous constituents is suggested by the presence of graded beds in the overlying sublithofacies (see below).

Graded Limestone Sublithofacies

An association of thick to thin bedded bioclastic lime wackestone and Orbitolina wackestone, with intercalation of graded Orbitolina wackestone (Bouma AE, 1962) and lime mudstone may represent submarine carbonate turbidity flows, and therefore they exhibit resedimentation episodes. It is suggested here that this type of carbonate sediment gravity flow took place on a continental slope setting (cf. Krause and Oldershaw, 1979).

The carbonate clasts, e.g. bioclastic lime packstone, grainstone, boundstone and coral, in the disorganised bed of the sublithofacies indicate that this slope setting was in the vicinity of fore-reef complex.

All of the foregoing depositional environments presented in this section will be used in reconstructing a paleogeography and tectonic evolution of the Meratus Mountains and on broad scale southeastern part of the Sunda continental margin (Chapter VIII).
4.3 PITANAK FORMATION

4.3.1 Description

The Pitanak Formation, consisting of amygdaloidal PL-phyric lava flows and their pyroclastic rocks, is thought to overlie the Lower Cretaceous (Barremian-Aptian) Batununggal Formation unconformably. Both of these formations have been intruded by the Rimuh plutonic rocks (see Chapter VII).

The volcanic strata of the Pitanak Formation are extensively distributed from Sungai Raya in the southwestern end of the Tambak Range to the northeast of the Tamban Range, beyond the study area, in the southern part of the Amuntai Quadrangle (see Heryanto et al., in prep.). The Tambak and Tamban Ranges are separated by a narrow belt of Tertiary deposits (see Fig. 31 and Geological Map).

Outcrops and stratigraphic relationships of the Pitanak Formation have been examined in a large number of localities. Samples were collected and petrographically examined. Four geological traverses, two located in the Tambak Range (Sungai Raya and Sungai Binuang) and the other two in the Tamban Range (Sungai Rimuh and Sungai Pitanak), were systematically examined. From these four traverses, a river section along the Sungai Pitanak was chosen for the type section of the formation.

The volcanics of the Pitanak Formation include lava flows and flow breccias with a total thickness of more than 800 m. Pillow lavas are present at one locality (NS-815). In many localities, these rocks are deeply weathered and hydrothermally altered. Relatively fresh outcrops are normally found only in narrow rivers, such as the Sungai Pitanak.
The rocks as a whole are relatively uniform, both in hand specimen and in thin section. The colour is brownish black (5 YR 2/1) and dusky brown (5 YR 2/2) when weathered. All the rocks are porphyritic; containing phenocrysts and microphenocrysts of euhedral to subhedral PL and minor CPX. The PL phenocrysts vary in size, <1 mm to >1 cm long. The groundmass is microlites and granular-textured secondary epidote, magnetite, chlorite and anhedral quartz.

White (carbonate, zeolite or quartz) to pale green to dusky green (celadonite or chlorite) amygdales are also the main characteristics of the Pitanak Volcanics. They are from 1 mm to 1.8 cm in diameter. Flow structures are commonly defined by the alignment of plagioclase phenocrysts and microlites. On the other hand, the amygdales are irregularly distributed.

PL phenocrysts, which occur in all samples observed, are the dominant rock constituents, making up about 30 to 50 of the thin section. They commonly form euhedral to subhedral lath-shaped crystals, with the size ranges from 0.4 mm - 1.1 cm. Many of them are as single grains, however intergrown glomerocrysts are also occasionally present (e.g. NS-814 and DS-27). Partial replacement of the PL by calcite, sericite, chlorite, epidote, haematite and magnetite is commonly found. The degree of alteration varies from sample to sample. As expected from hand specimen, the PL phenocrysts are far fresher in the Sungai Pitanak (e.g. NS-814 and NS-815) and therefore their composition can still be determined (see below). If the alteration is intense, as in IU-182 and NS-253C, the PL phenocrysts exhibit a sponge-like texture. Composition determinations (Michel-Levy's method) from a few thin sections (e.g. NS-814, DS-27 and NS-253C) indicate that the PL ranges from An 44 to An 62 (andesine to labradorite).
CPX phenocrysts, as additional phenocrysts or microphenocrysts, are found in some samples (e.g. NS-814, DS-27 and NS-253C), making up less than 1% of the thin section. The PX is normally fairly fresh, forming subhedral to anhedral grains, with the size ranges from 0.4 mm to 1.6 mm in length. They occur as single grains or intergrown with PL phenocrysts.

Amygdales are also abundant in the lava flows, and are present in nearly all samples (e.g. NS-814, NS-815, NS-817, DS-27, NS-253C and IU-182). They are normally spherical to ellipsoidal, some are elongate with irregular rims, and are filled with a mixture of chlorite or celadonite(?), zeolite, micropoly crystalline quartz and minor amounts of opaque aggregates. Amorphous quartz or zeolites are commonly present along the rims of amygdales, whilst the cores are filled with micropoly crystalline quartz, chlorite (?) celadonite) and magnetite. In addition, anhedral quartz and micropoly crystalline quartz are scattered, either as small patches (0.2 mm) or microveins, throughout the groundmass.

Textural and compositional features described above together with the PL composition, andesine to labradorite, demonstrate that the Pitanak volcanics are of amygdaloidal PL-phyric basaltic andesites and associated pyroclastics. They were extruded to form a series of volcanic lava flows along the NE trending Tambak-Tamban mountain range.

4.3.2 v e

The volcanic rocks of the Pitanak Formation are considered to be of early Upper Cretaceous (Turonian) age. This age is based on the following evidence:

1. The Pitanak Formation overlies the early Lower Cretaceous (Barremian-Aptian) limestone of the Batununggal Formation unconformably.
2. Stratigraphic relationships and petrographic examination suggest that the amygdaloidal lava flows of the Pitanak Formation resembling the amygdaloidal volcanic clasts in the Upper Cretaceous (Upper Turonian-Coniacian) conglomerate of the Pamali Formation of the Manuggul Group.

4.3.3 Environment and Source

The presence of low temperature minerals in amygdales, coupled with the rare occurrence of pillow lavas, indicate that water was available in the site of depositional environment over which the hot lavas flowed.

The extrusive volcanics of the Pitanak Formation were formed in the early Upper Cretaceous (Turonian) time, prior to the deposition of the Manunggul Group. The diorite and granodiorite, as earliest phase of the Rimuh Plutonic rocks was probably intruded shortly after or contemporaneously with the extrusion of these Pitanak volcanics.
CHAPTER V

ALINO GROUP: VOLCANICLASTIC DEPOSITS

1. PUDAK FORMATION: COARSE-GRAINED VOLCANICLASTIC DEPOSITS WITH LIMESTONE BLOCKS AND RADIOLARIAN MUDSTONE

2. KERAMAIAN FORMATION: VOLCANICLASTIC TURBIDITE AND RADIOLARIAN CHERT
The Alino Group, originally termed the Alino Formation by Koolhoven (1935), comprises an association of radiolarian chert, siliceous mudstone, tuffaceous sandstone, intermediate - to basic volcanioclastics and lavas, and minor crystalline limestone.

Recent field mapping by Sikumbang et al (1982) and present study indicate that the Alino Formation can be conveniently divided into two distinct rock-units:

1. Pudak Formation: A chaotic assemblage of rocks which passes up into graded and stratified beds, i.e. mainly coarse-grained volcaniclastic deposits with limestone blocks. Volcano-sedimentary melange and radiolarian mudstone occur as intercalations.

2. Keramaian Formation: A volcaniclastic turbidite which contains interbeds of radiolarian chert in the upper part of the sequence.

These formations should be amalgamated and raised to group status and is proposed that it should be called the Alino Group.

Although the exact geographic location of Alino is not known, it is necessary to retain the name of Alino because it has been widely used in many published and unpublished works (e.g. Bemmelen 1949; Hashimoto and Koike 1973; Katili 1978; Haile et al 1979; Hamilton 1979; Situmorang 1982 and Iijima et al 1983).

The Alino Group is almost everywhere in tectonic contact with adjacent rock-units, but is overlain unconformably by younger sedimentary rock strata such as the Manunggul Group and Tanjung Formation.

The aims of this chapter are:

1. to give the lithological and petrographic characteristics of each rock-unit of the Alino Group;
2. to observe critical relationships between the Alino Group and the surrounding rock-units;
3. to interpret the environment of deposition and provenance;
4. to propose the site or geological setting of deposition; and
5. to resolve the tectonic evolution of the Alino Group.

5.2 PUDAK FORMATION: COARSE VOLCANO - SEDIMENTARY DEPOSITS

5.2.1 Definition

The Pudak Formation is a new formal stratigraphic unit that was proposed by Sikumbang and Heryanto (1982) to describe a heterogeneous mixture of rocks which consist mainly of coarse grained submarine volcaniclastic deposits with limestone blocks. The name of this formation taken from the Sungai Pudak, a main tributary of the upper Sungai Kintap located on the southern flank of the Meratus Mountains. The type section is in the Sungai Pudak, as shown in Figs. 75 and 76.

The usage of "melange" as it was first introduced by Greenly (1919) and then defined by Hsu (1968 and 1974) is not applicable to the chaotic assemblage of the Pudak Formation (see below). This is because according to these two authors the term has to be related to some kind of tectonic fragmentation and mixing of rocks of different origin. Melange of this kind has commonly been regarded as an important product of subduction at an active convergent plate environment.

The present study shows that volcaniclastic deposits are the characteristic rock types of this unit, occurring both as native blocks as well as matrix in disrupted and fragmented zones or beds within the section of the Pudak Formation. Therefore it is recommended here that the rock-unit as a whole should be designated as volcano-sedimentary deposits. However, the disrupted and fragmented zones, characterised by a chaotic fabric, with limestone and igneous
FIG. 75. Simplified geological map of the Banjarmasin Quadrangle, showing distribution of the Pudak and Keramaian Formations of the Alino Group and other rock-units (modified from Sikumbang et al 1982).
blocks of various sizes and shapes set in a fine-grained muddy matrix, can descriptively be distinguished as a volcano sedimentary melange. In the writer's view, this term is more meaningful and will be used throughout this thesis as its identification and application influence the interpretation of the tectonic setting and more importantly the history of the Meratus Mountains.

Although the lower contact of the Pudak Formation with other rock-units is everywhere obscured by faulting, the base of the formation can still be inferred from the occurrence of conglomerates and sandstones (see below).

5.2.2 Occurrence

The Pudak Formation occurs in two separate NE trending belts, Northern and Southern Belts, flanking the Meratus Mountains on the NW and SE, respectively (Fig. 75). The Southern Belt is the main belt, extending from the eastern foot of the Ambungan Range in the SW to the upper Sungai Satui, at the NE end. Whilst the Northern Belt extends from Gunung Keramaian to Imban area. The description together with the significance of each of these belts is given below.

5.2.3 Southern Belt: Pudak - Satui - Parang Ilang

The Southern Belt, as shown in Fig. 75, is over 130 km long, and 3 to 11 km wide. Here the contact between the Pudak Formation and the ophiolite in the north is marked by a thick zone (up to 200 m) of ultramafic schist and highly sheared serpentinite, with occasional ultramafic mylonite and foliated limestone. The foliation in these zones ranges from 68° - 80°. Shear zones can be seen in the Sungai Pudak and the Sungai Satui (Figs. 76 and 77). In the south, the formation is in fault contact against the Batununggal Formation.
Poorly exposed breccia composed of altered breccia/lamprophyre rocks (e.g. diorite and gabbro). They are cut by breccias.

Limestone block across the river, 45 x 15 m in size

Ten largest clasts

11.5 cm, 0 X 23
20 X 25

Bryozoan graptolite

Planktonic foraminifera

Calcic limestone (up to 30 m in size)

Fig. 76 KINTAP RIVER TRAVERSE SOUTHEAST KALIMANTAN
The geological traverses in the Southern Belt were concentrated in the Pudak and Satui rivers where the rocks are best exposed (Figs 76 and 77). These two traverses are perpendicular to the trend of the Manjam Range. In addition, the area around Parang Ilang and Batubelaran in the SW end of the belt was also examined and sampled.

Due to the complexity of the structure, rapid facies changes, as well as discontinuous exposures, it is not possible to describe the Pudak Formation as a complete and comprehensive stratigraphic sequence. However, there are a number of lithological facies recognised. Their distribution, together with the lithological and sedimentological characteristics in all the areas traversed, are given below.

5.2.4 **Northern Belt: Gunung Keramaian - Imban**

The Pudak Formation in the Northern Belt extends from the Gunung Keramaian to the area just NE of the village of Imban (Fig. 75). The belt is about 32km long and 1.5 to 4.5km wide. The rocks here which include the Keramaian Formation, trending NW-SE and dip steeply to the NW or SE, are largely overlain unconformably by either Tanjung Formation of Eocene age or by Quaternary deposits in the W, and in the E they are marked by a highly sheared serpentinite zone, becoming broader towards the NE, 50m at the foot of Gunung Malahin, and about 300m at the foot of Gunung Pematan.

Although the outcrops in the Northern Belt are sporadically and poorly exposed, they can still satisfactorily be matched with the rock types of the Pudak Formation in the Sungai Pudak and Satui in the Southern Belt. Here the rocks are composed of a comparatively simple lithology, seemingly nearly entirely of volcanic breccia conglomerate with subordinate volcanic sandstone. The volcano-sedimentary melange seen in the Southern Belt is not observed in the Northern Belt.
Rantau Jangkang
Oligocene-Early Miocene

- Terrigenous calcarenite
- Sponge spicular limestone
- Radiolarian chert

Tertiary strata (mainly quartz sandstone & limestone with minor mudstone & coal

- Terrigenous calcarenite
- Sponge spicular limestone
- Radiolarian chert

Location of sample number
- Strike and dip
- Fault
- Thrust
- Strike-slip fault

Key to symbols:
- Limestone
- Calcite
- Serpentinite
- Orbitolina limestone
- Polycrystalline conglomerate
- Quartz sandstone
- Quartz sandstone with coal
The volcanic breccia conglomerate forms a lowland area with a number of small hills, ranging from 25-50m above sea level in the northeastern half, and a hilly morphology with an elevation up to 253m in the southwestern half of the belt.

Due to the widespread deep soil profiles caused by intense weathering and leaching processes and, because little removal of the soil occurs, the rocks of the Pudak Formation in the Northern Belt cannot be examined and studied in detail. Therefore no geological traverses were made in this belt. Instead a good coverage of systematic field observations, together with sampling localities, as a control for lithological distribution, was undertaken. Approximately 150 field localities were visited throughout the Northern Belt (field localities at the scale of 1:50,000 are available). Fig. 78 shows the distribution of the Pudak Formation with its relationship to other rock units in the northeastern part of the Northern Belt.

5.2.4.1 Description of Lithology, Petrography and Structures

The volcano-sedimentary deposits of the Pudak Formation in the Pudak and Satui Traverses are composed of the following rock types:
6. Limestone breccia conglomerate
5. Volcaniclasticturbidite
4. Radiolarian volcanic mudstone
3. Volcanic breccia conglomerate
2. Polymictic breccia conglomerate (melange)
1. Plutonic breccia conglomerate

Limestone blocks are encountered in both the Pudak and Satui Traverses, but are far more common and conspicuous in the former traverse. Limestone blocks also occur in other localities, e.g. on Gunung Parang Ilang and Gunung Batubelaran in the southwestern part of the Southern Belt.
Fig. 78. Simplified geological map of the northeastern end of the Northern Belt, showing the distribution of the Pudak Formation and its relationships to the surrounding rock-units (after Sikumbang et al., 1982). Location is in Fig. 75.
A.1 Plutonic Breccia Conglomerates

Plutonic breccia conglomerates comprise very poorly sorted and subrounded to angular clasts. They occur only in the Sungai Pudak in a restricted area just adjacent to the fault zone with the Manjam ophiolite (Fig. 76). The size of the clasts ranges from fine pebble- to cobble sized, with the matrix making up about 20% of the section. The matrix is commonly fine- to very coarse sand grade, composed of the same composition as the clasts with which they are associated.

The rocks are now weathered or leached out, thus, it is difficult to determine whether the plutonic breccia conglomerates occur as thick single bed or as a number of beds. Obvious stratification and graded bedding were not observed. In one of the outcrops observed, however, the breccia conglomerate starts with very fine to fine pebbles, followed by coarser material and which then fines upward. This breccia conglomerate dips steeply (80°) to the SE. The thickness of the plutonic breccia conglomerates, on the basis of strike and dip and the extent of the outcrops, is estimated to be in the order of 150 to 200 m.

The clasts of the breccia conglomerates are intermixed with sands and sandy granules. Petrographically, they are composed mainly of altered gabbro (e.g. NS-329 B.1, NS-329 B.2) and diorite (NS-329 B.3), with minor amounts of altered trondhjemite (NS-329 C) and metadolerite.

The diorite and gabbro are shown in Figs. 79 and 80. The former is medium grained and has a hypidiomorphic texture, consisting of andesine PL (An 32-38) and HB, with accessory apatite and magnetite. The HB is pleochroic from dusky yellow to light olive brown, subhedral to euhedral, and many crystals show twinning. Some HB grains show a lighter green colour along their rims and olive brown in the core.
The rim has a more actinolitic composition as a result of a changing environment of crystallisation. Epidote, chlorite, zeolite, quartz and sericite, as secondary minerals, are also present in the diorite.

Although the rock is altered, the main constituents of the gabbro is still observable in thin section (Fig. 80). It consists largely of PL and CPX. Secondary minerals, in particular epidote and zeolite, were also observed. Zeolite is far more abundant in this rock than in the HB diorite, and is commonly present in veins and in small patches.

Cataclastic textures are fairly commonly found in some of the clasts. Sheared zones can be seen (e.g. NS-329 B.1), displaying a microscopic texture characteristic of microbreccia or cataclasite, and the zones are filled with elongated aggregates of plagioclase, epidote, quartz and gabbro fragments.

A.2 Polymictic Breccia Conglomerate – "Melange"

Although the polymictic breccia conglomerate is exposed only in a few localities, they are the most conspicuous as well as the most perplexing rock type within the Pudak Formation (see Figs. 76 and 77). These rocks commonly occur as thick disorganised breccia conglomerate displaying the typical features of a chaotic melange with a heterogeneous assemblage of unsorted blocks set in a highly sheared fine-grained matrix (Figs 81 and 82). These chaotic deposits make up about 20% of the formation in the Pudak Traverse and 5% in the Satui Traverse.

Melange (see definition above) is used here only as a descriptive term. There are two types of melange present within the area studied. The first includes an assemblage of rocks that belongs to the sequence of the Pudak Formation. These are closely associated with and occur as intercalations in the volcanic breccia conglomerates which will be described below. Whereas the second type includes an assemblage of extremely unsorted rocks set in a highly sheared matrix which are
found as clastic sill-like zones between thrust sheets of the limestones of the Batununggal Formation (see Figs. 57 and 76).

The following subsection presents a brief account of the lithologic characteristics and petrographic descriptions of the polymictic breccia conglomerate.

Polymictic breccia conglomerate ("melange") has been mapped on 1:10,000 geological traverses in the following rivers:

1. In the upper Sungai Pudak, melange occurs at four stratigraphic levels, at localities NS-327 and NS-328, NS-319, NS-314 and NS-313; and NS-289 to NS-290, and NS-292 to NS-296 (Fig. 76).

2. In the upper Sungai Satui, melange occurs at localities NS-537, NS-540 and NS-544. These three localities form a continuous belt about 150 m S of the Manjam ophiolite (see Fig. 77). A small exposure near the confluence of the Sungai Satui and the Sungai Aritan (NS-560) may also be included in the polymictic breccia conglomerate unit.

In general the polymictic breccia conglomerate, comprises a mixture of rocks, consisting mainly of limestones and basic to intermediate igneous (gabbro and diorite). Rare clasts include basalt, dolerite, ultramafic rocks, metabasalt ("spilite") and foliated radiolarian chert, trondhjemite, pebbly sandstone, PL-bearing sandstone and volcanic sandstone. All of these pebbles and blocks are floating in a fine-grained highly cleaved and pervasively sheared matrix. The clasts are mostly angular to subangular, some are subrounded and commonly they vary in size from granule-sized to a few tens of metres long.
Fig. 79  Photomicrograph of hornblende diorite, consisting of andesine plagioclase and hornblende. Some of the secondary minerals can also be recognised in the XPL view (e.g. epidote and zeolite). Sample No: NS-329.B.3. Scale bar 0.2mm.

Fig. 80  Photomicrograph of altered gabbro, consisting of plagioclase and pyroxene, with secondary minerals, e.g. epidote and zeolite. Sample No: NS-329.B.2. Scale bar 0.3mm.
Fig. 79  Photomicrograph of hornblende diorite, consisting of andesine plagioclase and hornblende. Some of the secondary minerals can also be recognised in the XPL view (e.g. epidote and zeolite). Sample No: NS-329.B.3. Scale bar 0.2mm.

Fig. 80  Photomicrograph of altered gabbro, consisting of plagioclase and pyroxene, with secondary minerals, e.g. epidote and zeolite. Sample No: NS-329.B.2. Scale bar 0.3mm.
Fig. 81 Highly sheared matrix-supported polymictic conglomerate ("melange") in the upper Sungai Pudak. Clasts or blocks are mainly limestone (e.g. centre). Location: NS-327. Hammer is 45cm long. Close-up photo of the matrix is shown in Fig. 82.

Fig. 82. Matrix of the polymictic breccia conglomerate ("melange"). Note weathered clasts are embedded in a sheared reddish brown matrix. Location: near NS-327. Protractor is 11 cm long.
Fig. 81 Highly sheared matrix-supported polymictic conglomerate ("melange") in the upper Sungai Pudak. Clasts or blocks are mainly limestone (e.g. centre). Location: NS-327. Hammer is 45 cm long. Close-up photo of the matrix is shown in Fig. 82.

Fig. 82. Matrix of the polymictic breccia conglomerate ("melange"). Note weathered clasts are embedded in a sheared reddish brown matrix. Location: near NS-327. Protractor is 11 cm long.
Moreover, at localities NS-314 and NS-289, in the Pudak Traverse, a 80 x 200 m limestone block of bryozoan grainstone and planktonic foraminiferal micrite is also found. This is the largest block that has been found so far in the polymictic breccia conglomerates.

The matrix in both traverses, in the Sungai Pudak and in the Sungai Satui, shows a steeply dipping (70°-80°) foliation, of which the foliation itself also tends to parallel or subparallel to the long axis of clasts and blocks (Fig. 81). On a larger scale this foliation is roughly parallel to the trend of thrusting and the ophiolite belt of the Manjam Range. Local deviations in the attitude of the foliation occur where the foliation is intersected by a fault. The foliation in the Sungai Pudak dips steeply toward the SE, whereas in the Sungai Satui it dips toward the N.

A.2.1 Character of Matrix

The matrix in the polymictic breccia conglomerates ranges between 30% and 50% mud-to sand grade and, is often variegated, dusky brown (5 YR 2/2) to greyish red (5 R 4/2), with light grey (N7) spots. It is strongly interlaminated and foliated, with altered sand-to granule limestone and igneous clasts (porphyroclasts).

The matrix is composed largely of an association of volcanic and sedimentary (carbonate) detritus, consisting of plagioclase, hornblende (some actinolitic), porphyritic andesite, glass, recrystallised bioclastic and pelagic limestones (e.g. see NS-327 C, NS-327 F and NS-327 B.1) and, associated with small amounts of sand-sized diorite, gabbro, dolerite, basalt and deformed radiolarian chert.

Many of these matrix constituents are now cataclastically fractured oblique to the foliation which is marked by the elongation or flattening of the grains (Fig. 83). Fracturing is quite conspicuous among the matrix grains and, in places, asymmetrical microfolds are developed in the matrix (Fig. 84). The fracturing or
segmentation can also be seen in the granule-sand sized grains mentioned above. In some cases, the elongate granule-sand sized matrix show several stages of segmentation, forming a micro-duplex structure. These structures (i.e. foliation and cataclastic structures) are then cut by an extensional veins filled with calcite, quartz and chalcedonic quartz, epidote and magnetite.

A.2.2 Character of Blocks

As mentioned earlier, the clasts and blocks are set in a highly cleaved and pervasively sheared matrix. The types of these clasts/blocks are essentially the same as the sand-sized matrix with which they are associated (see above). The general characteristics of the various types of these clasts or blocks are described below.

**Diorites.** Megascopically, the diorites are pale olive (10 Y 6/2) to greenish grey (5 GY 6/1) in colour, mostly fine-grained, thus, they are classified as microdiorite (e.g. NS-537C, NS-540, NS-540 A and NS-327.2). Some of the microdiorites may fall into trachytic microdiorite category. They are composed mainly of PL (andesine) and altered mafic phenocrysts. Due to alteration, perhaps by hydrothermal low-grade metamorphism, it is not possible to recognise the original composition of the other grains. Secondary minerals microcrystalline carbonate, magnetite, chlorite, epidote, albite and quartz are present.

**Porphyritic Andesite.** Porphyritic andesite blocks include PX and PL-phyric andesites that show distinct petrographic similarities to those found in adjacent coarse volcaniclastic beds. These rocks are fine-grained, greenish grey in colour and are locally vesicular, consisting of either PX or PL phenocrysts, set in a groundmass of PL with accessory minerals, magnetite and carbonate.
Fig. 83 Close-up of cataclastic texture in the matrix of the melange. Sample NS-327C, Sungai Pudak. PPL. Scale bar 0.3mm.

Fig. 84 An asymmetrical microfold, showing that the matrix of the melange was ductile at the time of deformation. Sample NS-327F, Sungai Pudak. PPL. Scale bar 0.3mm.
The PX phenocrysts are colourless in thin section (clinopyroxene) subhedral crystals, 0.1-0.2 mm in size, and are partly altered to carbonate with occasional fine magnetite crystals. The PL (andesine) occurs as subhedral lath-crystals, 0.1-0.25 mm long, and in places altered to carbonate pseudomorphs. Other secondary minerals observed include zeolite, chlorite and minor amount of epidote.

Limestone. Limestone clasts or blocks occur at various localities in the Sungai Pudak and in the Sungai Satui (Figs 85 and 86). These rocks are also encountered in other places, to the W of the Sungai Pudak, for example in the southern flank of Gunung Batubelanaran (e.g. IU-20) and at Bukit Parang Ilang (e.g. NS-166 D) in the southwestern portion of the Southern Belt. In general most of the limestone blocks are elongate or tabular in shape and greatly vary in size from millimetres to blocks up to 80 m thick and 200 m long. Distribution of the largest blocks is shown in Figs. 76 and 77.

Field and petrographic examinations reveal that the blocks are composed of various kinds of disrupted, recrystallised or deformed/foliated/ nodular-like limestones. At least seven different kinds of limestone are recognised. These are recrystallised bioclastic mudstone, foliated sponge spicular mudstone, planktonic foraminiferid mudstone, nodular limestones (i.e. include Orbitolina - bearing mudstone - wackestone), bryozoan packstone/grainstone, pebbly limestone and recrystallised bioclastic coral limestone.

Most of them have been cleaved, and in many cases are cross-cut by several stages of calcite veining. Segmentation, nodular fabrics and stylolitic structures, which are commonly defined by the presence of thin bands of clear sparry calcite and solution seams (i.e. usually haematite) were frequently observed.
Fig. 85  Block of Orbitolina - bearing limestone in the polymictic breccia conglomerate ("melange") of the Pudak Formation, exposed in the upper course of Sungai Pudak (see Locality NS-328 in Fig. 76).

Fig. 86  Block of recrystallised Orbitolina - bearing limestone in the polymictic breccia conglomerate ("melange") of the Pudak Formation, exposed in the upstream part of the Sungai Satui Traverse.
Recrystallised Bioclastic Mudstone (Micrite) The blocks are found in several localities, particularly in the Sungai Satui (e.g. NS-537 B). The mudstone is homogeneous and contains no sedimentary structures. The rock is very light grey (N8 8). The type of fine sand-silt (0.2-0.1mm) grade bioclasts in the mudstone cannot be recognised as they have been completely recrystallised. Clear calcite veining is apparent in the rock. Petrographic characteristics suggest this bioclastic mudstone is equivalent to that of the Batununggal Formation exposed in the lower Sungai Satui (cf. NS-614 and NS-615 E). The Sungai Satui limestone has been interpreted as a pelagic carbonate accumulated in very low energy conditions, probably in an abyssal or basinal setting. The blocks in the melange were presumably formed under similar conditions.

Sponge Spicule-Bearing Mudstone The blocks of mudstone are commonly found in the Sungai Pudak (e.g. NS-295 B). The mudstone is light grey (N7 7) to very light grey (N8 8) in colour, consisting predominantly of very distinctive sponge spicules, which are made up of amorphous siliceous material or opaline skeletons (Fig. 87). Other constituents, (about 1%) comprise mainly sand- to silt sized bioclastic detritus. These include recrystallised echinodermal plates and spines. Several whole Orbitolina fossils are also found in this mudstone. Terrigenous material is negligible. Texturally, the sponge spicules are arranged in a disordered manner, thus, they could be turbidity current deposited. The rock is cross-cut by clear sparry calcite veins, in which the calcite crystals are oblique to the margins of the vein.

The sponge spicule-bearing mudstone clast or block is equivalent to the thrust sheet of the Batununggal Formation that is exposed about 5 km due south of Locality NS-295 B (see Fig. 57). This mudstone has
been interpreted as a pelagic siliceous deposit which accumulated in basinal setting (see Chapter IV).

**Planktonic Foraminiferid Mudstone** The planktonic foraminiferid mudstone (Fig. 88) is found in the same block as poorly sorted bryozoan packstone-grainstone in the Sungai Satui. The block is 80 m x 200 m in size (NS-312 to NS-314). The rock is greyish black (N₂2) in colour, consisting predominantly of recrystallised planktonic foraminifers with rare echinodermal spines (up to 0.8 mm). Other bioclastic grains cannot be recognised as they have suffered neomorphic crystallisation. It also contains pyrite, as small patches and as planktonic foraminiferid chamber fillings. The latter is commonly present together with clear sparry calcite. Microstylolites, parallel to subparallel to the bedding, are well developed in the mudstone.

**Megascopically and microscopically,** this rock is equivalent both in age and environment to the ammonite-foraminiferid-bearing mudstone of the Batununggal Formation which occurs due south of this limestone block (see NS-307 in Fig. 57). The planktonic foraminiferid mudstone of this type has been interpreted as having been deposited in a deep-water environment (see Chapter IV).

**Nodular Limestones** Nodular limestone clasts/blocks are only found in the polymictic breccia conglomerate ("melange") deposit in the Sungai Pudak. The nodules are often in contact, showing a fine conglomeratic appearance, and are usually aligned so that they lie more or less parallel to the foliation in the matrix (Fig. 89). They are commonly lenticular in shape with either smooth, or irregular/sutured rims. Individual nodules range in size from a few mm to 1.5 cm in diameter. The clasts or blocks observed include bioclastic sponge spicular mudstone (e.g. NS-327.1), bryozoan packstone (e.g. NS-327.4) and Orbitolina - bearing mudstone-wackstone (NS-292 D). The nodules and
Fig. 87 Photomicrograph of sponge spicular mudstone block in the polymictic breccia conglomerate ("melange"). Note spicules are infilled by amorphous siliceous material or opaline skeletons. Sample NS-295B, Sungai Pudak. XPL. Scale bar 0.3mm.

Fig. 88 General view of planktonic foraminiferid mudstone. Note microstylolites cross-cut bioclastic grains. The interior of planktonic foraminifers is now infilled by pyrite (cf. Fig 63). Sample NS-312, Sungai Pudak. XPL. Scale bar 0.3mm.
sparry calcite bands are cut by solution seams or stylolitic structures (i.e. 0.05 mm - 1 mm in thickness). Locally stylolitic structures contain silt-sized terrigenous grains, usually plagioclase, with rare monocrystalline quartz. Many of the nodules have been sliced and displaced obliquely from their earlier position (Fig. 90). Displacement ranges from 200 microns to nearly 1 cm. Structurally, the nodular bryozoan packstone and Orbitolina-bearing mudstone/wackestone are very similar to the bioclastic sponge spicule mudstone described above; their description is not repeated here.

The evidence of these nodular limestones, including morphology of the nodules, the relationship between the nodules and the matrix or cement, along with the presence of structural slicing, stylolitic structures and calcite veining suggest that they were produced by diagenetic and tectonic processes.

Bryozoan Packstone - Grainstone Bryozoan packstone-grainstone blocks are found in the Sungai Pudak (e.g. NS-313), characterised by medium dark grey ($N^4_4$) colour and poor sorting, fine-to sand grade (0.2 - 1.8 mm), and are made up largely of bryozoan debris and micritic peloids. Other conspicuous constituents include echinodermal plates, coralline algae, Orbitolina, worm tubes and shell fragments. A single test of biserial benthic foraminifer, probably Textularia was also observed. Some bioclasts are now completely recrystallised, e.g. shell fragments and echinodermal plates. The bioclastic grains are all set in fine sparry calcite (micrite). In addition, clear granular sparry calcite also occurs as small patches, floating in the micrite. Calcite veins cuts the bryozoan packstone-grainstone and, some bioclastic grains (e.g. bryozoan) are cut and displaced for about 100 or 150 microns across the veins. This rock is similar to that of bioclastic packstone of the Batununggal Formation (cf. NS-308 A and NS-308 B). Therefore this rock can be referred to the bioclastic
Fig. 89  Photomicrograph of nodular limestone. The nodule is rimmed by a solution seam (i.e. haematite). Sample No: NS-327.1. Scale bar 0.2mm.

Fig. 90  Structural slicing in the nodules. Sample No: NS-327.1. PPL. Scale bar 0.2mm.
packstone facies of the Batununggal Formation, i.e. a carbonate mass-flow (see Chapter IV).

**Pebbly Limestone**  
Pebbly limestone blocks up to 80cm x 3.5m in size, have been observed both in the Sungai Pudak (e.g. NS-293 B) and in the Sungai Satui (e.g. NS-544). The limestone is poorly sorted, consisting of various types of limestone granules and pebbles (2mm - 6cm in diameter), i.e. peloidal packstone-grainstone, *Orbitolina* and sponge spicular mudstone, and recrystallised mudstone (micrite). Some benthic foraminifers were observed in Sample NS-544. One of the most interesting constituents in this rock is a cataclastic vesicular basalt clast (spilite) in Sample NS-293 B. It is 3 x 5 mm in size, angular in shape, and vesicles are filled with either chlorite or quartz. Locally iron oxide and magnetite also contribute to the composition of the vesicle fillings. Lath-shaped plagioclase crystals of the basalt are now completely altered to calcium carbonate. The groundmass of the basalt is largely occupied by microgranular aggregates of magnetite with some micrite. This pebble is interpreted as derived from the upper section of the Meratus Ophiolite.

The pebbly limestone is commonly cut by a number of calcite veins up to 4 mm in width. Petrographic examination reveals that this rock is a variety of the bryozoan packstone - grainstone which has been described in Chapter IV.

**Pebbly Sandstone.** Rare pebbly sandstone blocks are found only in one locality (i.e. NS-293 A) in the Sungai Pudak. This rock is poorly sorted and grain-supported, consisting of sands and fine pebbles (up to 6 mm in diameter) which vary from angular to very angular and are usually rimmed by thin films of iron oxide (haematite). Most parts of the sands and pebbles have been recrystallised to cryptopolycrystalline quartz (i.e. chert-like).
Due to intense recrystallisation, it is difficult to identify the original types of these pebbles. But on the basis of porphyritic texture which is still vaguely preserved, coupled with the outline of subhedral to euhedral plagioclase, it can be concluded that the pebbly sandstone is composed predominantly of porphyritic volcanic detritus. The occurrence of monocrystalline quartz and plagioclase grains in the pebbles suggest that they are probably dacitic or quartz-andesitic in composition. Some of the pebbles may be fall into rhyolite category.

**Volcanic Sandstone.** A few blocks of volcanic sandstone (lithic crystal tuff) have been found only at one locality in the Sungai Pudak (NS-327 A). The volcanic sandstone is medium grained, poorly sorted and consists of approximately 20% CPX, 15% strained PL and 10% strained monocrystalline QZ. Other constituents include microlithic lava and seriate-textured basalt. The latter is up to 2 mm in diameter. All of these sand-grade constituents are set in a silt-sized matrix which is composed largely of PL, PX and magnetite.

**Plagioclase-bearing Sandstone.** PL-bearing sandstone blocks are also found in one locality in the Sungai Pudak (NS-295 A, Fig. 91). The sandstone is poorly sorted, with grain size ranging from 0.2-2 mm. Grains vary from angular to very angular and are grain-supported. The rock is dominated by PL. Subordinate constituents are microlitic lava and very rare fine-sand sized CPX. Many of the grains and matrix have been recrystallised, forming crypto-crystalline QZ aggregates. Furthermore, many of the framework grains have also been fractured or cut and the spaces are occupied by clear calcium carbonate.

**Metabasalt ("Spilite").** Metabasalt blocks are commonly found in the Sungai Pudak (e.g. NS-327.0 and NS-327.D, Fig. 92). They are also encountered in the Sungai Satui (NS-588). The clasts ranging from 5 mm to 4 cm in diameter. They are subangular to subrounded in shape,
cross-cut by calcite veins, seriate-textured, and consisting of micro­
lath crystals of PL with mafic phenocrysts which have now been altered
to carbonate. Grain-size ranges from less than 0.01 to 0.5 mm. A
small proportion of magnetite also contributes to the rock
composition. Other secondary minerals are represented by an
assemblage of quartz, chlorite and a minor amount of epidote.

Another type of basalt clast (4x6cm in size) recognised is OL
basalt (e.g. NS-540 B). The phenocrysts, which are now altered to
carbonate and chlorite, are clustered ("glomerocrysts") in a ground­
mass that is composed of microlath crystals of PL, PX and secondary
minerals (magnetite, carbonate and chlorite, Fig. 93). It contains a
granular-textured peridotite (OL and CPX) xenolith, 1.6 to 3.8 mm in
size.

Radiolarian Chert. So far radiolarian chert clasts (up to 3 to 3.5mm
in size) have been found only in the Sungai Satui (NS-538). The type
of chert clast is recognisably different from radiolarian volcanic
mudstone that has been found as intercalations in the volcanic breccia
conglomerate (cf. NS-324) and the volcanioclastic turbidite (cf. NS­
299 C and NS-299 D, see below) in the Pudak Traverse. Here the chert
clasts are obviously foliated, and are cut by calcite veins (i.e.
perpendicular, oblique or parallel to the foliation). Microfolds can
also be observed in the thin section (Fig. 94). Radiolarian chert of
this sort perhaps represents the missing radiolarian chert (pelagic
facies) of the Meratus Ophiolite (see discussion below).

Trondhjemite. Trondhjemite (e.g. NS-327.2) is a rare component of the
polymictic breccia conglomerate ("melange"). The trondhjemite has
been altered and, many of its constituents, except quartz, are now
replaced by secondary minerals. Replacement can be seen in plagioc­
close crystals where most parts of the crystals are now occupied by
Fig. 91  Plagioclase-bearing sandstone (feldsarenite), showing poorly sorted texture and the framework constituents and matrix. Sample No: NS-295 A. XPL. Scale bar 0.2mm.

Fig. 92  Seriate-textured basalt clast in the polymictic breccia conglomerate of the Pudak Formation. It consists of lath-shaped crystals of plagioclase and augite phenocrysts, with a small proportion of magnetite. Plagioclase phenocrysts also occur in a very small amount. Sample No: NS-327 D. PPL. Scale bar 0.3mm.
Fig. 93 Augite-plagioclase-phyric basalt clast in the polymictic breccia conglomerate. The rock consists of labradorite plagioclase, augite, glass and a small proportion of magnetite. The size of plagioclase and augite crystals ranges from 0.01-2.4 mm. Sample No: NS-327.0. In PPL it can be seen that patches between the grains of plagioclase/pyroxene are occupied by brown glass. XPL. Scale bar 0.2 mm.

Fig. 94 Typical photomicrograph of foliated radiolarian chert clast in the polymictic breccia conglomerate, Sungai Satui (NS-538). Note calcite veins cut the foliation. Note microfold in the centre. PPL. Scale bar 0.2 mm.
fine microcrystalline carbonate. Petrographic examination indicates
that the trondhjemite has been cataclastically fractured and sheared.
Calcite veining and microfaults were also observed.

A.3 Volcanic Breccia Conglomerate

The volcanic breccia conglomerate described in this section
includes pebbly conglomerate and pebbly sandstone. In the Southern
Belt, these rocks occupy approximately 55% of the Pudak Formation in
the Sungai Pudak and 70% in the Sungai Satui. In contrast, they form
100% in the Northern Belt. The distribution of these rocks and their
relationships to other lithologies can be seen in Fig. 78. The
section of the breccia conglomerate in the Southern Belt (Figs 76 and
77) is occasionally interrupted by polymictic breccia conglomerate
("melange") that has been described earlier.

In fresh outcrops, the rocks are dense, hard to very hard and
some are even as hard as chert. They splinter with a conchoidal
fracture if struck with hammer, and are dark grey (5 GY 4/1) to
greyish black (N 2 2) in colour. In most outcrops they are thick to
very thick bedded (40cm to over 2m), with clasts up to 40 x 80 cm in
size and chaotic or disorganised fabrics (Figs. 95 to 96), which are
closely similar to those of Facies A1 and A3 (Fig. 155) of redeposited
submarine conglomerates (gravity flows) of Walker and Mutti (1973).

Moreover, on the basis of graded bedding and the common occur­
rence of volcanic sandstone and mudstone in the upper portion of the
volcaniclastic beds, the volcanic breccia conglomerate and pebbly
breccia sandstone in general become finer and thinner upward. The
coarsest and the thickest beds are seen in the upper courses of the
rivers (Figs. 76 and 77). Thus the size of the pebbles in the
volcanic breccia conglomerates gradually decreases to the NW and the
SE away from the Meratus Mountains. The grain size variation was
Fig. 95  Volcanic breccia conglomerate, poorly sorted and well cemented. Sungai Pudak, Southern Belt. Hammer is 35cm long.

Fig. 96  Coarse, angular to subrounded, very poorly sorted conglomerate in the upper course of the Sungai Satui, Southern Belt. Hammer is 45cm long.
documented by measuring the ten largest clasts at a number of good exposures in the Sungai Pudak and the Sungai Satui (Figs. 76 and 77).

In the Southern Belt the sand-matrix in these coarse volcanioclastic beds ranges between 20% and 60%. In contrast the proportion of matrix in the Northern Belt is relatively low, i.e. ranging between 10% and 30%, compared to the Southern Belt. Therefore the texture of the volcanic breccia conglomerate in the Northern Belt is often clast-supported or matrix to clast-supported (Figs. 97 and 98) rather than the matrix-supported breccia conglomerate as in the Southern Belt. Field observation suggest that the sand matrix increases in proportion downstream and the clasts decrease in size with increasing sand matrix.

Although the matrix of the volcanic breccia conglomerate differs in the proportion of constituents compared to that of the Southern Belt, its composition is very similar, mainly consisting of the same materials as the clasts. The matrix consists of very poorly sorted sands which range from fine to very coarse sand grade, subrounded to angular in shape, and consisting of a mixture of volcanic rock fragments (i.e. porphyritic and microlitic lavas) and crystal grains (i.e. PX and PL). High power magnified observation reveals that the clasts and the matrix are cemented by silica and, in other cases, coated by a thin film of Fe-oxide which is identified as either haematite or goethite. Apart from silica and Fe-oxide cements, locally zeolite and micro-polycrystalline QZ which occur as pore fillings, also contribute to the cement or lithifying agent of the volcanic breccia conglomerate.

Volcanic clasts are round to angular and most of them are poorly to very poorly sorted. The type of clasts include porphyritic and amygdaloidal andesite, amygdaloidal microlitic lava, porphyritic microlitic lava, glassy amygdaloidal andesite, dacite, and in addition
Fig. 97 Volcanic breccia conglomerate in the Northern Belt. The rock is very poorly sorted, matrix to clast supported, and is compositionally monomictic andesitic composition. Photo is taken near the village of Tambangulang.

Fig. 98 Surface-cut view of volcanic breccia conglomerate, showing texture and fabric (i.e. angular to rounded, clast-supported and poorly sorted), and general composition (i.e. various kinds of andesitic clasts, see text). Note a limestone clast at the lower right corner (white). Locality NS-380, southwestern flank of Bukit Kubuk, Northern Belt (see Fig. 78).
andesitic pyroclastic debris. Plutonic clasts that have been distinguished on the basis of texture, composition of PL and grain size of the groundmass are commonly found in the Southern Belt. These include trachytic microdiorite (NS-326 F) and medium-grained diorite (NS-324 B).

The dioritic clasts are typically concentrated in the lower portion of the coarse volcaniclastic sequence (e.g. NS-326 F and NS-324 B). They are intimately intermixed with porphyritic andesite clasts. The type of clasts displays variation from upstream to downstream in the Pudak Traverse, that is from andesitic to dacitic (i.e. NS-326 to NS-321) composition. However, andesitic pebbly sandstone is also present further downstream (NS-315 and NS-316).

Non volcanic clasts (e.g. limestone, gabbro and dolerite) are minimal in the volcanic breccia conglomerate, forming less than 1% of the rock, particularly in the northeastern half of the Northern Belt. In contrast, they are quite common in the remainder of the belt, for instance near Gunung Keramaian (e.g. NS-200A and NS-200B).

Andesitic Clasts

There are two kinds of porphyritic andesite present, one with PL phenocrysts (PL-phyric) and the other with CPX phenocrysts (CPX-phyric) or combination of those two (Fig. 99). In some samples, the phenocrysts, particularly CPX, are clustered in clots or as "glomerocrysts". Furthermore, PL crystals are occasionally found in the central part of CPX clusters (cumulophyric texture). The groundmass of the porphyritic andesites is usually made up of fine lath-shaped PL, CPX and magnetite, with addition of chlorite, epidote and haematite.

The microlitic lava consisted of fine lath-shaped PL crystals, commonly showing alignment as an indicator of the flow direction of
the lava. As additional constituents microphenocrysts of either CPX or PL also occur in some microlitic lava detritus (e.g. IU-24).

Amygdaloidal andesite clasts are quite conspicuous seen either in hand specimen or under microscope. Amygdales are often infilled with micro-polycrystalline QZ or chlorite and, in places, by zeolite. In some cases the amygdales show gradation in size from the margin or rim toward the core of the clast. Most of the amygdales are ellipsoidal or lenticular in shape with rather irregular rims. The size range of amygdales observed is between 0.4 and 2.5 mm in length.

The hyalocrystalline amygdaloidal andesite clasts also contribute to the composition of the volcanic breccia conglomerate. In XPL the glassy groundmass is seen as black masses within which phenocrysts are set. Normally CPX is altered in places to an association of secondary minerals: micro-polycrystalline QZ, chlorite, epidote and magnetite.

Dioritic Clasts

The trachytic microdiorite (NS-326 F, Fig. 100) is dark greenish grey (5 GY 4/1) in colour, consisting mainly of PL (andesine) and PX, with a fair amount of magnetite (5%). Most PL is now largely altered, particularly in the core, to sericite with minor aggregates of epidote and magnetite. The PL usually occurs as coarse lath-shaped crystals and forms a trachyte-like texture (Fig 100). The size of PL laths is between 0.2 and 1.2 mm long. PL forms about 12% of the thin section, occurring both as phenocrysts and groundmass. Several amygdales with chlorite filling were also observed, up to 1 mm by 4 mm in size.

The medium-grained diorite is also dark greenish grey (5 G 4/1) in colour, consisting of PL and PX. Therefore, in some respects it is similar to the trachytic microdiorite, but coarser grained. The PL crystals form an alignment which perhaps can be compared to trachytic texture. The largest PL crystal is up to 5 mm long. CPX forms approximately 5% of the thin section. Both PL and CPX are now largely
Fig. 99 Photomicrograph shows the characteristics of a porphyritic andesite clast in the volcanic breccia conglomerate. It consists of plagioclase and clinopyroxene. XPL. Sample No: IU-26.

Fig. 100 Trachytic microdiorite clast in volcanic conglomerate, consisting of aligned columnar plagioclase and clinopyroxene phenocrysts. Sample No: NS-326F. XPL. Scale bar 0.2mm.
replaced by secondary minerals such as sericite, chlorite, epidote and magnetite microcrystalline aggregates.

Porphyritic Dacite

Porphyritic dacite clasts are found only in breccia-conglomerates in the Sungai Pudak (NS-316 and NS-315). They are medium light grey ($N_g6$) with very light grey ($N_g8$) spots. The porphyritic dacite contains phenocrysts of PL, less calcic than andesine, QZ and subordinate mafic minerals HB and PX. These are set in a fine-grained groundmass that is composed mainly of PL and QZ.

The PL shows a complete gradation in size from phenocrysts through microphenocrysts to groundmass crystals. Some of QZ phenocrysts are embayed. HB and PX are largely replaced by carbonate. Some of phenocrysts are now completely replaced by magnetite. The whole pebble is cut by QZ veins. Secondary minerals present in the rock include QZ, calcite, chlorite, epidote and magnetite.

The dacite-bearing conglomerate in the Sungai Pudak fines upward, and is capped by a chert-like rock. The chert-like rock is about 15 m thick, consisting of pale olive (10 Y 6/2) to greyish olive (10 Y 4/2), well-sorted and well cemented sandy siltstone. Microstructures such as fractures and faults with displacements can only be seen in polished section. The fractures and faults are marked by the presence of microquartz and zeolite fillings. Sand to silt grains are mainly of QZ and PL, forming about 60% and 25% of the rock volume respectively. The matrix/cement is estimated to be around 15%. The crystal grains are typically compacted to overcompacted and commonly exhibit micro-pressure solutions (stylolites). Magnetite occurs as patches and sometime as irregular strings between the grains.
A.4 Radiolarian Volcanic Mudstone

Radiolarian volcanic mudstones are found at two stratigraphic levels in the Pudak Traverse, in the upper section of the coarse volcanic conglomerate (i.e. NS-324) and in several beds of the volcanioclastic turbidite (e.g. NS-299 C and NS-299 D). The exact localities of the samples are shown in Figs. 76 and 103. As these radiolarian-bearing mudstones are important for inferring the paleoenvironment and as well for plate-tectonic interpretation, the writer attempts herein to describe each particular sample in detail. Note the radiolarian volcanic mudstone from the volcanioclastic turbidite will also be described in this section.

A.4.1 Sample NS-324

As mentioned above, this radiolarian volcanic mudstone occurs in the upper portion of the volcanic conglomerate described earlier (see Figs. 76 and 103). The thickness of the entire bed (i.e. volcanic conglomerate and mudstone) is not known, but it is estimated to be in the order of 100m, of which the radiolarian volcanic mudstone itself makes up more than 10m.

In polished section (Fig. 101), the radiolarian volcanic mudstone is characterised by a distinctive colour and by microstylolites. The latter are commonly developed in the lighter layer/laminae. On the basis of these criteria, coupled with the petrographic data, two distinctive layers or laminae can be recognised in the radiolarian volcanic mudstone. They are summarised as follows (in ascending order):

1. Terrigenous sponge spicule - radiolarian mudstone, olive black (5 Y 2/1) in colour. This represents the lower portion of the graded layer (Bouma A), with the thickness of individual laminae ranging from 1 to several mm, consisting of both siliceous
fossils (sponge spicules and radiolarians) and terrigenous materials. The latter includes CPX, PL and small patches of carbonate, which are most likely pseudomorphs after either mafic or PL grains. All of these are coarse silt to very fine sand-grade, floating in a black matrix/cement that is made up of a mixture of pyrite and organic matter, with minor amounts of haematite. The interior of both sponge spicules and radiolarians are now infilled by either microcrystalline QZ or chalcedonic QZ, occasionally with the addition of chlorite and/or carbonate. Although the base of laminae is sharp and somewhat irregular, the laminae are discontinuous, displaying scour and fill-like structure. In places, the laminae form a micro-channel and in other cases it/they interfinger/s with the terrigenous-free layer/laminae. On the whole there is a tendency for the proportion of terrigenous materials to decrease sharply upward, with a corresponding decrease in grain size.

2. Sponge spicule-radiolarian mudstone, olive grey (5 Y 4/1) in colour. This is the dominant lithology, which may be classified as Bouma D/E, and consisting almost entirely of silt to very fine sand-grade sponge spicules and radiolarians in a matrix/cement of siliceous carbonate. The internal structures of these siliceous microfossils are now occupied by either crystalline QZ or chalcedonic QZ. Microstylolitic structures are quite conspicuous and are defined by discontinuous strings of haematite and some by pyrite strings. Terrigenous materials in this layer are negligible.

A.4.2 Sample NS-299

Two radiolarian-bearing mudstone beds (NS-299 C and NS-299 D) have been recognised in the volcaniclastic turbidite of the Pudak Formation. The precise stratigraphic position as well as relation—
ships between these two beds and associated turbidite divisions is shown in Figs. 102 and 103. In the field these radiolarian-bearing mudstone rest depositionally upon the coarser turbidite beds.

The first bed (NS-299 C) is 40 cm thick and is immediately underlain by a thick bedded sandstone turbidite, and in turn is overlain by the second bed (NS-299 D), which is 70 cm thick, of radiolarian-bearing mudstone (see Fig. 103). These two beds (NS-299 C and NS-299 D), however, show similar lithological and sedimentological characteristics. Thus, they are described together below.

Similar to the radiolarian-bearing mudstone described in the volcanic breccia conglomerate (NS-324, see above), these rocks are also made up of an alternation of graded terrigenous-radiolarian mudstone laminae (Bouma A, pale olive, 10 Y 6/2) and terrigenous-free radiolarian mudstone laminae (Bouma E, greyish olive, 10 Y 4/2). The thickness of individual laminae in these mudstone turbidites is more or less uniform, that is in the range of 2-2.5 mm thick. Each set of the micro-turbidite (Bouma AE) is therefore 4-5 mm thick. It has a sharp base which is defined by the presence of PL and altered PX, of which the size ranges from less than 0.1 mm to approximately 0.25 mm.

Primary sedimentary structures recognised include micro channels, rip-up clasts, scour and fill structures. Microstylolites, are also observed in thin section.

A.5 Volcaniclastic Turbidite

As has been mentioned earlier volcaniclastic turbidite occurs as an intercalation in the Pudak Formation. The section is exposed about 40 m upstream of the confluence between the Sungai Pudak and the Sungai Langset (Fig. 76). Here the volcaniclastic turbidite is about 28 m thick (measured section, Fig. 103).
Fig. 101 Polished section of sponge spicule-radiolarian mudstones. Grey-coloured layers (mottles) consist of terrigenous-free sponge spicule-radiolarian mudstone, whereas dark grey to black is made up of terrigenous, sponge spicules and radiolarians which are floating in a pyrite-haematite cement. Sample NS-324, Sungai Pudak. Bar represents 1cm.

Fig. 102 Close-view of alternation of graded radiolarian terrigenous mudstone (Bouma A) and radiolarian-free mudstone (Bouma E). See Fig. 124 for location. Bar is 1cm long. Sample no. NS-299C.
Volcanic sandstone

Massive volcanic sandstone bed
Attitude 98/62N

No exposure

Alternation of volcanic sandstones and radiolarian volcanic mudstone. Each bed has a sharp base, marked by the presence of coarser terrigenous (i.e. plagioclase and pyroxene) materials. Locally small channels are also present.

Alternation of graded radiolarian terrigenous mudstone (2mm, pale olive 10Y6/2) and radiolarian terrigenous-free mudstone (2mm, greyish olive 10Y4/2). Detail description is given in the text.

Amalgamated beds of graded pebbly sandstones. Lithology and composition of the sandstones are described in the text.

Attitude 89/74N

Fig. 103. Measured section of volcaniclastic turbidite, upper portion of the Pudak Formation. Locality 40m upstream of the Sungai Pudak and Sungai Langset confluence. Scale 1mm = 20 cm. Location of Samples and Sample Numbers is given.
Though the lower and upper contacts of the section are not exposed, it is likely that (based on distribution of strikes and dips and way-up indicators) the volcaniclastic turbidite section represents the upper portion of the Pudak Formation (see Fig. 76).

The volcaniclastic turbidite comprises thin to thickly bedded sandstones, and is characterised by amalgamated beds of graded pebbly sandstones in the lower part and alternating sandstones and radiolarian mudstones in the upper part with a sand: mud ratio of about 1:1 (Fig. 103). Radiolarian mudstone has been described in Subsection A.4.2, whereas sandstone is described below.

**Volcanic Sandstone**

The volcaniclastic sandstones are represented by samples from the amalgamated beds of graded pebbly sandstones that occur in the lower turbidite section (Fig. 103). They comprise poorly subrounded to angular and sorted clasts, ranging in size from 1-14 mm, set in a matrix of fine to very coarse sized sedimentary (carbonate) and volcanic (e.g. microlitic lava and PX) sand. Pebble to coarse sand clasts comprise mainly PX-phyric microlitic lava, PX, bioclastic limestone with or without corals, *Orbitolina* - limestone, with some pebbles of cataclastic trondhjemite. Other constituents observed include dacite (up to 4 mm in diameter), altered tuff and altered dolerite in Sample NS-299 A and equant monocryalline (uniform extinction) QZ, basalt, bivalve and gastropod fragments in Sample NS-299 B.

The most interesting and important constituents to be described in more detail here are volcanic and trondhjemite detritus as they reflect quite unique provenance contributors. These constituents are significant for tectonic interpretation of the area studied (see Chapter VIII).
Volcanic Detritus

Volcanic detritus (see NS-299 A and NS-299 B) is the most conspicuous constituent after limestones in the amalgamated beds of the pebbly sandstones. They occur mainly as elongated microlitic granules and pebbles. Locally microlitic lava is complexly replaced by or intergrown with carbonate detritus, in particular with microcrystalline carbonate aggregates (micrite). In some clasts the microlitic lavas containing CPX phenocrysts.

CPX also occurs as individual grains, ranging from fine sand to granules (up to 3.5 mm across), and is present in amounts of 10-15% (see NS-299A and NS-299 B). The pyroxenes are colourless to pale greenish yellow augite, highly fractured ("cataclastic") and some grains show displacement for about 0.2 mm along fractures. They sometimes contain magnetite inclusions and are, in places, altered to either uralite or carbonate. Furthermore, fine-sand grade CPX grains are also found within internal cavities of some bioclastic detritus, e.g. in recrystallised bryozoans and in corals (Fig. 104). Other terrigenous detritus found in association with PX include PL, microlitic lava, magnetite and chlorite (altered volcanic lavas).

Trondhjemite

Trondhjemite (Fig. 105) composed of PL together with QZ and small quantities of pseudomorphs of chlorite, after biotite and epidote, occurs as coarse sand to pebble grade in the pebbly sandstones. The largest trondhjemite clast found so far is 6 x 13 mm in size (NS-299 A). Magnetite and apatite are commonly present as accessory minerals.

Nearly all grains of trondhjemite show cataclastic texture and fractures filled with clear calcium carbonate veins. Sheared bands also occur in places. They are filled with secondary minerals QZ, epidote, magnetite and chlorite, and are in turn cut by calcite veins.
Fig. 104 Photomicrograph shows limestone clast containing clinopyroxene (reddish yellow to violet interference colours) and altered microlitic lava (brownish black). Sample No: NS-299E. XPL. Scale bar 0.2mm.

Fig. 105 Photomicrograph shows texture and composition of trondhjemite clast. It is composed of quartz and plagioclase with accessory minerals biotite (i.e. now chlorite). Note cataclastic texture and fractures filled with clear calcium carbonate solution and epidote. Sample No: NS-299A.
A.6 Limestone Breccia Conglomerate

The limestone breccia conglomerate has so far been found in two areas, near the confluence of the Sungai Langset and the Sungai Pudak (see Fig. 76) and at the summit of a hill in the eastern portion of the hilly terrain in Parang Ilang. The best exposure is in the latter area (Fig. 106 to 108).

Although the rocks are only exposed in a small area in Parang Ilang (NS-166), the limestone breccia conglomerate is steeply dipping (80-85°) toward the S. In this locality, it is seen that the limestone breccia conglomerate is overlain unconformably by volcanioclastic turbidite which is believed to be the lower part of the overlying Keramaian Formation. Therefore, stratigraphically and structurally, the limestone breccia conglomerate unit is likely to be the uppermost part of the Pudak Formation at least in the Southern Belt.

The limestone breccia conglomerate is characterised by distinctive white (Ng9) to pinkish grey (5 YR 8/1) limestone pebbles with greyish red (5 R 4/2) to dusky red (5 R 3/4) matrix and cement (Fig. 109). In hand specimen, the limestone pebbles are seen to have been elongated, approximately 4:1 to 6:1 extension, and are either in contact or separated by very thin to thin (0.5-2cm) layers of haematitic matrix. Most of the clasts are sausage-like and pinching on both sides, and exhibiting irregular margins. Overall they are aligned parallel or subparallel to the general trend of the foliation of the rock unit which is defined from the matrix.

Petrographic observation reveals that all limestone clasts (e.g. NS-166 B.1.1 and NS-166 B.1.2) are now completely recrystallised either to dusty coloured micrite or clear sparry/micro-sparry calcite (Fig. 110). There are three types of terrigenous detritus, silt to sand-sized grains, present in the recrystallised limestone clasts,
Fig. 106. Measured section of the limestone breccia conglomerate at the summit of a hill in the eastern portion of the Parang Ilang hilly terrain. Note as a result of deformation the pebbles are now stretched or flattened, with approximate extension 4:1 to 6:1. Therefore the measured thickness does not represent the original thickness. Flattening is parallel to bedding.
Fig. 107 Small exposure of the limestone breccia conglomerate and associated rocks at the summit of a hill in the eastern portion of the hilly complex in Parang Ilang. Loose blocks are found and are scattered throughout this hilly terrain. To the left of this photo is found an exotic rock (8x4m) of highly recrystallised bioclastic limestone.

Fig. 108 Close-up of the limestone breccia conglomerate above, showing the lower part of the measured section (see Fig. 107). The rock is steeply dipping toward the left (i.e. south).
i.e. CPX, PL and rare microlitic volcanic lava. These terrigenous grains are usually concentrated along micro-shear zones or along solution seams (i.e. microstylolitic structures) in the limestone clasts. In addition, cataclastic pyroxenite, altered HB diorite and microgabbro (dolerite) clasts also contribute in a small amount to the limestone breccia conglomerate (e.g. NS-166 B.2). They vary from 2-4 mm in length. Fracturing and structural slicing are quite conspicuous in these clasts.

Nearly all the sand-sized matrix consist of crystals of CPX which vary in size and shape. The CPX, pale yellowish grey (5 Y 7/2) in thin section, grades up to 4 mm in length. They are equant to elongate in shape (i.e. the latter is more predominant), highly cataclastically fractured and the spaces between the fractures are filled with secondary minerals (e.g. carbonate) but in places magnetite with association of crypto-polycrystalline QZ, epidote, sericite and haematite were also observed. In some grains magnetite or calcite have completely replaced the pyroxenes.

The limestone breccia conglomerate beds (Fig. 106) normally fine upward and, in many cases, their upper portions are represented by olive grey (5 Y 3/2) granular sandstones. The granular sandstones show intense stylolitic fabrics defined by grey olive (10 Y 5/6) solution seams (Fig. 111). All the granules observed are composed of recrystallised limestone, and many of them form lenticular clasts ("porphyroclasts") or discontinuous laminae, light grey (N 7) in colour, and rimmed by pressure solution seams marked by an irregular film of ferric oxide. The lenticular limestone clasts or discontinuous laminae are intimately intermixed with CPX and microlitic lava. The CPX and microlitic lava grains also occur as equant (rounded) to lenticular inclusions in the discontinuous limestone laminae.
Fig. 109 Surface-cut view of the limestone breccia conglomerate showing limestone clasts set in a haematitic clinopyroxene-bearing matrix. Note the limestone clasts have now been elongated, with their long axes parallel to the general trend of the foliation.

Fig. 110 Photomicrograph of the limestone breccia conglomerate. A micritic limestone clast is shown in lower half, whereas in upper half it can be seen that sand-sized matrix (i.e. largely clinopyroxene) set in opaque cement. Note nearly all sand-sized matrix grains are rimmed by a very thin film of calcium carbonate. The matrix is made up largely of clinopyroxene and limestone. XPL. Sample no. NS-166 B.1. Scale bar 0.3mm.
Fig. 111 Photomicrograph of the upper part of the limestone breccia conglomerate. It consists of cleaved clinopyroxene-bearing (light brownish green) sandstone and a discontinuous elongated carbonate (white) grains. Cleavage is represented by seams of insoluble constituents. PPL. Sample No: NS-166 B.4. Scale bar 0.2mm.
The CPX and microlitic lava grains vary in size, ranging from silt to fine sand grade, and approximately comprise 20-30% of the thin section. The CPX dominates over microlitic lava. The largest proportion of the rock constituents is carbonate grains, most of which have been elongated and, to some extent, converted to micritic matrix or micro-sparry calcite cement. Magnetite and altered PL occur as rare constituents.

5.2.5 Depositional Environment

The Pudak Formation, occurring on both flanks of the Meratus Mountains, represents the lowest and the coarsest as well as the thickest volcano-sedimentary unit of the Alino Group. The formation is characterised by a chaotic assemblage of rocks but passes into graded and stratified beds in a downstream direction NW and SE-wards away from the mountains. The rocks are composed predominantly of matrix-supported volcanic breccia conglomerate with intercalations of polymictic breccia conglomerate, volcanic sandstone and mudstone with or without radiolarians, and limestone breccia conglomerate.

On the basis of both vertical and lateral distribution of these rock-types over the area studied, as shown earlier, the ratio between volcanic material: non-volcanic material can be estimated, that is not less than 10 : 1. Hence, the type of volcanic activity, together with lithological and textural characteristics of its products has to be taken into account in inferring the depositional environment of the Pudak Formation.

Most of the volcanic materials (i.e. clasts and matrix) of these coarse deposits, display porphyritic and microlitic textures with or without additional amygdales, have been derived from erosional disintegration and fragmentation of lavas. They are occasionally intermixed, in a rather chaotic fashion, with pre-existing sedimentary
(i.e. limestone of the Batununggal Formation and sandstone of the Paniungan Formation) and igneous (e.g. leucocratic to mafic to ultramafic rocks of the Meratus Ophiolite) materials. None of the porphyritic and microlitic lavas as described above are encountered as coherent sheet (massive) flows or as pillow lavas. The reasons for this are not yet fully understood. But the steepness of the slope of the source terrain ("volcanic arc") and the narrowness of volcanic vents are suggested, as some of the causes that could explain the absence of the massive and pillowed flows (cf. Fisher, 1984).

The interpretation of the environment of deposition here is based on the foregoing lithological, sedimentological (i.e. primary sedimentary structures) and palaeontological criteria. The coarse grain-size, poor internal bedding (i.e. particularly in the lower part) poor sorting as shown by the high proportion of matrix among the clasts is characteristic of both subaerial and subaqueous volcanic debris flows (e.g. Fisher 1984). Furthermore, the common occurrence of intercalations of volcaniclastic turbidite in which its mudstone (Bouma E) contains radiolarians, indicate that all rock types of the Pudak Formation were transported by gravity flow (mass flow) processes and re-deposited in full marine environment of unknown water depth.

The presence of radiolarians has long been regarded as indicative of deep-sea sediments which originated as pelagic radiolarian ooze, thus biogenic in origin, and not from volcanic emanations nor even alteration/weathering products of volcanic material (e.g. Bramlett 1946, Siever 1957 and Audley-Charles 1965). However, from recent literature (see Iijima, Hein and Siever 1983), it becomes clear that the radiolarians are not restricted to a single environment as they occur in a wide range of depositional settings such as shelf, ocean and fore-arc/back-arc/trench slope.
The common occurrence of thick volcanic breccia conglomerate beds, which characteristically lack of grading and stratification (cf. lahar) in the lower part (i.e. upstream or near the mountains) and are graded-stratified in the upper part (i.e. downstream, away from the mountains) of the formation, may fall into "disorganised-bed model" and "graded-stratified model" of Walker (1975), respectively (Fig. 155). In many respects, they also closely resemble the "debris-flow" of Walker and Mutti (1973).

On the other hand, polymictic breccia conglomerate or "melange", and limestone breccia conglomerate, which both occur as intercalations in the volcanic breccia conglomerate, could be interpreted as "sedimentary melange" (i.e. olistostrome) documented in literature (e.g. Naylor 1982).

The range of composition of the non volcanic clasts, which include various kinds of bioclastic limestone and mudstone, pyroxenite, serpentinite, gabbro, trondhjemite, dolerite, basalt, spilite, radiolarian chert and schist can be easily explained, as being derived from basement rocks (i.e. calcareous to carbonate sediments, ophiolite and metamorphic) of a volcanic arc, by ejection from volcanic vents and by a simple sedimentary debris flow process (picked up from the slope).

In summary, all the conglomerate beds and associated rocks strongly indicate the products of deposition by debris flows from a subaerial volcanic arc and its pre-existing (basement) rocks. The coarser grain size and angularity of the clasts, especially those clasts derived from the volcanic vents, suggest proximity to the source. The limestone detritus and blocks, such as bioclastic bryozoan packstone-wackestone, bioclastic mudstone, sponge spicular mudstone, planktonic foraminiferid mudstone and Orbitolina-bearing mudstone-wackestone are equivalent to those, and therefore most likely
derived from the area of thrust sheets of the Batununggal Formation, lying to the south. They are considered to have been transported north or northward into the frontal basin of the volcanic arc (see Chapter VIII for detail). Another possible source of the limestone detritus was from the north, derived from the slope of volcanic arc.
5.3 KERAMAIAIN FORMATION: VOLCANICLASTIC TURBIDITE WITH CHERT

5.3.1 Definition

The Keramaian Formation is proposed here for the first time to describe all volcaniclastic sandstone and mudstone and chert with or without radiolarian skeletons. This formation overlies the Pudak Formation conformably. It therefore represents the upper portion of the Alino Group volcano-sedimentary sequence.

The Pudak Formation passes into the Keramaian Formation by a gradual change in lithology, from volcanic breccia conglomerate dominated deposits (i.e. volcanic debris flows) to volcanic sandstone and mudstone, with radiolarian chert at a higher stratigraphic level (i.e. volcaniclastic turbidite).

The name of the formation is derived from Gunung Keramaian, about 10 km WNW of the town of Pelaihari, where a road section on its southwestern flank (Figs. 112 to 114) provides the best rock exposure in the area studied and in the whole of South-East Kalimantan. For this reason the type locality, together with its measured section was established at Gunung Keramaian (Fig. 115) and is described in detail.

5.3.2 Occurrence

The Keramaian Formation flanks the Pudak Formation on the northwest side of the Northern Belt and on the southeast side of the Southern Belt. The distribution of this formation throughout the study area is shown in Fig. 75.

The Keramaian Formation is well exposed in the Northern Belt from the Gunung Keramaian to the northeast of Gunung Batarung. In addition, the exposures of the Keramaian Formation in the village of Kuringkit, northwestern part of Gunung Parang Ilang and also at and around the southern tributary of the Sungai Abalang, east of Tanjung, which all lie on the northern flank of the Manjam Range, are included and regarded as the southern continuation of the Northern Belt.
FIG. 112 Geological traverse along the road at the summit of Gunung Keramaian. The rocks of the Keramaian Formation are largely covered by either solifluxion deposits or soil profiles. See Fig. 75 for map locality.
Fig. 113 Type section of the Keramaian Formation. Section is made up of alternating volcanic sandstone and mudstone, with occasional chert layers. Bed thickness and other sedimentological characteristics can be seen in Fig. 115. The section measured is near the car. Way-up is to the right.

Fig. 114 Part of the measured section, showing very thin-bedded to laminated mudstone and massive mudstone (right). Way-up to the right.
Fig. 115 Stratigraphic section of the Keramaian Formation, road cut at Gunung Keramaian, 10 km WNW of Pelaihari.

**EXPLANATION**

<table>
<thead>
<tr>
<th>Bed Type</th>
<th>Bed Thicknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massive and weathered sandstone</td>
<td>&gt;100 cm = v.thick</td>
</tr>
<tr>
<td>Thick-bedded turbidite</td>
<td>100-30 cm = thick</td>
</tr>
<tr>
<td>Thin-bedded turbidite</td>
<td>30-10 cm = medium</td>
</tr>
<tr>
<td>Massive mudstone</td>
<td>10 - 3 cm = thin</td>
</tr>
<tr>
<td>Very thin-bedded to laminated mudstone</td>
<td>3 - 1 cm = v.thin</td>
</tr>
<tr>
<td>Siltstone</td>
<td></td>
</tr>
<tr>
<td>Granular sandstone</td>
<td></td>
</tr>
</tbody>
</table>

* Chert intercalation

Thinning upward
VERTICAL VARIATION OF SANDSTONE BED THICKNESS.

<table>
<thead>
<tr>
<th>Bouma Divisions (1962)</th>
<th>Vertical Scale in cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE</td>
<td>10</td>
</tr>
<tr>
<td>AE</td>
<td>30</td>
</tr>
<tr>
<td>ABE</td>
<td>50</td>
</tr>
<tr>
<td>ABDE</td>
<td>70</td>
</tr>
<tr>
<td>ABDE</td>
<td>90</td>
</tr>
<tr>
<td>ABDE</td>
<td>110</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scale in metres</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

**STRATIGRAPHIC COLUMN**

- NS.635 De
- Ce
- Se
- Be
- Ae
- De
- Co

**Legend**

- AE
- ABE
- ABDE

**Horizontal Scale in cm**

10 30 50 70 90 110

---

212
In order to portray the vertical variation of lithological, sedimentological and petrographical characteristics within the formation, samples were taken from nearly every bed, and from the base, middle and upper part of the thicker beds at the type section of Gunung Keramaian (see Figs. 113, 114 and 115).

5.3.3 Northern Belt: Keramaian-Waringin-Batarung-Kuringkit

The Keramaian Formation is present in four areas along the Northern Belt: Gunung Keramaian in the southwestern end, a small exposure near the village of Banyuirang and Gunung Waringin in the central part, and Gunung Batarung in the northeastern end of the belt (Figs. 75 and 116). The length of this belt is approximately 75 km, with the breadth varying from 1 to 7 km.

The rocks of the Keramaian Formation in the Northern Belt have been affected by intense folding and faulting or tectonic slicing so that the thickness of the formation is difficult to determine. However, a crude estimation, based on the areal extent of the outcrops and distribution of the strike and dip of the exposed strata suggests that the thickness of the formation is not uniform, varying from several hundred metres in Gunung Keramaian to over 600m in Gunung Batarung. Thus the formation thickens considerably towards the northeast.

At the summit of Gunung Keramaian the formation has a minimum (measured) thickness of 90 m in the road section (see Fig. 115) but the rocks are folded, faulted and locally sheared.

5.3.4 Southern Belt: Satui River Section

Rocks of the Keramaian Formation in the Southern Belt occur adjacent to the Pudak Formation (see Fig. 75). The belt was geologically traversed and studied in great detail, in particular along the river section of the Sungai Satui, as shown in Figs. 77 and 117.
FIG. 115 SIMPLIFIED GEOLOGIC MAP OF THE NORTHEASTERN END OF THE NORTHERN BELT, SHOWING DISTRIBUTION OF THE KERAMAIAIN FORMATION AND ITS RELATIONSHIP TO THE SURROUNDING ROCK UNITS.
KEY TO SYMBOLS

- Massivw sandstone
- Laminated sandstone
- Graded sandstone
- Very thin-bedded to layered mudstone

BD Bouma Divisions (1962)

Channel structure
Cross-bedding
Lamination
Wavy lamination
Thinning upward

Sketch map of quartz veins at Locality NS-612

Fig. 117 SOME STRATIGRAPHIC SECTIONS OF THE KERAMAIAIN FORMATION IN THE SUNGAI SATUI.
The formation was also briefly examined in the Sungai Meweh, a main eastern tributary of the Sungai Satui.

At the northern end of the section the contact between the Keramaian Formation and the Pudak Formation (between localities NS-560 and NS-561, see Fig. 77) is interpreted as a thrust fault. From here downstream the lithology is volcanic sandstone beds, except at localities NS-561 to NS-563, NS-565 and NS-570 to 571 where pebbly volcanic conglomerate, with the largest clast up to 30x70cm, are poorly exposed.

From the distribution of the outcrops and strike and dip of the beds, shown in Fig. 77, the formation exhibits a fining upward sequence. Apart from the fault, the contact between the Keramaian Formation and the Pudak Formation is not sharp but gradational or interfingering.

Near locality NS-613 the formation is inferred to be in tectonic contact with the limestones of the Batununggal Formation (for evidence see Fig. 77 and text below). Elsewhere in the south, away from the river section, the formation is unconformably overlain by the Eocene Tanjung Formation (see Geological Map).

Due to poor exposures, and locally due to deviation of strikes and dips by faults, the thickness of the formation here can only be estimated, but it is not less than 500m.

5.3.4.1 Description of Lithology

The Keramaian Formation is characterised by alternating volcanic sandstone and mudstone, and chert with or without radiolarians in the upper part of the formation. Pebby sandstone also occurs at several stratigraphic levels, particularly in thick-bedded or in amalgamated sandstone beds. All of these are commonly confined to the lower portion of the formation. The rocks of the Keramaian Formation as a whole are often well bedded and highly indurated.
In many outcrops the rocks have been folded, disrupted and dissected by several stages of faulting. Other conspicuous features seen in the outcrops are quartz or calcite veining. These veins are quite common throughout the rocks, particularly in jointed and fractured rocks or near fault zones. The veins range from a few mm to over 1 cm in thickness, with the thicker beds commonly displaying shearing zones. All veins seen are either normal or oblique to bedding surfaces.

There are three main lithologies present in the Keramaian Formation, sandstone, mudstone and chert. The latter is considered to represent the upper portion of the formation. Each of these lithologies are described below.

A.1 Volcanic Sandstone

The volcanic sandstone includes massive, graded and laminated sandstones. The former is characteristically found in the central (e.g. Gunung Waringin) and the northeastern end (e.g. Abirau and Gunung Batarung) of the Northern Belt, whilst the last two types of sandstones above are typical of both the southwestern end of the Northern Belt and the Southern Belt (i.e. Sungai Satui).

Massive Sandstone

Massive sandstone beds show no grading or lamination. Generally the beds are coarse to very coarse grained with no internal sedimentary structures except a number of granules or fine pebbles which are occasionally scattered throughout the lower part of the bed. The thickness of the beds is often thicker than 30cm.

Good exposures of the graded and laminated beds are found at Gunung Keramaian, in Kuringkit Village and in the Sungai Satui. In general the rocks in these three areas closely resemble each other and even exhibit the same state of lithification, hard to very hard, and
break into splinters if struck with hammer (Figs. 118 to 121). Most of the sandstone beds are parallel-sided, with sharp bases, but unfortunately lateral variation cannot be recognised, as the rocks are only exposed in restricted areas.

Graded beds, however, are also found in a few localities at the northeastern end of the Northern Belt, (e.g. in Abirau, NS-712; Sungai Paning Paning, NS-727). These graded beds normally comprise thickly bedded sandstone, and are characterised by coarse to very coarse sand grade with a few granules at the base and medium sand grade with faint laminations at the top of the bed. In some graded beds, a very thin layer (i.e. <1cm) of mudstone is present at the top of the bed. Note that amalgamation of the successive sandstone beds are dominant here. On the basis of the above characteristics, these sandstone beds can be assigned to facies B2 (Fig. 155) of Walker and Mutti (1973).

Most sandstone beds show very simple grading, with a continuous upward decrease in grain size, from coarse or very coarse sand grade at the base to mudstone at the top. But in other cases, the grain-size of the sandstone beds is uniformly distributed, where fine to very fine grained sandstone rapidly becomes mudstone. Thus there is no obvious grain size variation in the middle part of the bed. Instead they show very faint lamination. These beds can be assigned to division BE of Bouma (e.g. NS-635 0 and P).

In another type of graded bed the bed shows granular texture with a few mud-chips (i.e. derived from the underlying beds) at the base, faint lamination in the middle, and a thick (up to 40 cm) mudstone in the upper portion of the bed (e.g. NS-636X).

Channel structures were observed at several stratigraphic levels in the sandstone beds (Fig. 117). Beds of this volcanic sandstone also display other sedimentary structures such as wavy or ripple laminations. This type of structure is more often found at Kuringkit.
Fig. 118 The Keramaian Formation at Kuringkit in the southwestern end of the Northern Belt. The rocks are well bedded, dipping into the section, and show grading, parallel and convolute laminations which can be described by Bouma Sequence. Way-up to top. The rock face is a strike section with the bedding picked out by joint surfaces dipping back into the face.

Fig. 119 Close-up view of the above photograph, showing graded, parallel bedded and rippled sandstones, with sharp base.
Furthermore, parallel lamination is fairly common in medium to fine grained sandstone beds. In addition, parallel laminated fine-grained sandstone (Bouma B), with either very thin mudstone (Bouma E), usually 1 to several cm thick, or cross-laminated sandstones at the very top of the bed are only found in the Sungai Satui.

The beds in the Gunung Keramaian section (see Fig. 115) range from 2cm to 2.4m, but many of these beds are in the order of 2cm to 10cm (30%) and 10cm to 50cm (44%). At Kuringkit the sandstone beds exhibit similar thickness variation to that of the Keramaian section.

The individual thickness of the bed is variable in the Sungai Satui, from 1cm to 1.5m. Thicker beds occur in the upper course of the river, as can be seen in locality NS-566 (Fig. 117) and become progressively thinner towards the downstream end of the section (locality NS-575, in Fig. 120). At localities NS-612 and NS-613 (Fig. 121) the sandstones are less than 10cm to a few tens of centimetres, of which 28cm is the thickest bed.

The sand : mud ratio is 1 : 4 at Keramaian, whereas at Kuringkit it is estimated to be slightly higher than 1 : 4. The sand:mud ratio for the central part and northeastern end of the Northern Belt is very high, that is greater than 10:1.

In thin section the sandstones from both the Northern and Southern Belts are essentially similar. They are composed predominantly of CPX grains, associated with altered opaque groundmass, volcanic lava fragments (CPX or PL phric and some microlitic). The matrices are often glassy, with scattered fine altered materials which are identified as CPX, PL, volcanic fragments and glass. Locally carbonate and opaque aggregates are also present (see Section 5.3.4.2).
Fig. 120 View of well bedded volcanic sandstone turbidite (alternating Bouma AE) in the Sungai Satui. The rocks are exposed for about 6m thick at locality NS-575, 400m downstream of the Tandui Camp.

Fig. 121 Exposure of volcanic sandstone turbidite at locality NS-613, showing repetition of laminated sandstone beds (Bouma B) with either rippled sandstone (Bouma C) and laminated mudstone (Bouma D) or structureless mudstone (Bouma E) in the upper part of each bed.
Fig. 120 View of well bedded volcanic sandstone turbidite (alternating Bouma AE) in the Sungai Satui. The rocks are exposed for about 6m thick at locality NS-575, 400m downstream of the Tandui Camp.

Fig. 121 Exposure of volcanic sandstone turbidite at locality NS-613, showing repetition of laminated sandstone beds (Bouma B) with either rippled sandstone (Bouma C) and laminated mudstone (Bouma D) or structureless mudstone (Bouma E) in the upper part of each bed.
A.2 Volcanic Mudstone

Volcanic mudstones occur in a number of localities, such as in Keramaian (e.g. NS-635M and NS-635R), Kuringkit (e.g. NS-188B and C, NS-188.2 and NS-188.3) and in Abirau (e.g. NS-712).

Regionally, the volcanic mudstones occur as a distinct portion (Bouma E) of graded or massive volcanic sandstone beds. They are commonly massive and range in thickness from less than 1cm to about 2.2m. In other cases, particularly in the southwestern end of the Northern Belt, e.g. in Keramaian and Kuringkit, the volcanic mudstones also occur as thick to very thick intercalations in the volcaniclastic turbidite sequence. The thickness of individual intercalations is highly variable, ranging from 15cm to about 13m. They are predominantly composed of very thinly bedded to laminated mudstone.

Both the layers and laminae are parallel, continuous and well developed (Fig. 122), except when they are churned or burrowed by small indistinct trace fossils. Furthermore, on the basis of petrographic examination, many layers or laminae exhibit grading, with coarse silt to very fine sand grade terrigenous grains (e.g. CPX, PL and QZ) concentrated at the base of the graded division (Bouma A). The graded laminae range from 1mm to 3mm in thickness. The grains are poorly sorted and tend to occur in very thin layers or laminae.

Rare sandy siltstone with sandstone (medium to very coarse grained CPX-bearing sandstone) channels (NS-188.3) occurs as intercalations in the laminated mudstone beds. The lower contact of the channelised sandy siltstone is very sharp and undulating, with several mm relief. The thickness is slightly variable, ranging from 8mm to over 1cm. In the channel, the sandstone contains many pyroxene grains, together with conspicuous porphyritic (CPX + PL-phryic) volcanic fragments (up to 3mm in length), amygdaloidal hyalocrystal-
line volcanic lava (up to 1.8mm), gabbro, dolerite and PX sand-sized detritus. The matrix is altered but most likely volcanic as indicated by the relicts of microlites of PL, CPX and fine vesicular microlitic lava.

Post depositional structures such as cleavages and extensional veins are present in some laminated mudstone beds (e.g. NS-188C). They are best seen under the microscope. The cleavage typically displays an angle to bedding surfaces. The veins, occupied by micropolycrystalline quartz with some epidote and magnetite, are commonly parallel to the cleavage direction.

In the northeastern end of the belt, e.g. in the Abirau area (e.g. NS-712.9), the volcanic mudstone is characteristically similar in colour (olive grey, 5 Y 4/1), structure and texture to those at the southwestern end of the belt, as described above. However, nearly all coarse silt very fine sand-sized terrigenous grains are now largely palagonitised or chloritised in the Abirau area. The only grains that can still be observed with difficulty are CPX, PL and altered volcanic lava. In some respect, the volcanic mudstone is related to the cherts of the southwestern part, because it contains similar sedimentary structures (i.e. lamination) and a number of radiolarians.

A.3 Cherts with or without Radiolarians

There are two kinds of cherts present, chert without or in rare examples with only a very small number of radiolarians, and chert with a lot of radiolarians. The former occurs in the Keramaian type section (Fig. 115), whereas the latter has been found only near the southern tributary of the Sungai Abalang, east of the village of Tanjung. In the Keramaian section, the cherts with few radiolarians are characteristically associated with thinly to very thinly bedded volcanic mudstone and sandstone of the volcanioclastic turbidite.
Cherts containing many radiolarians are exposed in a restricted area near the Sungai Abalang (NS-859). Although these cherts are poorly exposed, the rocks themselves are fairly fresh. The megascopic and petrographic appearance of the above two types of cherts are shown in Figs. 122 to 124. Note that the description concerns the radiolarian cherts from the Sungai Abalang area.

Most of the chert beds near the southern tributary of the Sungai Abalang are characterised by distinctive greenish grey (5 GY 6/1) to greenish green (10 GY 5/2) colour, and greyish red (5 R 4/2) if affected by some sort of oxidation or weathering. They are dense and very hard, and break into splinters, with typical conchoidal fractures.

Although the base of these radiolarian cherts is not exposed, they are likely to represent the uppermost part of the Keramaian Formation. This consideration is based on lithological and internal sedimentary structural similarities to the cherts found in the Keramaian Section. The new age data (see below) from the Abalang radiolarians also fits in with the well constrained age of the Keramaian Formation. However, further study is needed, in particular to examine detailed sedimentary structures, bedding direction, thickness and their relationship to adjacent rock units.

Radiolarian cherts make up less than 0.5% of the total section of the formation. Faint lamination is the only sedimentary structure that can still vaguely be seen in the cherts in the field. But the rock is highly fractured, hence it is not possible to trace the lateral extent of the lamination in the outcrops.

The cherts contain well-preserved radiolarian skeletons (see below). Therefore, the radiolarian cherts in this particular locality are very important in the present study. The radiolarians were identified by Dr. Benita L. Murchey of the U.S. Geological Survey
Fig. 122 Close-up of laminated volcanic mudstone. Many layers or laminae exhibit grading. See text for detail. White bar is 1 cm. In hand specimen this rock resembles the radiolarian chert below.

Fig. 123 Close-view of radiolarian chert at Locality NS-859, near Sungai Abalang, showing faint lamination. This rock yields a number of datable radiolarian species, as given in the text and shown in Figs. 124B and 125.
Fig. 124 Photomicrographs of cherts of the Keramaian Formation.


B. Radiolarian chert. Note grading is marked by the coarsest and the highest percentage of radiolarians in the lower part of each lamina (upper part of photograph). Scale bar 0.2mm.
(pers. comm. to Dr. A.J. Barber 1984). They include the following species:

- **Amphipyndax mediocris**
- **Acanthocircus carinatus** Foreman
- **Acanthocircus trizonalis**
- **Eucyrtidium(?)**
- **Pantanellium sp.**
- **Archaeodictyomitra sp.**
- **Pseudodictyomitra sp.**
- **Thanarla conica**
- **Praeconocaryomma sp.**
- **Napora or Ultranapora**
- **Parvicingula(?)**

Dated as Early Cretaceous (Valanginian) to Late Cretaceous (early Cenomanian), probably Early Cretaceous.

In thin section the radiolarian chert is characterised by poorly sorted radiolarian skeletons set in pale reddish brown clay which is high in Fe-oxide. The radiolarians vary in size, from less than 0.05 to 0.25 mm in diameter, and make up about 35% of the thin section. The interior of the radiolarians is usually occupied by either micro-crystalline QZ or chalcedonic QZ. Some radiolarians are infilled by dusty coloured aggregates, possibly a mixture of unidentified clay minerals and Fe-oxide.

Other conspicuous features seen under microscope are lamination, grading and micro-polycrystalline QZ veins. Terrigenous materials occur in a very small amount. They are recognised as altered silt to very fine sand grade PL and PX.
Fig. 125 SEM photomicrographs of radiolarians from the upper portion of the Keramaian Formation in the Sungai Abalang (NS-859).
5.3.4.2 Petrography

Representative sandstone samples (some samples from pebbles and matrix of pebbly conglomerate intercalations) from both the Northern and Southern Belts were cut and petrographically studied.

The sandstones are mostly composed of relatively simple constituents, consisting of variable proportions of lithic volcanic fragments (Lv, 10-100%), CPX (0.5-35%), PL (0.5-30%) and limestone (LS, 0-35%). Other constituents are minimal but very significant for provenance assessment. These include sedimentary (siltstone and shale), leucocratic (i.e. trondhjemite, microdiorite and diorite), mafic (i.e. gabbro, dolerite and basalt or "spilite"), ultramafic (i.e. pyroxenite and hornblende) and metamorphic (i.e. schist and phyllite or slate) rock fragments. In addition, secondary minerals such as calcite, epidote, micro-polycrystalline QZ, magnetite, chlorite and zeolite which commonly form as small patches or inclusions in the crystals (i.e. in CPX and PL) or as veins, are also documented.

Petrographically, the sandstones can be divided into four rock types or petrofacies:
1. CPX-PL-bearing volcanic litharenite;
2. lithic volcanic CPX-PL arenite;
3. pure volcanic litharenite; and
4. lithic volcanic carbonate litharenite.

These petrofacies are defined on the basis of relative percentages of the following constituents:
1. plagioclase (PL),
2. pyroxene (PX),
3. volcanic rock fragments (Lv), and
4. limestone fragments (LS). (Table 3).
Fig. 126 Photomicrograph of CPX-PL-bearing volcanic litharenite, showing texture and composition. Note CPX (in blue-pink-orange), PL (in white-light grey), and volcanic lithic detritus (fine lath-shaped PL crystals in dark groundmass). Sample NS-635F. Gunung Keramaian. XPL. Scale bar 0.35mm.

Fig. 127 Photomicrograph of lithic volcanic CPX-PL arenite, showing texture and composition. Many CPX grains are now altered and replaced by opaque minerals (upper left). Sample NS-188.1. Kuringkit Village. XPL. Scale bar 0.25mm.
Fig. 128 Photomicrograph of pure volcanic litharenite, showing texture and composition. Lithic volcanic grains are shown by the presence of microlitic and microphenocrysts of plagioclase floating in opaque and glassy groundmass. Sample NS-727. Abirau Village. PPL. Scale bar 0.25mm.

Fig. 129 Photomicrograph of lithic volcanic carbonate litharenite, showing texture and composition. Carbonate grains are all bioclastic limestones, with grain size ranging from granule to silt grade. Note altered microlitic lava (centre), CPX (in pink-orange) and PL (in white). Sample NS-635K. Gunung Keramaian. XPL. Scale bar 0.5mm.
Other diagnostic minerals and rock constituents in each petrofacies are listed in Table 3. Thin sections of these rocks are shown in Figs. 126 to 129. Brief description of each rock type above is given below.

B.1 CPX-PL-bearing volcanic-litharenite

The most dominant and striking feature of the volcanic sandstone of this type is the occurrence of CPX, PL and volcanic lithic (Lv) detritus which are characteristically grain-supported, poorly sorted and fine to very coarse sand grade (Fig. 126, Table 3). The matrix which consisted of a mixture of CPX, PL and Lv coupled with secondary minerals such as chlorite, carbonate and magnetite normally forms less than 10% of the rock volume.

All CPX grains are subangular to angular in shape, range in size from silt to coarse sand grade, and may be twinned or untwinned, with uniform extinction. Many of them are now cataclastically fractured. However, fracturing in the CPX in this rock is not so intense as that of the CPX in the Pudak Formation. To some extent the CPX grains are altered to iron oxide around their rims. Some CPX grains contain magnetite inclusions. In addition, CPX also occurs as one of the main mineral constituents in the gabbro and dolerite fragments. Most of the finer CPX grains are altered either to carbonate or magnetite or a combination of these two.

The PL grains normally subangular to angular, andesine in composition, and many of their rims are altered to pale greenish yellow unidentified aggregates. They also contain magnetite and iron oxide aggregates, of which in some of the grains these secondary minerals occur parallel to the crystal cleavages.
<table>
<thead>
<tr>
<th>Studied Samples</th>
<th>Fabric</th>
<th>Rock Type</th>
<th>Texture</th>
<th>Ophiolite</th>
<th>Sediment</th>
<th>Meta</th>
<th>VeINS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Grain Size (mm)</td>
<td>Sorting (Folk, 1968)</td>
<td>QZ Poly KF Pyroxene Hornblende Muscovite Magnetite LV Ophiolite Dol. Gabb. Biot. Sill. LS Chert Phyl. Phyllite Calcitic Carbonate Zeolite</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Keramaian</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-635F</td>
<td>g-s</td>
<td>CPX-PL volcanic-litharenite</td>
<td>0.2-2</td>
<td>Sa-a v.p.s. 0.4</td>
<td>27 23</td>
<td>40 Tr Tr 0.3 0.3</td>
<td>1 Tr 8</td>
</tr>
<tr>
<td>NS-635K</td>
<td>g-s</td>
<td>Volc. carbonate litharenite</td>
<td>0.1-2.5</td>
<td>Sa-a v.p.s. 1 Tr</td>
<td>10 0.5 Tr 4 32.5</td>
<td>0.6 0.4</td>
<td>2 36 1 12</td>
</tr>
<tr>
<td>NS-635X</td>
<td>g-s</td>
<td>Volc. carbonate litharenite</td>
<td>0.2-7</td>
<td>Sa-a v.p.s. 0.4 0.6 Tr</td>
<td>14 5 25</td>
<td>3 3 Tr 1 0.6 0.5 2.4 0.5 37</td>
<td>Tr Tr</td>
</tr>
<tr>
<td>NS-636D</td>
<td>g-s</td>
<td>CPX-PL volcanic litharenite</td>
<td>0.1-1</td>
<td>Sa-a p.s. 2</td>
<td>30 22</td>
<td>38 Tr Tr</td>
<td>1 1 6</td>
</tr>
<tr>
<td><strong>Kuringkit</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-188.1</td>
<td>g-s</td>
<td>Volc. CPX-Plaerenite</td>
<td>0.2-3</td>
<td>Sa-a p.s.</td>
<td>40 35</td>
<td>4 10</td>
<td>2 4</td>
</tr>
<tr>
<td>NS-192</td>
<td>g-s</td>
<td>CPX-PL volcanic-litharenite</td>
<td>0.1-1.2</td>
<td>Sa-a p.s.</td>
<td>28 25</td>
<td>2 35</td>
<td>Tr Tr</td>
</tr>
<tr>
<td><strong>Abirau</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-712.2</td>
<td>g-s</td>
<td>CPX-PL volcanic-litharenite</td>
<td>0.2-2.2</td>
<td>Sr-a p.s.</td>
<td>15 10</td>
<td>3 72</td>
<td>Tr Tr Tr</td>
</tr>
<tr>
<td>NS-727</td>
<td></td>
<td>Pure volcanic-litharenite</td>
<td></td>
<td></td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Waringin</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-823</td>
<td></td>
<td>Recrystallised sandstone</td>
<td></td>
<td></td>
<td>Tr Tr Tr</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Modal analyses of representative samples from sandstones of the Keramaian Formation at Gunung Keramaian, Kuringkit, Abirau and Gunung Waringin.  
Note: Mono = Monocrystalline, Poly = Polycrystalline, Qz = Quartz, Fs = Feldspar, Pl = Plagioclase, KF = Potassium Feldspar, LV = Volcanic, Tron = Trondhjemite, Dio = Diorite, HBT = Hornblendite, BST = Basalt ("Splitite"), Dol = Dolerite, Gab = Gabbro, PXT = Pyroxenite, SS = Sandstone, ST = Siltstone, LS = Limestone, CHT = Chert, Phyl = Phyllite, CC = Calcium Carbonate and Z = Zeolite.
One of the lithic grains in Sample NS-636F, 0.8mm in length, consisted of strained QZ and epidote, with a parallel fabric. This is classified as schist. Another grain (1mm) is composed of oligoclase/andesine PL, QZ with wavy extinction and a very tiny grain of unidentified basic mineral, with association of secondary epidote, magnetite and calcite. This is included in the trondhjemite category.

Although nearly all volcanic fragments are largely altered to magnetite or haematite, the occurrence of relict microlites and coarser grains of PL reveal that there are at least three kinds of volcanic detritus present. They are microlitic lava, porphyritic andesite with PL and CPX as phenocrysts and microphenocrysts respectively, and crystal tuff (>2mm). The groundmass in most of the volcanic fragments has been altered to magnetite or haematite. The volcano-lithic grains are up to 1.2mm in length.

The original nature of the limestone detritus cannot be recognised in NS-635F as all of them have been recrystallised. QZ grains with uniform extinction are common. But polycrystalline QZ with metamorphic sutured boundaries also occur in the rock (e.g. NS-636D). Some polycrystalline QZ occurs together with CPX. Chert (1%) is found in NS-636D.

At the northeastern end of the Northern Belt, the CPX-PL volcanic-litharenite contains nearly equal amounts of CPX and PL (Table 3). The volcanic detritus makes up 75% of the rock with limestone (include bioclastic detritus), altered (limonitised) siltstone and radiolarian chert as minor constituents. The rock is grain-supported and poorly sorted, with a subangular to angular texture.

The volcanic fragments are nearly all palagonitic rocks (lavas and tuffs), yellow to yellowish brown in colour. They are associated with chlorite, carbonate, magnetite, CPX and PL (i.e. the last two are relict minerals in palagonite glass). Vesicular palagonitic fragments
display typical micro-bubbly structure that is infilled by unidentified isotropic minerals.

Occasionally chlorite and epidote, Fe-oxide and magnetite are found as alteration products in the CPX grains. Wavy flow structures are commonly found in the palagonitic tuff fragments. Other features found include micropolycrystalline QZ and epidote veins that cut the rock.

The matrix of the rock consists of palagonitised PL, CPX, magnetite, palagonitic tuff and other unidentified palagonitic detritus. All PL and CPX is likely to be volcanic in origin. One of the most conspicuous features of the CPX-PL volcanic-litharenite at the northeastern end of the Northern Belt is that all framework grains are rimmed by a very thin film of Fe-oxide.

From the foregoing field and petrographic descriptions it is concluded here that the CPX-PL-bearing volcanic-litharenite is concentrated at the southwestern end of the Northern Belt. For instance, it is frequently found in the following areas: Keramaian (e.g. NS-635F and NS-636D), Kuringkit (e.g. NS-180) and southwest of Kuringkit or near the eastern foothill of the Ambungan Range (e.g. NS-192). Although this rock type can also be seen in the northeast end of the belt, e.g. near the village of Abirau (i.e. NS-712 at the Sungai Riampunai), it occurs only in a subordinate amount.

8.2 Lithic Volcanic CPX-PL Arenite

Both in hand specimen and in thin section this rock (e.g. NS-188.1) is very much the same as the CPX-PL-bearing volcanic-litharenite. The only difference is that the former is typically dominated by CPX which occupies nearly half of the thin section (Fig. 127 and Table 3). The second major constituent is PL grains (25%), most of them now altered. In this particular type of sandstone the CPX also occurs in the form of clusters, thus, they are regarded as
aggregates or rock detritus of pyroxenite. These are up to 3.5mm in diameter and make up about 4% of the rock. Apart from pyroxenite, gabbro also occurs in an appreciable amount (2%) whereas volcanic fragments only form less than 5%.

As a whole the lithic volcanic CPX-PL arenite is poorly sorted, 0.2-3mm, grain-supported, subangular to angular, and very hard, presumably cemented by silica cement.

The CPX grains are mostly augite. To some extent, they are commonly replaced by carbonate and magnetite. In other cases these are further partially recrystallised to indistinctly cryptocrystalline aggregate. Calcite micro-veins are present in the CPX grains.

CPX and PL arenite (fine to very fine grained) also commonly occurs at the base of strongly interlaminated and graded siltstone – mudstone. They are commonly accompanied by very fine aggregates of opaque minerals.

B.3 Pure Volcanic-Litharenite

The pure volcanic-litharenite (Fig. 128) so far is found only in and around the village of Abirau and Gunung Batarung (e.g. NS-727). In hand specimen and under thin section this rock is very much the same as that found in the Sungai Satui in the Southern Belt (see below). It is fine to very coarse grained (0.2-1.4mm), poorly sorted, and is almost 100% volcanic in origin. The dominant volcanic detritus includes altered porphyritic vesicular lava and bubbly glass. This detritus is normally rimmed by palagonite. The rock appears to have been cemented by amorphous silica. Zeolite may also act as a cement. The occurrence of zeolite veins, up to 1mm wide, supports the above suggestion.
B.4 Volcanic Carbonate Litharenite

The volcanic carbonate litharenite (i.e. NS-635K and NS-635X) is the most conspicuous rock type within the Keramaian Formation but makes up less than 1% of the formation (Fig. 129). It only occurs in Gunung Keramaian (Fig. 115).

In hand specimen the rock is hard, medium grey (N₅⁵) to dark grey (N₃³) with very light grey (N₈⁸), olive grey (5 Y 3/2) and greyish black (N₁₂²) grains, up to 3mm in longest diameter and very poorly sorted. In thin section the rock is seen to be grain-supported, 0.01-2.5mm, consisting mainly of limestone (35-37%) and volcanic grains (25-30%), and CPX (5-14%). Other constituents include gabbro, dolerite, sheared or metamorphic peridotite, trondhjemite, hornblendite, stretched metamorphic QZ, diorite, phyllite or slate and metabasalt or "spilite" (Table 3).

The limestone occurs both as framework grains (up to 2.6mm in length) and matrix. Many of the limestone fragments (Ls) have been recrystallised and converted to micrite. In NS-635K, the limestone can still be recognised, as the following:

1. micritic packstone-grainstone,
2. bioclastic wackstone,
3. recrystallised sponge spicular mudstone,
4. Orbitolina fragments (e.g. NS-635K), and
5. micritic limestone (the original texture has completely been destroyed).

The limestone fragments vary in size and shape, equant to lenticular and, some form discontinuous laminae. In some limestone fragments, PL, CPX or volcanic fragments occur as inclusions. In other cases these terrigenous grains are also present along stylolitic structures.

As can be seen in Table 3, volcanic fragments are the second most abundant constituent in the volcanic carbonate litharenite. They
vary in size, from 0.6-1.2 mm in length, and are recognised as having microlitic and porphyritic characters (CPX or PL as phenocrysts). Some microlitic lava show alignment which can be assigned to trachytic texture.

There are two kinds of QZ grain present, monocrystalline with uniform extinction and polycrystalline QZ with sutured crystal grain boundaries (Fig. 130A). The former is more common than the latter (Table 3). Siltstone fragments form about 2% of the rock, up to 3 mm in length, altered, but with identifiable constituents of monocrystalline quartz, plagioclase, magnetite and chlorite (Fig. 130B).

Gabbro (Fig. 130C) and dolerite clasts (Fig. 130D) account for just over 1% of the rock. The former is distinguished by grain size, texture, and the presence of PL and CPX, up to 1 mm in length. Locally the gabbro is altered to calcite, magnetite and epidote.

PL forms 10% of the thin section in Sample NS-636K, but it only occurs in minor amounts in NS-635X. Many of the PL grains have been sericitised or replaced by calcite or an association of micropolycrystalline QZ, calcite, magnetite and epidote. Due to alteration their composition cannot be determined but it is considered that they are andesitic in composition. However, one PL grain in a limestone clast, i.e. in Sample NS-635X, was found to be labradorite (An64).

Two subrounded grains of hornblendite, up to 2.2 mm in length, have been identified in Sample NS-635K and NS-635X. Chert detritus contains no obvious radiolarians. Most cherts observed have been altered in places to carbonate, epidote and magnetite. Altered chert grains can be mistaken for recrystallised igneous or plagioclase clasts which petrographically (in XPL) exhibit similar characters to true chert. Normally the outline of crystal grains or relict textures in igneous rocks is still preserved to some extent.
Trondhjemite clasts (Fig. 130F) make up 3% of the rock in NS-635X. The clasts are up to 5mm in diameter, consisting of PL and Qz with calcite veins, apatite and fluid inclusion(?), chlorite (after biotite), with epidote and magnetite as replacement of basic minerals.

Sheared pyroxenite (Fig. 130G) up to 2mm in length forms 2% of the rock. It has been cataclysmatically fractured and sheared. Secondary minerals, e.g. talc, epidote, carbonate and magnetite are found in the pyroxenite.

Gabbro clasts (Fig. 130C) occur up to 2.2 x 3mm in size, consisting of labradorite plagioclase (An 68) and CPX associated with secondary minerals chlorite, magnetite and calcite. Fractures occur perpendicular to crystal twinning of the PL. Epidote is normally concentrated along cleavages or fractures of the PL. Petrographic observation reveals that the gabbro has undergone deformation. This is shown by shearing planes and the bending of CPX in the gabbro.

Deformed shale or phyllite is up to 1.2mm in length. It is made up of fine grained material which cannot be resolved under microscope. The characteristic platy shape is probably a result of derivation from a cleaved source rock containing abundant platy minerals.

5.3.5 Depositional Environment

As presented earlier, most volcaniclastic deposits of the Keramaian Formation can be described in terms of the Bouma sequence (1962). The only exception to the Bouma sequence is the presence of the massive sandstone beds at the northeastern end of the Northern Belt, i.e. Gunung Waringin and Gunung Batarung and its surrounding area. Although uncommon, this type of sandstone bed also occurs in Gunung Keramaian (NS-635 J-L), at the southwestern end of the Northern Belt. Where the beds cannot be appropriately described by the Bouma sequence, Facies B2 (massive sandstones) of Walker and Mutti (1973) has been used.
Fig. 130 Photomicrographs (XPL) of lithic grain types in volcanic sandstones of the Keramaian Formation:

A. Stretched meta quartz (NS-635X, 10X)
B. Siltstone (NS-500, 25.2X)
C. Gabbro (NS-635K, 10X)
D. Dolerite (NS-635X, 25.2X)
E. Trondhjemite (NS-635X, 10X)
F. Pyroxenite (NS-635X, 25.2X)
Generally, the Bouma sequence (e.g. see Walker and Mutti, 1973) indicates two types of depositional mechanics and environments of deposition, proximal and distal turbidites. The graded beds at Gunung Keramaian (see Fig. 115), Kuringkit and Sungai Satui (see Fig. 117) show the following characteristics: sharp and flat based, beds with thickness generally of 2cm to 10cm and 10cm to 50cm, a sand : mud ratio is about 4:1, amalgamation of sandstone beds is present, but uncommon, uncommon parallel and ripple cross-lamination, each sandstone bed tends to grade up into a Bouma E, and the typical and classical turbidite is an AE bed. This evidence indicates that the graded beds on both the northern and southern flanks of the Meratus Mountains resemble proximal, rather than distal, turbidites (Walker and Mutti 1973). Such an inference is compatible with suggestions that the volcanic source terrains were lying within and parallel to the mountain ranges of the Meratus Mountains (see discussion below).

As stated above, the dominant lithology of the Keramaian Formation in the northeastern end of the Northern Belt, e.g. Gunung Waringin and Gunung Batarung, is massive sandstone beds, generally coarse-grained sandstones which often contain granules at the base. These sandstone beds correspond very closely to "massive sandstones without dish structure" or "Facies B2" described from turbidite sequences by Walker and Mutti (1973).

The characteristics of this facies, according to Walker and Mutti (1973), include:

1. the beds lack parallel lamination, but may contain crude, sub-parallel, faintly parallel stratification,
2. lack of ripple cross-lamination at the top,
3. a sand : mud ratio is very high of greater than 10:1, thus the sandstones tend to be amalgamated,
4. bed thickness ranges from tens of centimetres to about 2m,
5. scouring at the base is common, and
6. granules or pebbles are commonly present at the base.

All of these characteristics are seen in the sandstones at the north-eastern end of the Northern Belt.

Furthermore, the sandstone beds here probably represent channel deposits. As the sandstone beds are widely distributed, that is over 20 km in lateral extent, stretching from Gunung Waringin in the S to Gunung Batarung in the N and, because pelagic mudstone (Facies G) is only present in Gunung Batarung, the kind of channel deposits is likely to be the type located in an inner fan setting, rather than the channelled slope setting of an idealised slope-fan-basin floor system (see Chapter VIII). Gunung Batarung could probably be the overbank of the channel.

Other evidence which can support this interpretation is that the grain size of the sandstone beds is coarser in Gunung Waringin than their counterparts in Gunung Batarung. Such evidence would also suggest that the area around Gunung Waringin at the time of deposition was acting as the centre of the channel. However, the lack of good exposures in these two areas prevent a more detailed and comprehensive lateral relationship between the centre and the overbank of these channel deposits.

As has been mentioned earlier, cherts with or without rare radiolarians are characteristically intercalated with volcanic mudstone which have some of the physical characters of cherts, in the volcaniclastic turbidite section in Gunung Keramaian. Radiolarian-bearing cherts found near the Sungai Abalang have been previously considered to be the uppermost part of the Keramaian Formation (see above). As all of these cherts exhibit conspicuous internal sedimentary structures, e.g. lamination, grading and erosional contacts, they are

It has been suggested that radiolarian cherts of the Alino Group are lithified radiolarian pelagic sediments and they have been compared with recent deep-sea open-ocean radiolarian oozes (e.g. Koolhoven, 1935; Hamilton, 1979). They have therefore been regarded as the uppermost layer of an oceanic plate ("ophiolite") formed in a spreading ridge environment. However, lithologic and stratigraphic relationship of the cherts, the new evidence on age of radiolarians, together with the occurrence of current-formed structures and the presence of terrigenous materials (e.g. PL and CPX) preclude such interpretation.

Recent studies on siliceous deposits in the Pacific Region (Iijima et al, 1983); on the basis of lithologic associations, sedimentary structures, modes of formation, sedimentation rates and mechanism, and geochemistry; have shown that radiolarian cherts in orogenic belts are not always equivalent to deep-ocean cherts in the Pacific basin. According to these studies (in Iijima et al 1983, p3 ) "... cherts in the orogenic belts probably formed in young ocean basins, block faulted continental margins, back arc basins, or adjacent to island arcs."

Lithological associations and sedimentary structures, as outlined above, suggest that the cherts of Keramaian Formation were more likely laid down by turbidity currents, in depositional continuity with volcanic sandstone and mudstone turbidites of the lower part of the
formation. Therefore, these cherts were not deposited on an oceanic crust but rather adjacent (i.e. fore and back arcs) to island arcs (see Chapter VIII for detail).

5.4 PALEONTOLOGY AND AGE

The age of the Alino Group (i.e. formerly known as the Alino Formation) has intrigued many authors (Koolhoven, 1935; Hashimoto and Kioke, 1973; Situmorang, 1982; and Sikumbang et al, 1982). Koolhoven (1935) stated that the Alino is associated with and older than the Meratus Ophiolite, and was regarded as the oldest sedimentary unit in the Meratus Mountains. He considered the Alino to be of Jurassic age. Since then this Jurassic age for the Alino has frequently been adopted or quoted by people who worked on or wrote about the geology and tectonics of the Meratus Mountains.

The main evidence against a Jurassic age for the Alino Group, are:
1. contains fragments of Lower Cretaceous (Barremian-Aptian) limestone. The Alino Group must therefore be younger than Aptian.
2. Radiolarian cherts with Lower Cretaceous (Valanginian-Early Cenomanian) radiolaria indicate the age of the Alino deposit.
3. Since the Alino Group contains fragments of ophiolitic rocks (e.g. pyroxenite, dolerite, gabbro and radiolarian chert) it must be younger than emplacement of ophiolite.

On the basis of the above facts, it is clear that the Alino Group is younger than ophiolite and the Orbitolina limestone (Barremian-Aptian) because of their derived fragments. Radiolarians from the upper part of the Keramaian Formation are of Lower Cretaceous (Valanginian - Early Cenomanian) age. As conclusion, it is suggested that the age of the Alino Group ranges from Albian to Early Cenomanian. This is supported by K-Ar age 95 Ma on granite that intrudes the Alino Group. Such age is very important for establishing the date of commencement of major volcanism in the Meratus Mountains.
CHAPTER VI

MANUNGGUL GROUP: SEDIMENTARY AND VOLCANIC STRATA

1. **PAMALI FORMATION**: SANDSTONE, CONGLOMERATE AND MUDSTONE

2. **BENUARIAM FORMATION**: VOLCANICLASTIC DEPOSITS WITH MINOR LAVAS

3. **TABATAN FORMATION**: CONGLOMERATE AND SANDSTONE

4. **RANTAULAJUNG FORMATION**: ESTHERIID BLACK SHALE

5. **KAYUJOHARA FORMATION**: LAVAS AND PYROCLASTICS
6.1 Introduction

The rocks of the Manunggul Group were previously designated the Manunggul Formation by Koolhoven (1935). The type section was established by Koolhoven (1935) near the drowned village of Manunggul in the previously northern bank of the Sungai Riam Kanan, 26 km SE of the town of Martapura. Koolhoven (1935) recognised both sedimentary and volcanic facies in the Manunggul Sequence.

Hashimoto and Koike (1973) who worked just before the submergence of Manunggul Village by the Riam Kanan Reservoir (1972) raised the Manunggul Formation into group status. They subdivided the group into four formations (Table 4). But since then, this classification has been neglected by most workers. This is probably because of the following reasons:

1. all type localities of the four formations above were flooded by the reservoir soon after Hashimoto completed his field work;
2. rapid facies change of some of the proposed formations;
3. poor exposures or deep soil profiles; and
4. complicated relationships between sedimentary and volcanic extrusions and intrusions.

On the basis of present geological findings, obtained from a number of key geological traverses in the central part of the Meratus Mountains, the writer suggests that the term Manunggul Group, as proposed by Hashimoto and Koike (1973), should be accepted and employed. However, modifications are needed, particularly in relation to names, lithological characters and type sections of units of the group.

The aims of this chapter are to present new findings that redefine the stratigraphy of the group, to interpret the sedimentary environments and sources and to use these and other evidence to resolve the paleogeographic and tectonic history of the Manunggul Basin.
6.2 Definition

The Manunggul Group is proposed here to include all Upper Cretaceous sedimentary strata, andesitic lavas and pyroclastics, and associated volcanogenic sediments that occupy a trough like basin in the central axis of the Meratus Mountains. Rhyolitic volcanics which occur in and outside the basin are also included within the group.

The Manunggul Group is subdivided into five major units or formations which are herein informally defined (Table 4 and Fig. 131). The subdivision is solely based on the lithological changes, sedimentary structures and paleontological characteristics, using both already available and proposed names. In order to differentiate rock-units more clearly the petrographic characteristics of conglomerate and sandstone are also taken into account.

6.3 Occurrence

The Manunggul Group occupies a sedimentary basin which rests on and between rocks of the Meratus Ophiolite to the SE and the Tambak-Tamban Volcano-Plutonic Belt to the NW. The basin is also bounded to the SW by the Meratus Ophiolite, the Hauran Schist, the Paniungan Formation and the Alino Group. In the W it is partially overlain by the Tertiary sedimentary sequence of the Barito Basin (Fig. 131).

The Manunggul Basin can be divided into two subbasins: the Riam Kiwa and the Riam Kanan (Fig. 131). The former which occupies the northwestern half of the basin extends from the upper Sungai Riam Kiwa in the NE, to the area just S of the village of Abirau in the SW. Whilst the other, in the southeastern half of the basin, stretches from the Sungai Kusan in the NE to the Riam Kanan Reservoir in the SW. The Riam Kanan Subbasin is separated from the Riam Kiwa Subbasin by an uplifted thrust sheet of the ophiolite and associated rocks forming the Bobaris Range. These two subbasins converge to the NE of the range.
<table>
<thead>
<tr>
<th>PREVIOUS WORK</th>
<th>PRESENT WORK (Sikumbang, 1982 and in this thesis)</th>
<th>THICKNESS in metres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Koolhoven (1935)</td>
<td>RANTAU LAJUNG FORMATION</td>
<td>KAYUJOHARA VOLCANIC FORMATION</td>
</tr>
<tr>
<td>Hashimoto &amp; Koike (1973)</td>
<td>TABATAN FORMATION (sediments)</td>
<td>RANTAU LAJUNG FORMATION (sediments)</td>
</tr>
<tr>
<td></td>
<td>TABATAN FORMATION (sediments)</td>
<td>TABATAN FORMATION (sediments)</td>
</tr>
<tr>
<td></td>
<td>BENUARIAM FORMATION (volcanics)</td>
<td>BENUARIAM VOLCANIC FORMATION</td>
</tr>
<tr>
<td></td>
<td>KALAAN FORMATION (sediments)</td>
<td>KALAAN FORMATION (sediments)</td>
</tr>
<tr>
<td></td>
<td>BENUARIAM VOLCANIC FORMATION</td>
<td>BENUARIAM VOLCANIC FORMATION</td>
</tr>
<tr>
<td></td>
<td>PAMALI FORMATION (sediments)</td>
<td>PAMALI FORMATION (sediments)</td>
</tr>
</tbody>
</table>

Table 4. Stratigraphic nomenclature of the Manunggul Group.
FIG. 131 Simplified geological map showing distribution and subdivision of the Manunggul Group in the central axis of the Meratus Mountains. Geological traverses (in red), palaeontological and radiometric samples (diamond) are shown on the map. Previous palaeontological data are indicated by: HK (Hashimoto and Koike, 1973), K (Kobayashi, 1973), BS (Bona Situmorang, 1982), and RS (Rah Sukamoto, 1984).
The Manunggul Basin forms the largest, the thickest and the most continuous Pre-Tertiary sedimentary sequence in SE Kalimantan, with areal extent exceeding 85 km long and 35 km wide in the study area. The basin continues northeastward, as far as the Kotabaru (Rustandi et al, 1982) and Sampanahan (Supriatna et al, 1982) quadrangles.

Systematic geological mapping (Sikumbang et al, 1982), coupled with on the spot field observations (e.g. Sungai Pitanak suggest that the Manunggul Basin is bounded to the NW by a major strike-slip fault. The original extent of the Manunggul Group strata in the Riam Kiwa Subbasin is therefore reduced, by folding or faulting or combination of both. This is shown by steeply dipping sedimentary beds along the northern margin of the basin. In contrast, the rocks in the Riam Kanan Subbasin (e.g. Sungai Pamali, Mihak and Paau), with NE-SW trend and dip (17°-32°) toward the axis of the basin, are relatively unaffected by folding and faulting.

Stratigraphic contacts between the Manunggul Group and the underlying rocks can be seen in the upper Sungai Pamali and in a main southern tributary of the Sungai Paau where the lowest part of the group is marked by an ophiolitic rich sediment. Such stratigraphic relationships can also be observed in the upper Sungai Tabatan (approx. 1.5 km S of Puliin). Elsewhere such as in the Sungai Julung and the Tiwaang the contacts are obscured either by weathering, faults or igneous intrusions.

On the basis of the strike and dip of the sediments and outcrop width, the thickness of the Manunggul Group is approximately 1,000 m in the Riam Kanan Subbasin where it contains four lithostratigraphic units:

4. Rantaulajung Formation (<5 m estherid-bearing black shale).
3. Tabatan Formation (300 m polymictic conglomerate and sandstone);
2. Benuariam Formation (400 m volcaniclastic deposits and lava flows);
1. Pamali Formation (200 m ophiolitic sandstone and conglomerate);
In the Riam Kiwa Subbasin the group is estimated to be in the order of 1,500 m and 2,000 m in the SW (i.e. Sungai Paning-Paning) and it grades northward into a thick (approx. 5,000 m) sequence of sandstone turbidites in the NE (i.e. Sungai Pitanak). The subbasin contains two units, the Pamali and Kayujohara Formations (Fig. 131).

Detailed field descriptions and discussion of each subbasin, together with their sedimentological and structural characteristics, are given below.

6.4 Subdivision of the Manunggul Group

6.4.1 Southern Portion of the Manunggul Basin – Riam Kanan Subbasin

The general location of the Riam Kanan Subbasin to the surrounding tectonic terrains can be seen in Fig. 131. Part of the Manunggul strata in the northern subbasin (e.g. Fig. 132) has been intruded by a number of microdioritic dykes or sills.

The geological traverses in this subbasin were concentrated in the following rivers: Pamali, Julung, Tiwaang and Paau. The first three traverses are on the southern foothills of the Bobaris Range. These rivers, perpendicular to the trend of the range, drain to the Sungai Malinau and then flow to the Riam Kanan Reservoir. Whilst the Paau River, on the northern foothills of the Manjam Range, flows in the opposite direction to the Sungai Pamali, but it also enters the Riam Kanan.

Four out of five formations of the Manunggul Group occur in the Riam Kanan Subbasin: 1. Pamali, 2. Benuariam, 3. Tabatan, and 4. Rantaulajung Formations. Each of these are described and discussed in the following section.
6.4.2 Northern Portion of the Manunggul Basin - Riam Kiwa Subbasin

The subbasin (Fig. 131), elongate in shape, forms the northern half of the Manunggul Basin. The length of this subbasin in the area studied is approximately 64 km and the width ranges from 1.5-8 km. The subbasin is parallel to the Riam Kanan Subbasin. Correlation between the Riam Kiwa and the Riam Kanan subbasins is based on lithological similarity, paleontological data and environmental interpretation.

A number of rivers from the Bobaris Range flow northwestward into the southern subbasin. Whilst in the N the subbasin is crossed, in eastward direction, by rivers from the Tambak-Tamban Range. All of these rivers are perpendicular to the long axis of the subbasin (Fig. 131).

In the southern Riam Kiwa subbasin, most of the beds dip steeply inward forming a simple syncline between the ophiolite and associated rocks in the SE and the volcano-plutonic belt and Alino Group in the NW. Variations in strike and dip are found along the southeastern margin of the subbasin.

In the northern portion of the subbasin the beds trend uniformly northeast-southwestward, with the dip ranging from 65° to 88°. They are sub-parallel to the general trend of the Sungai Riam Kiwa. In this area the rocks are folded against the Tambak-Tamban Range to the NW. As in the Riam Kanan Subbasin, the sedimentary strata here have been complicated by extrusion and intrusion of intermediate volcanic rocks, as shown by the outcrops in the Bukit Keminting and E of Pengaron (Fig. 131).

Due to deep weathering, caused by the morphology of the hill slopes, it is difficult to find good exposures. The best and most complete exposures, however, can be seen along four river traverses, transversely across the Riam Kiwa Subbasin, where the relationship of
the formation to adjacent rock-units is shown clearly on the subbasin margins. They are Paning-Paning and Tambulihin in the southern subbasin, and in the N the Pitanak and Hananai Traverses.

6.5 **Pamali Formation**

6.5.1 **Name and Type Section**

The Pamali Formation, named from the Sungai Pamali, is defined as the rocks immediately overlying a complicated Pre-Tertiary tectonic complex in SE Kalimantan. This is equivalent to Kalaan Formation of Hashimoto and Koike (1973). There are a number of reasons for dropping the name Kalaan and instead re-introducing the Pamali of Koolhoven (1935). Among the reasons are:

1. the type locality in the Sungai Pamali can still be observed or revisited for the purpose of comparison or correlation (standardisation) of the lithological and sedimentological characters together with fossil content, while Kalaan has been drowned by the Riam Kanan dam.

2. An honour to the thorough and excellent geological work of Koolhoven (1933 and 1935) who was first to introduce the name, though it was initially intended for describing "diamond-bearing breccia";

3. the name Pamali ("Pamali breccia") has been widely known both in published and unpublished literature;

4. to redefine and upgrade the "Pamali breccia".

The Pamali Formation is a very important unit in the study area as it represents the basal unit of the Manunggul Group and it also can be used to define the minimum age for the emplacement of the Meratus Ophiolite and its associated rocks (Chapter VIII).
A type section is proposed in the upper Sungai Pamali, that is on the southern foothills of the Bobaris Range (Fig. 132). The formation in this locality is partly underlain by ultramafics of the Meratus Ophiolite and partly by metamorphics of the Hauran Schist (Fig. 131), and is intruded by numerous intrusions of microdiorite. Another section where the Pamali Formation shows good relationships with both the underlying and overlying rock-units, is in a southerly tributary of the Sungai Paau, in the northern foothills of the Manjam Ophiolite Range.

6.5.2 Description of Lithology and Interpretation

The formation is represented by four lithologies, conglomerate, pebbly sandstone, sandstone and mudstone. The first two are commonly found in the southwestern portion of both the Riam Kanan and Riam Kiwa subbasins (see below). In addition, limestone (micrite and calcarenite) is occasionally present within sandstone and mudstone sections.

Because of the difficulty in finding good outcrops along the rivers traversed, the precise stratigraphic subdivision of the Pamali Formation cannot be established. However, on the basis of field observation in a number of localities (Fig. 131), the sequence of the Pamali Formation in these two subbasins can be generalised as follows.

6.5.2.1 Riam Kanan Subbasin

There are two members present within the formation in the Riam Kanan Subbasin, the Lower Member and the Upper Member.

A.1 Lower Member

The Lower Member of the Pamali Formation, characterised by ophiolithic-volcanic conglomerate and sandstone; muddy sandstone and mudstone; crops out in the upper Sungai Pamali (i.e. in the northern subbasin, Figs. 132 to 134) and in the upper tributary of the Sungai
Paau (in the southern subbasin, Figs. 135 to 138). Although the rocks in the lower part of member are weathered and poorly exposed the lower contact between the Lower Member and the underlying Meratus Ophiolite is still recognisable in these two rivers, in particular in the Sungai Paau (Fig. 135).

The upper contact of the Lower Member is designated at the locality where Hashimoto and Koike (1973) placed the unconformable boundary of Paniungan and Manunggul Formations. The present writer found that there is no evidence of unconformity at this locality. As far as lithological characteristics and the mappability of the rock units are concerned, the writer considers all the rocks exposed in the Sungai Pamali belong to the Pamali Formation of the Manunggul Group. Thus the upper contact of the Lower Member is defined here as a conformable boundary.

There are five lithologies recognised in the Lower Member: 1. conglomerate, 2. pebbly sandstone, 3. sandstone, 4. calcarenite and 5. mudstone. The first two are commonly found in the Sungai Pamali, whereas the third occurs in many parts of the subbasin. The latter is mainly found in the northern part of the subbasin, e.g. Sungai Pamali, Tiwaang and Julung.

**Conglomerate**

Conglomerate occurs as the lowest part of the Lower Member in the Sungai Pamali (NS-853, Fig. 132). The section is over 10 m thick, and consists of olive black (5 Y 2/1) densely packed and crudely fining upward mafic–ultramafic (ophiolite)–volcanic pebbly conglomerate (Figs. 133 and 134). The conglomerate is associated with pebbly sandstone. These ophiolitic-volcanic clastic deposits were previously described as the "Pamali diamond pipe" (i.e. "Pamali breccia") by Koolhoven (1933 and 1935).
FIG. 132. Simplified geological map along Sungai Pamali, a northern tributary of the Sungai Riam Kanan (modified from Koolhoven, 1935).
Fig. 133 View showing part of the southeastern foothills of the Bobaris Range (Ophiolite) where the Sungai Pamali flows (i.e. about 150 m to the left) and the type section of the Pamali Formation is established. Note diamond pit of Koolhoven (1933 and 1935) is near the tree (centre).

Fig. 134 Close-view of ophiolitic pebbly conglomerate in the lower part of the Pamali Formation, Sungai Pamali (NS-853). Note the clasts are subrounded to angular, poorly sorted and are set in a semi consolidated ophiolitic sand matrix.
FIG. 135. GEOLOGICAL TRAVERSE ALONG THE UPPER COURSE OF SUNGAI PAMU, IN THE NORTHERN FOOTHILLS OF THE MANIAN RANGE. FEBBLE COUNTS ON SEVERAL CONGLOMERATE BANDS ARE SHOWN IN THE FIGURE.

KEY TO SYMBOLS

- **Conglomerate**
- **Pebby Sandstone**
- **Sandstone**
- **Lava Flow**
- **Tabatan Formation**
- **Benuxam Formation**
- **Pamali Formation**
- **Meratus Ophiolite**
- **Granite**
- **Volcanics**
- **Chert**
- **Limestone**
- **Schist**
- **Diorite**
- **Gabbro**
- **Ultramafics**
**Lithologic Description**

- **Graded pebbly sandstone and pebbly conglomerate beds, normal to inversely-normally graded, well sorted, calcium carbonate cemented, with parallel laminated sandstone in the upper part of the bed. Occasionally x-beds are also present.**

- **Clast-supported conglomerate, commonly equant, and well sorted. Over 90% of the clasts are limestone.**

- **Graded pebbly sandstone, clast-supported in lower part, and matrix-supported in upper half, rounded-subrounded, showing parallel to very low angle stratification in upper half. Base is not sharp. Inversely-normally graded sandstone, coarse-very coarse grained, with some pebbles, subangular-angular. Inversely-normally graded sandstone, medium-coarse to granule grade, angular. The sandstone is faintly laminated in the upper part, with rare quartz fragments (up to 3 cm in size).**

- **Nodular sandstone beds, light olive grey (5Y 3/2), poorly-to very poorly sorted, pebbly sandstone (up to 2 cm in diameter) in the lower part of the bed. Most of the detritus consist of ultramafic fragments, gastropods, and limestone concretions are common in the upper half of the bed.**

- **Muddy sandstone, olive black (5Y 2/1), non-calcareous, pyrite in fractures & chambers, erudelygraded, granular at base, poorly exposed, with many bivalves and gastropods floating in the sandstone.**

- **Sickly bedded sandstones, weathered, medium-coarse grained, and very coarse to granule grade in the lower part of the bed. They are poorly sorted, containing many fragments of ophiolitic rocks, with common gastropods and bivalves.**

- **Thickly bedded sandstones, weathered, medium-coarse grained, and very coarse to granule grade in the lower part of the bed. They are poorly sorted, containing many fragments of ophiolitic rocks, with common gastropods and bivalves. Weathered layered serpentinised peridotite, cross-cut by numerous quartz veins.**

---

**FIG. 136 Generalised stratigraphic section of the Pamali Formation (the lowest unit of the Manunggul Group), exposed along the right tributary of Sungai Pau (see Fig. 131 for the exact location). Key to symbols:**

- **Cross bedding**
- **Parallel Lamination**
- **Nodular structure**
- **Macrofossils**
- **Bivalve**
- **Gastropod**
- **Pebble Count**

**Key to Symbols:**

- NS-590 Sample locality

---

263
Fig. 137 Thick bedded sandstone of the Lower Member of the Pamali Formation exposed along the road cut at Locality NS-581, north-east of the Sungai Paau. Note pebbles are dispersed in the sandstone. Clasts are composed predominantly of mafic (i.e. gabbro, dolerite and basalt) and ultramafic (i.e. peridotite and serpentinite) rocks, limestone and radiolarian chert. Exposure of the Meratus Ophiolite is out of view to the right of the photograph.

Fig. 138 Pebble concentration in the sandstone of the above photograph, forming quite conspicuous sedimentary layering in the surrounding rock. Locality NS-581.
The clasts of the coarse clastic deposits are rounded to subrounded in shape, poorly to very poorly sorted and displaying chaotic fabric, fine to coarse pebble sized. They are made up largely of serpentinised peridotite, pyroxenite, serpentinite, lithic volcanics (i.e. PX-phyric andesite and rare crystal tuff), with minor constituents of gabbro, diorite, schist, basalt, limestone and skeletal debris (e.g. Orbitolina and molluscan shells), PL, QZ (i.e. undulose mono- and polycrystalline quartz) and PX. The matrix may be classified as coarse to medium poorly sorted ophiolitic sands, which are commonly cemented by either Fe-oxide or calcium carbonate.

**Pebbly Sandstone**

Pebbly sandstone is found both in the Sungai Pamali and Paau. In the Sungai Pamali, the pebbly sandstone is closely associated with the conglomerate described above, thus its lithological and textural characteristics are referred to those of the conglomerate (see above). The pebbly sandstone in the Sungai Paau area is represented by the exposures at locality NS-581 (Figs. 137 and 138), approximately 2.5 km NE of the Paau River section (NS-586 and NS-587). The rocks there are greyish brown (5 YR 3/2) in colour and consist of thick to very thick interbedded pebbly sandstone; the pebbles normally form layers (Fig. 138). Vertically the clasts are arranged with inverse or normal grading, intermixed with coarse to very coarse sands and sandy granules. These clasts (include granules) are poorly sorted, show no imbrication, and are composed predominantly of mafic (i.e. gabbro, basalt and dolerite) and ultramafic (i.e. sepetinised periodotite and serpentinite) rocks, with significant amounts of light coloured limestone and reddish brown radiolarian chert (NS-581).
Sandstone

Sandstone is the commonest rock type found so far in the Lower Member. It crops out in the following rivers: Pamali, Tiwaang, Julung and Paau.

The sandstone is commonly thickly bedded, medium to coarse grained, non-calcareous to calcareous, with common granules and fine pebbles in the lower part of the bed (Fig. 136). They are normally light olive grey (5 Y 6/1) to olive grey (5 Y 3/2), poorly sorted and commonly containing gastropods and bivalves. Individual beds range from 35 cm - 2 m in thickness, of which the thicker beds (1.8 - 2 m) occur in the upper part of the member. Other sedimentological attributes are shown in Figs. 132, 135 and 136.

Calcarenite

Calcarenite (terrigenous limestone) is only found in the Sungai Paau. It normally occurs in the form of nodules in the upper part of the Lower Member (Fig. 136). These nodules are regularly dispersed throughout the calcareous sandstone, lenticular or kidney shaped, subrounded to angular, and ranging in size from a few cm up to 16 cm in diameter. They are olive grey (5 Y 3/2) to olive black (5 Y 2/1) in colour and are aligned sub-parallel to bedding.

Mudstone

Mudstone generally occurs as interbeds within the sandstone section, for instance in the Sungai Pamali (Fig. 132) and in the Sungai Julung (Fig. 140). No mudstone has been observed in the Sungai Paau.

The mudstone is generally affected by weathering or leaching, and is poorly exposed. In the Sungai Pamali the mudstone contains considerable amounts of juvenile mollusc fossil. Some foraminifers from this locality have previously been recorded by Hashimoto and Koike (1973).
FIG. 139. Geological traverse along Sungai Julung, in the southern foothills of the Bobaris Range. Outcrops of the Pamali Formation and their relationships with other rock-units are shown in the figure.

KEY TO SYMBOLS

- **Microdiorite 65.3 m.y (NS-670)**
- **Andesitic lavas and breccias**
- **Sandstone**
- **Paniungan Formation**
- **Meratus Ophiolite**
- **Fault**
- **Tributary**
- **Molluscan fossils**

**Sample Localities**

- NS-660
- NS-663
- NS-664
- NS-668
- NS-669
- NS-662
- NS-665
- NS-667
- NS-666

**Measurement**

- 10 cm
- 20 cm
- 40 cm
- 80 cm
FIG. 140 Geological traverse along Sungai Tiwaang, in the southern foothills of the Bobaris Range. Outcrops of the Pamali Formation and their relationships with other rock-units are shown in the figure.

KEY TO SYMBOLS

- Microdiorite
- Andesitic lavas and breccias
- Sandstone
- Panungian Formation
- Meratus Ophiolite

- Lithological boundaries
- Fault
- Sample Locality

KEY MAP

- Sungai Tiwaang Traverse
- Ophiolite

JAVA SEA

Molluscan fossils
Fossils

Gastropods and bivalves are very common in the Lower Member (NS-587, see Figs. 135 and 136 for sample locality). These were identified by Drs N J Morris and R Cleevely of the British Museum as follows (Figs. 141 and 142):

Gastropoda:  ?Cylindrites sp.
"Actaeonella" sp.
Actaeonella/Cylindrites
Pygnellus
?Procerithid
Nerinaeid
?Procerithid with small Pyrazus-like axial ribs and

?Veneridae (2 genera) and
?Astartidae

According to Drs Morris and Cleevely, these fossils are typical of the Upper Cretaceous throughout the world, particularly Acteonella (Trochactaean) solomonis Frans from Egypt occurs in rocks said to be of Turonian Age (Abbas, 1963, person. comm. with Drs Morris and Cleevely).

A.2 Upper Member

The Upper Member of the Pamali Formation comprises three main lithologies, pebbly conglomerate, granular or pebbly sandstone and mudstone. The first two are present both in the northern and southern parts of the Riam Kanan Subbasin. Whilst the latter is mainly found in the northern part of the subbasin, particularly in the Sungai Pamali. Their stratigraphic position, together with sedimentological characters are shown in Figs. 135 and 136.
at 20°C

Fig. 141 *Cylindrites* sp. occurring in the Lower Member of the Pamali Formation. Locality NS-587, Sungai Paau.

Fig. 142 *Actaeonella/Cylindrites* from the Lower Member of the Pamali Formation. Locality as above.
Conglomerate and Pebbly Sandstone

Conglomerate and pebbly sandstone occur as a thick bedded coarse grained sedimentary sequence both in the Sungai Pamali and Paau (Figs. 132 and 136). Figs. 143 and 144 show the main textural and compositional characteristics of these deposits.

In the southern part of the basin conglomerate and pebbly sandstone extend laterally from the SW to the NE. Apart from the section in the Sungai Paau, exposures can also be observed in the Upper Sungai Hajawa and Tabatan.

In the Sungai Pamali, conglomerate and pebbly sandstone occur in the basal portion of the member, characterised by a thick bed (4-6 m thick) of conglomerate (Fig. 143). The conglomerate is clast-supported and is composed of at least 70% quartzite and schist detritus. Other constituents include mafic-ultramafic and intermediate volcanic lithic fragments. Limestone is also present in small amounts. The fragments range from pebble to cobble sized (up to 45 cm in diameter), are poorly sorted, and vary in shape from round to angular. The sand matrix is approximately 10-20% of the rock volume. Although the conglomerate has a chaotic fabric, some elongate clasts tend to have long axes parallel to the stratification within the adjacent strata (i.e. pebbly sandstone, see below).

Stratigraphically, the pebbly sandstone occurs just a few metres above the conglomerate. It is exposed in a very small area, less than 2 x 4 m in extent, and is characterised by having poor stratification, crude graded bedding, olive grey (5 Y 3/2) colour, coarse to very coarse sand size and is poorly sorted. The pebbles in this bed comprise rock types similar to the underlying conglomerate, of which the commonest clasts are metamorphics (i.e. muscovite quartzite, QZ-MV-GR schist and HB schist or amphibolite).
Fig. 143  Very coarse pebbly conglomerate, showing texture (i.e. rounded subangular and poorly sorted), fabric (clast to matrix supported) and monomictic (schist) composition. Note the clasts are elongate in shape. Sungai Pamali.

Fig. 144  Crude graded pebbly conglomerate, poorly sorted and well cemented, Pamali Formation, Sungai Paau. The pebbles are made up of various types of limestone (e.g. bioclastic packstone and grainstone and radiolarian sponge spicular wackestone), with a mixture of ophiolitic rocks (e.g. gabbro, dolerite, basalt and peridotite), porphyritic volcanics (e.g. andesite), schist, granite ("adamellite") and some reddish brown radiolarian chert. Pebble count analysis near this photograph (NS-591) is shown in Fig. 135.
In the Sungai Paau conglomerate and pebbly sandstone are thick to very thick bedded, moderately to highly indurated and exhibit horizontal to cross-stratification. These pebbly conglomerates and pebbly sandstones, in general coarsen and thicken upward. Field observation suggests that the clasts increase in size with decreasing sand matrix. The coarsest and the thickest beds can be seen in Fig. 136. Cross-beds, i.e. between Locality NS-590 and NS-591, in this Upper Member are all planar, with foreset beds dipping at about 15°-20° to the N. Beds range from a few tens of centimetres in thickness to 2.5 m. Sedimentary structures include massive to stratified bedding, inverse to normal grading and in some cases low-angle cross bedding and channel structures.

The clasts of these coarse clastic deposits are either set in a sand matrix (matrix-supported) or in contact with each other (clast-supported), composed mainly of the same composition as those of the matrix with which they are associated. The sand matrix is composed of a mixture of limestone and associated with gabbro, basalt, dolerite, diorite, peridotite, granite, porphyritic andesite and reddish brown radiolarian chert. Both the clasts and the matrix are cemented by calcium carbonate.

Nearly all of the clasts are rounded to subrounded and poorly sorted. Volcanic clasts are round to angular and most of them are poorly to very poorly sorted. The type of the clasts include porphyritic and amygdaloidal andesite, amygdaloidal microlitic lava, dacite, and in addition andesitic pyroclastic debris. Plutonic clasts include gabbro, medium grained diorite and granite. Dolerite, basalt and tectonised peridotite also occur as clasts.

In the Sungai Tabatan the coarse clastic deposits are clast to matrix supported, subangular to angular, with poor sorting. They differ in composition from those of the Sungai Paau. The clasts in
the Sungai Tabatan are composed mainly of mafic and leucocratic rocks of the Meratus Ophiolite and intermediate volcanic rocks. The matrices have the same composition as the clasts with which they are associated. Unlike those seen in the Sungai Paau, the coarse clastic deposits here are not cemented by calcium carbonate, and furthermore, no fossils have been found at this locality.

Molluscan fossils, i.e. bivalve and gastropoda are also common in the Sungai Pamali. One of the gastropods closely resemble *Cylindrites* sp. that occurs in the Sungai Paau, thus indicating a Turonian age (Fig. 132, see Fig. 141 for comparison).

A.3 *Petrography*

Thin sections of sandstones from river sections in the Riam Kanan Subbasin (for the Riam Kiwa Subbasin see Section B) were petrographically examined. These sandstone samples are from the Sungai Pamali (e.g. NS-853), the Sungai Julung (NS-663 to NS-666) and the Sungai Tiwaang (e.g. NS-686) in the northern subbasin, and the Sungai Paau (NS-586C, NS-587B, NS-587D, NS-587E, NS-589 and NS-590) and the Sungai Tabatan (NS-705) in the southern subbasin. Due to intermittent outcrops, poor exposures and thick soil profiles, vertical variation of the sandstone compositions can only be examined in the Sungai Paau (see Fig. 136).

Most of these rocks have not been subjected to deformation or post-depositional alteration (diagenesis and metamorphism), except samples from near faults or igneous intrusions (i.e. microdiorite).

Typically, the sandstones from the southern Riam Kanan subbasin (e.g. Sungai Paau) are medium to very coarse grained, angular to very angular and poorly to very poorly sorted. They are all cemented by calcium carbonate and are lithic to arkosic lithic composition. Representative photomicrographs of these sandstones are shown in Fig. 145 to 148. Their modal analysis are tabulated in Table 5.
<table>
<thead>
<tr>
<th>STUDIED SAMPLES</th>
<th>ROCK TYPE</th>
<th>TEXTURE</th>
<th>QUARTZ</th>
<th>FELDSPAR</th>
<th>CLAY</th>
<th>LITHIC</th>
<th>FRAGMENTS</th>
<th>BIOLASTIC FRAGMENTS</th>
<th>CEMENT</th>
<th>MATRIX</th>
<th>FORMATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUNGAI TAMAN</td>
<td>Arkoetic</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>15</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>586c.</td>
<td>Ultrafels</td>
<td>0.25</td>
<td>s.a.r</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>SUNGAI TAMAN</td>
<td>Oligotic</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>587b</td>
<td>Ultrafels</td>
<td>0.25</td>
<td>s.a.r</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>SUNGAI TAMAN</td>
<td>Ultrafels</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>587d</td>
<td>Ultrafels</td>
<td>0.25</td>
<td>s.a.r</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>SUNGAI TAMAN</td>
<td>Oligotic</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>587e</td>
<td>Ultrafels</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>SUNGAI TAMAN</td>
<td>Ultrafels</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>589</td>
<td>Ultrafels</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>SUNGAI TAMAN</td>
<td>Oligotic</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>590</td>
<td>Ultrafels</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>SUNGAI TAMAN</td>
<td>Arkoetic</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>705</td>
<td>Ultrafels</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>SUNGAI TAMAN</td>
<td>Oligotic</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>853</td>
<td>Ultrafels</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>SUNGAI TAMAN</td>
<td>Oligotic</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>863</td>
<td>Ultrafels</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>SUNGAI TAMAN</td>
<td>Oligotic</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>865</td>
<td>Ultrafels</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>SUNGAI TAMAN</td>
<td>Oligotic</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>866</td>
<td>Ultrafels</td>
<td>0.1-</td>
<td>a-v.a.</td>
<td>p.s.</td>
<td>10</td>
<td>Tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 5. Modal analyses of representative samples from the sandstones of the Fajum Formation in the Rama Kanana Subbasin. Abbreviation: m=matrix-supported; g=g grain-supported; a-angular; n=angular; s=rounded; r=rounded; p=poorly sorted; v=very poorly sorted; w=well sorted; m=moderately well sorted; s=well sorted; w=well sorted; mon=monocrystalline; pol=polygonal; pl=plagioclase; K=F=K-feldspar; vol=volcanic; maf=mafic; sm=smectite; c=clay; s=carbonate; f=flaxtonic; b=benthonic; bry=bryozoa; ech=echinoderms; for=former; min=former; spar sp=sparry calcrite; fer mud=ferro-mud; terr=terrestrial mud; q=quartz; cc=calcium carbonate.
Fig. 145  Calcareous litharenite of the Pamali Formation from the upper course of Sungai Pamali, showing poor sorting, micrite-sparry calcite cement, with terrigenous composition: altered ultramafic (upper and lower left and centre), volcanic (upper centre and lower right), plagioclase (grey), quartz (white) and pyroxene (yellowish orange). Bar scale 1 mm.

Fig. 146  Photomicrograph showing transported Orbitolina fossil in the calcareous litharenite of the Pamali Formation, Sungai Pamali. Bar scale 1 mm.
Fig. 147 Arkosic plutarenite from the upper course of Sungai Tabatan showing poor sorting, fabric and major (e.g. granite, diorite and quartz) and minor (e.g. volcanic, gabbro and ultramafic) constituents. XPL. Bar scale 1 mm.

Fig. 148 Oolitic terrigenous calcarenite from the Sungai Julung, showing rather well sorting, terrigenous (e.g. quartz, plagioclase, and altered volcanic) and unidentified carbonate grains. Many of terrigenous and carbonate grains are coated by iron-rich micrite cement. XPL. Bar scale 1 mm.
The sandstones are composed of serpentinised peridotite (2-55%), undulose monocrystalline QZ (5-18%), PL (3-6%) and schist (2-6%). Limestone and fossil fragments occur in some samples (e.g. NS-587E, NS-589 and NS-590). Other constituents such as PX, muscovite and radiolarian chert can be seen (Table 5). Plant fragments occur in Sample NS-587E. Although many of them are not well preserved, a few fragments still show cell structures which is characteristic of angiosperms. The rocks are classified as ultramafarenite, arkosic ultramafarenite, oolitic arkosic ultramafarenite and oolitic terrigenous calcarenite (Table 5).

The sandstones become arkosic plutarenite towards the SW of the southern Riam Kanan Subbasin (i.e. Sungai Tabatan). Furthermore, in the present Sungai Kalaan, the sandstone is composed predominantly of schist, diorite, gabbro and granite. This is compatible with the composition of conglomerate that has been reported by Hashimoto and Koike (1973) from the submerged part of Sungai Kalaan.

In the Sungai Paaau section, the sandstones towards the top (see Fig. 136 and Table 5) become calcareous and oolitic, whereas the ultramafic content decreases with increasing fossil fragments and calcium carbonate cement (i.e. micrite and sparry calcite).

Sandstones from the northern Riam Kanan Subbasin show slight differences from those in the southern subbasin. They are characterised by abundant volcanic fragments (12-50%) and undulose monocrystalline QZ (2-20%). Ultramafic detritus, which is the most characteristic and dominant constituent in the lower part of the formation in the southern subbasin, only occurs in the Sungai Pamali (e.g. NS-853). The ultramafic detritus there make up about 19% of the thin section (Fig. 145 and Table 5). Despite the differences noted above, other constituents are quite similar to those observed in the southern Riam Kanan Subbasin (see Table 5). The sandstones here are
classified as calcareous litharenite (NS-853), calcareous arkosic volcarenite (NS-663 and NS-686), oolitic terrigenous calcarenite (NS-665), PX-rich volcarenite (NS-665 2) and calcareous lithic arkose (NS-686).

A.4 Environment of Deposition

On the basis of lithological and sedimentological characteristics, as presented in the preceding subsection, the Pamali Formation in the Riam Kanan Subbasin is interpreted as having been deposited in a shallow marine environment. Shallow water macrofaunas such as bivalves and gastropods which occur in a number of localities and in several stratigraphic horizons in the subbasin (see Figs 131, 132 and 135) strongly support this interpretation. Moreover the occurrence of oolitic calcareous sandstone/calcarenite, as was observed for instance in the Sungai Paau and Sungai Julung, is consistent with lagoonal sedimentation. An alluvial coastal environment is suggested for non calcareous and unfossiliferous sedimentary strata, in particular for the area in and around Sungai Kalaan in the southwestern portion of the subbasin.

As shown in Fig. 131, the formation is surrounded by complexly deformed Lower Cretaceous rocks that consist of the following assemblages:

1. an ophiolite (ultramafic rocks, gabbro and dolerite in the N, S and NE, belonging to the Meratus Ophiolite;

2. a metamorphic terrain (e.g. QZ-MV-EP-GR-schist and HB-EP-schist in the SW and partially in the S, belonging to the Hauran Schist;

3. volcaniclastic deposits and radiolarian cherts, belonging to the Alino Group; and
4. slices of calcareous mudstone and sandstone, and limestone occurring as tectonic inclusions within a complex of the three terrains above in the N and S, belonging to the Paniungan and Batununggal Formations, respectively.

All of the sedimentary detritus in the formation can satisfactorily be matched and therefore derived from these four major terrains (see below). The environment of deposition was controlled by the paleomorphology and tectonic setting defined by the terrains above.

Evidence from the composition of terrigenous detritus, together with the presence of angiosperm fragments suggest that Pamali sedimentation followed a break in sedimentation, probably after global sea level changes or major unconformity in early Upper Cretaceous (Cenomanian) time (cf. Vail et al., 1977). Such inference corresponds well with the given age of the Pamali Formation, which has been dated as early to middle Upper Cretaceous (see Subsection on Age below).

In the Sungai Paau section (Fig. 136), it can be seen that a vertical increase in grain size and bed thickness is evident, suggesting a change from low to higher energy environment. This coarsening and thickening sequence can be explained by: 1. active uplift in the source terrains; 2. uplift more rapid than erosion; 3. faulting along adjacent mountain front or basin margin; or 4. a combination of 1, 2 and 3. Overall the sediments, in the form of gravel, sand, silt and mud, which compose the Pamali, are interpreted to have flowed from three directions: 1. the SW, 2. the S and 3. the E, as can be envisaged in Fig. 185 (Section 6.5.4).

6.5.2.2 Riam Kiwa Subbasin

Due to poor exposures and limited time available in the field it has not been possible to describe a complete stratigraphic sequence of the Pamali Formation in the Riam Kiwa Subbasin. However, there are
two main lithological associations (facies) recognised: 1. sandstone and mudstone, and 2. conglomerate and sandstone. Each of these lithological associations has its own sedimentary characteristics and occurs at a different stratigraphic level.

The sandstone and mudstone association was observed in three places in the southwestern Riam Kiwa Subbasin:

1. in the upper Sungai Paning-Paning (NS-776 and NS-777, Fig. 149);
2. in the lower course of the Sungai Tambulihin (Fig. 150); and
3. in a road section near the upstream tributary of the Sungai Tambulihin (Locality NS-773, Fig. 153).

Elsewhere the rocks are obscured by weathering, faulting or Tertiary sedimentary cover. In the northeastern subbasin, represented by the outcrops along the Sungai Pitanak and Hananai, the sandstone and mudstone association is present throughout the exposed section of the formation.

The conglomerate and sandstone association, occasionally with mudstone intercalations, occurs as a thick coarse grained sedimentary sequence in the southwestern Riam Kiwa Subbasin, forming about 800 m in the Sungai Paning-Paning and over 2000 m in the Sungai Tambulihin (Figs. 149 and 150). Stratigraphically, the conglomerate and sandstone association occupies the upper part of the formation. In contrast, the conglomerate and sandstone association in the northeastern subbasin is relatively thin (approx. 300 m) compared to that of the southwestern counterpart, occurring as an intercalation or perhaps as a single channel fill in the sandstone and mudstone sequence.
B.1 Sungai Paning-Paning and Tambulihin

1. Sandstone and Mudstone Association

1.a Description

The sandstone and mudstone association normally occurs at the exposed margin of the subbasin both in the NW and SE, thus it represents the lower part of the formation. The rocks of this association are cut by faults against the ophiolite in the SE and the Alino Group in the NW (e.g. Fig. 149). No stratigraphic contact between these sediments and the underlying rocks was observed.

Most of the sandstone and mudstone association can be described in terms of the classical turbidite divisions of the Bouma sequence (1962). The sandstone is characterised by graded (Bouma A) and laminated (Bouma B) sandstone, with or without mudstone (Bouma E) in its upper portion. The most frequent turbidite sequences present are of AE, BE, AB and ABE.

In the northwestern margin of the subbasin, as shown by exposures in the lower Sungai Tambulihin (Fig. 150), the sandstone and mudstone association is made up of interbedded medium grained to very fine grained sandstone and mudstone laminae (1 mm - 5 mm). The beds all dip steeply (54° - 80°) toward the SE, with bed thicknesses ranging from 2.5 cm to 16 cm thick. Many of these beds, however, are of the order of 10 cm to 16 cm. The sand : mud ratio is estimated to be greater than 10 : 1. Most sandstone beds have sharp bases, are crudely graded or occasionally inversely graded, and begin with Bouma A or B (Figs. 150 and 151). They are commonly intercalated with thick beds of laminated or massive mudstone (Fig. 152). Some of the mudstones contain bivalves, gastropods and fragments of shell and bryozoa (e.g. NS-760).
FIG. 149 Geological traverse in the upper Bungai Paning-Paning in the northern foothills of the Bobaris Range. Outcrops of the Panam Formation are scattered along the river.
FIG. 150 Geological traverse in Sungai Tumbiluhin, showing outcrops of the Pamali Formation. See Fig. for explanation.
Fig. 151 Exposure of sandstone in the lower course of Sungai Tambulihin, showing repetition of graded sandstone beds (Bouma A) with laminated sandstone (Bouma B) or structureless thin laminae of mudstone (Bouma E) on their overlying lithology. Locality NS-758. Section youngs to the right. Strike and dip of the beds is 46/50 SE.

Fig. 152 Finely laminated mudstone exposed in the lower course of Sungai Tambulihin. In part, the laminae, in particular in the lower part of the bed, have been destroyed by burrowing organisms.
The sandstone and mudstone association in the upper Sungai Paning-Paning (NS-776 and NS-777) and in a road cut near the Sungai Tambulihin (NS-773), which both occur along the foot of the Bobarjis Range, represent the southeastern margin of the Riam Kiwa Subbasin. In the latter, although the sandstone and mudstone exposures are deeply weathered, sedimentary structures are still preserved throughout the measured section (Figs 153 and 154). The sandstone beds vary in grain size, from fine to very coarse grained, and are frequently inversely to normally graded, with conspicuous granules or pebbles at the base. Bouma sequences beginning with the A division are more frequent than those beginning with the B or C division. Some start with a C division. In a few cases an incomplete Bouma sequence ABC, ABE and CDE was observed (Fig. 154). The sand : mud ratio varies greatly from bed to bed, ranging from 1 cm to nearly 4 m thick (e.g. NS-773D and NS-773 O and P).

At locality NS-737, NS-776 and NS-777 (Fig. 154), the sandstone beds occur as tectonic slab between two bodies of highly foliated and sheared serpentinite of the Meratus Ophiolite. Further downstream, similar kinds of sandstones are in depositional contact with conglomerate (see below). Here the sandstones are frequently calcareous, hard and cemented, very thinly to thinly bedded, in which nearly all the beds are made up of an alternation of graded sandstone (Bouma A, light grey N7 to medium dark grey N4) and thin laminae (2 mm) mudstone (Bouma E). Very thin layers of limestone or fine grained terrigenous calcarenite (NS-776D) are present as rare intercalations. The thickness of individual beds in these sandstones is variable, but the beds are rarely thicker than 10 cm (Fig. 149).
Fig. 153 Interbedded sandstone and mudstone of the Pamali Formation in the southeastern portion of the Riam Kiwa Subbasin (locality NS-773). Section youngs to the right. Measured section is shown in Fig. 160.
FIG. 154 Measured section of sandstone turbidite in the southern Riam Kiwa subbasin, illustrating changes in lithology and sedimentary structure. Locality NS-773, in the road cut between the upstream tributary of Sungai Tambulihin and the upper course of Sungai Paniungan.
The limestone intercalation in the Sungai Paning-Paning is 2.5 cm thick, light olive grey (5 Y 6/1) to olive grey (5 Y 4/1) colour in the lower part (i.e. mottled, but olive grey (5 Y 4/1) in the upper part. This layer is made up of two divisions (in ascending order):

1. graded packstone (light olive grey to olive grey, 12 mm), and
2. faintly laminated packstone (olive grey, 13 mm).

Terrigenous (i.e. quartz, plagioclase, chlorite, epidote and mud clasts) material, occur in pockets (i.e. possibly due to bioturbation) and are concentrated in the graded packstone division. Due to extensive recrystallisation or micritization, it is not possible to identify the type of bioclastic grains. Endolithic burrows which are now infilled by frambooidal pyrite are quite conspicuous in many of the bioclastic grains. Furthermore, planktonic foraminifers (e.g. infilled by pyrite), which make up about 2% of the rock, are present both in graded and laminated divisions. Planktonic foraminifers are commonly found in the laminated packstone.

1.b Environment of Deposition

As described above, the association consists of interbedded sandstone and mudstone with bedding sequences and sedimentary structures indicative of deposition by turbidity currents. Most sandstone beds are graded or inversely to normally graded, and many can be described in terms of the classical Bouma divisions (Bouma 1962). This sandstone and mudstone association falls into medium grained turbidite category (Stow 1985).

Lithological and sedimentological characteristics reveal that most sandstone and mudstone beds correspond well with the submarine fan facies terminology of Mutti and Ricci-Lucchi (1972). The general characteristics of submarine fan system (Fig. 155) have been developed by a number of workers (e.g. Walker and Mutti 1973; Walker 1978; and
Fig. 155 A submarine fan facies terminology used in this thesis (adapted from Walker and Mutti 1973 and Walker 1980).
Howell and Normack 1982) and reviewed recently by Stow (1985). The type of submarine fan which would be suitable for the deposition of this sandstone and mudstone association is a shallow-water type of fan delta (Stow 1985). Evidence from the lower Sungai Tambulihin, where the massive and laminated mudstones (i.e. partially mottled or burrowed) contain bivalves and gastropods and broken pieces of shell and bryozoan, supports such an environmental interpretation. The occurrences of turbidites in fan deltas have been studied both in modern (e.g. Westcott and Ethridge 1980) and ancient (e.g. Westcott and Ethridge, 1983) sedimentary deposits.

On the other hand, in the upper Sungai Paning-Paning, a medium grained turbidite sequence is intercalated with a graded and laminated very fine grained packstone layer which contains planktonic foraminifers (2% of the rock volume) indicating the depositional setting of a turbidite in an outer shelf to bathyal environment. The high percentage of calcium carbonate (18-50% of the rock volume) as bioclastic grains and micrite or sparry calcite, and the presence of planktonic foraminifers in limestone (mudstone) interbeds in the sandstone turbidite sequence are all in good agreement with the above inferred environment.

2 Conglomerate and Sandstone Association
2a Description

This association normally comprises matrix to clast supported, thick to very thickly bedded (60 cm - 2.5 m) pebbly conglomerate, with very coarse to medium grained sandstone matrix. They are found both in the Sungai Paning-Paning (NS-781 to NS-782, see Fig. 149) and the Sungai Tambulihin (NS-765 to NS-768, Figs. 150), and are confined to the axis of the southern Riam Kiwa Subbasin. Pebbly sandstone was observed in the Sungai Tambulihin, occurring depositionally above or as intercalations within the conglomerate.
Structure in the two traverses above is either chaotic and disorganised (Figs. 156 and 157) or shows a crude organisation of grain size and stratification (organised fabrics). As a whole pebbly conglomerate passes upward into pebbly sandstone and becomes finer towards the top (fining upward sequence, see Figs. 149 and 150).

The clasts are rounded to subangular in shape, with the size ranging from fine to very coarse pebbles. The matrix normally makes up about 20-40% of the conglomerate. The coarsest clasts were observed in the Sungai Tambulihin, with 22 cm x 31 cm being the coarsest one. Lithologically, the clasts in the Sungai Tambulihin are composed largely of intermediate volcanics (e.g. PL-phyric andesite and microlitic lava), granitic detritus and metamorphics (e.g. QZ-MV-EP-schist and phyllite). Volcaniclastic sandstone, siltstone, limestone and rare radiolarian chert and serpentinitised peridotite were found.

In the Sungai Paning-Paning, the clasts of the conglomerate, intermixed with sands and sandy granules, are composed mainly of intermediate to basic volcanics, schistose pyroxenite, ultramafic mylonite, serpentinite, schistose gabbro, leucogabbro and dolerite. Subordinate constituents of the conglomerate are made up of recrystallised bioclastic limestone, reddish brown radiolarian chert and QZ-MV-CH-EP-GR schist.

To the N of locality NS-765 to NS-768, just a few km NE of the Sungai Tambulihin, similar conglomerate and associated sandstone beds are exposed for about 100 m along the road which leads to the east side of the village of Pengaron. The exposures are best seen at the bend of the road at locality NS-280 and NS-281 where thick bedded (60 cm - 1 m) matrix and clast-supported conglomerate beds dip steeply toward the SE. They are graded or inverse to normal grading, medium to coarse pebble-sized, and set in a very coarse to medium grained
Fig. 156 Stratified conglomerate occasionally intercalated with pebbly sandstone, Sungai Tambulihin. The conglomerate is normally crudely graded or inversely to normally graded, poorly sorted and well cemented, matrix to clast supported, and thickly bedded (80 cm - 1.2 m). The clasts are commonly imbricated, consisting of a mixture of volcanic, granite and sedimentary rocks. Measured imbrications show that the current from north-northwest.

Fig. 157 Close-up of conglomerate showing general texture (e.g. size and angularity) and fabric (clast to matrix supported), Sungai Tambulihin.
sandstone matrix. The ten largest clasts measured were: 3.5 x 6cm, 4 x 6cm, 4 x 9cm, 5 x 7cm, 5 x 7cm, 5 x 9cm, 6 x 10cm, 7 x 8cm and 7 x 12cm.

Although incomplete, typical divisions of coarse grained turbidite which consists of graded (R1), massive (R2), graded-stratified (S1), dish (S2) and a mixed dish and pipe (S3) structures, as proposed by Lowe (1982), have been recognised at locality NS-281. Among Lowe's divisions present at this locality are graded (R1), grade-stratified (S1) and dish (S2) structures. One of the most interesting differences here is that the dish structure is formed of arc-shaped shell materials rather than faint dark lines or arc-shaped muds as in the classical turbidite sequence (Wentworth 1967 and Stauffer 1967). Moreover, the arc-shaped shell fragments are not concave upward, but instead convex upward. Full description and explanation of these discrepancies are not possible within the scope of the present study.

2b Environment of Deposition

Lithological and sedimentological characteristics (e.g. chaotic fabrics, normal and inverse to normal grading, and crude horizontal stratification) of the conglomerate and sandstone association indicate deposition by gravity flows in a submarine fan (Fig. 155). The sedimentary features and broken molluscan fossils within the sandstone interbeds suggest that these coarse clastic deposits are redeposited sediments, which must have gone through a process of subaerial and submarine erosion, transportation and finally deposition in a submarine environment.

The lack of mud-matrix in the coarse redeposited deposits (i.e. sand matrix and clast supported conglomerate) suggest deposition by grain-flow processes. Such redeposition processes have been discussed by many workers (e.g. Stauffer 1967; Carter 1975).
If this inferred sedimentary mechanism can be accepted, thus resedimentation of the above coarse clastic deposits could have taken place on steep slopes, probably in an inner submarine fan setting (Fig. 155).

B.2 Sungai Pitanak and Hananai

1. Sandstone and Mudstone Association

The association is characterised by alternating sandstone and mudstone. Limestone interbeds which commonly contain planktonic foraminifers are present in the sandstone and mudstone section.

Exposures of these lithologies are found along the Sungai Pitanak and Hananai (Figs. 158, 159 and 160). The rocks in these geological traverses are confined, as folded sedimentary strata, between a volcano-plutonic complex in the NW and HB-phyric andesitic lavas in the southeast. As in the Sungai Tambulihin and Paning-Paning, upper and lower stratigraphic contacts of the sandstone and mudstone sequence in the Sungai Pitanak and Hananai are not known.

Beds of the sandstone and mudstone association display internal sedimentary structures which are characteristic of the classical Bouma sequence (1962). Most sandstone beds show parallel lamination (Bouma B) or a massive character (Facies B2, Mutti and Ricci Lucchi, 1972), but simple grading (Bouma A) with scoured or erosional base is also fairly common. Bed thicknesses range from 1.5 cm to 60 cm in the Sungai Pitanak and 3 cm to 50 cm in the Sungai Hananai. Many of the beds can be assigned to division BE, some AE and ABE (see Figs. 159 and 160).

In the Sungai Pitanak traverse there are at least two major thickening upward sequences recognised: 1. NS-788 A to NS-790, and 2. NS-791 to NS-812. General features of thick bedded and thin bedded turbidites are shown in Fig. 161 to 164. Thick conglomerate beds separate these two sequences (Fig. 159, see below for description).
FIG. 158 Geological map of the northeastern corner of the Banjarmasin Quadrangle, showing areal extent of the Pamali Formation and contacts with the surrounding volcanic rock-units.

KEY TO SYMBOLS
- NS-PHYRIC AMBIKITE
- PAMALI FORMATION
- PL-PHYRIC BASALT-AMBIKITE
- NS-798 SAMPLE LOCALITY

Scale 1:200,000
FIG. 159 Geological traverse in Sungai Pitana, showing distribution of outcrops of the Pamali Formation, with stratigraphic sections and general clast composition of the conglomerate. See Fig. 158 for index map.
FIG 160 Geological traverse along Sungai Hananai, showing outcrops of the Pamali Formation and its relationship with adjacent rock-unit. See Fig.158 for index map.
One of the most interesting features of this association is the occurrence of limestone layers (e.g. NS-789D, NS-790 and NS-794). They are dark grey (N₃3), macroscopically interlaminated (5-8 mm), and are made up of alternations of terrigenous silt (2%) planktonic foraminiferal mudstone or micrite (4-5 mm) and terrigenous free planktonic foraminiferal mudstone or micrite (6 mm). These sedimentary features can be described either by Piper's (1978) or Stow and Shanmugan's (1980) fine grained turbidite terminology (Stow, 1985).

In one of the limestone layers observed (NS-794), all three divisions of Piper's (1978) sequence have been recognised (in ascending order):

3. a planktonic foraminiferal ungraded mud (5 mm, E₃).
2. a planktonic foraminiferal graded mud (7 mm, E₂); and
1. a graded terrigenous silt-laminated mud division (14 mm, E₁);

2. Conglomerate and Sandstone Association

Conglomerate with interbeds of sandstone are found near NS-790, and NS-792. They form as very thick to thick bedded, matrix to clast supported, rounded to subrounded, and set in a very coarse to medium-sand grained matrix. The clasts are elongate to equant in shape, with the largest clast up to 40 x 50 cm in size. The ten largest clasts together with clast composition analyses are documented in Fig. 159. General features of these deposits are shown in Figs. 165 and 166.

The sandstone interbeds within the conglomerate section are characterised by poor sorting as they mix with fine pebbles or granules, calcium carbonate cemented, and exhibit gradual decrease in grain size towards the top of the bed. At locality NS-791 it is megascopically seen that the calcareous granular sandstone interbed contains abundant ultramafic detritus (Fig. 161).
Fig. 161 Interbedded sandstone and mudstone of the Pamali Formation in the upper course of Sungai Pitanak. Section youngs to the right.

Fig. 162 Thin-bedded graded sandstones, Pamali Formation, showing wavy or undulatory beds, with intervening mudstones. Note sandstone bases are sharp.
Fig. 163 Typical thick-medium bedded sandstones with intervening mudstone layers of the Pamali Formation in the middle part of Sungai Pitanak, which is stratigraphically above the conglomerate channel. Way up to left.

Fig. 164 Parallel laminated mudstone in the sandstone and mudstone association of the Pamali Formation, Sungai Pitanak.
Fig. 165 Matrix to clast-supported conglomerate, Pamali Formation, showing poor sorting texture and composition. Clasts are composed of intermediate volcanics, diorite, gabbro, granite, ultramafics, sandstone and limestone. Sungai Pitanak.

Fig. 166 Matrix to clast-supported conglomerate, Pamali Formation, showing texture/fabric and composition, Sungai Pitanak.
B.3 Petrography

Thin sections of sandstones from representative river sections in the Riam Kiwa Subbasin were petrographically studied (Table 6). These sandstone samples are from the Sungai Paning-Paning and Tambulihin in the southwestern subbasin, and the Sungai Pitanak and Hananai in the northeastern subbasin (Fig. 131, see Figs. 149, 150, 159 and 160 for sample localities).

The sandstones are made up of variable proportions of monocristalline QZ (Qm, 1-39%), polycrystalline QZ (Qp, Tr-15%), PL (Tr-25%), CPX (Tr-28%), lithic volcanic fragments (Lv, Tr-55%), ultramafic fragments (Lu, 0-48%), bioclastic fragments (Bf, 0-48%) and calcium carbonate cement (Cc, 0-50%), forming either as micrite or sparry calcite. Other constituents include potassium feldspar (Kf, Tr-10%), granitic fragments (Lg, 0-6%), limestone fragments (Ls, 0-5%), chert fragments (Lc, 0-8%), and schist fragments (Lm, 0-12%). Minor constituents such as epidote, chlorite and glauconite are listed in Table 6. These sandstones were classified into five petrofacies: 1. Calcareous ultramafarenite, 2. Terrigenous calcarenite, 3. Volcarenite, 4. Calcareous arkosic volcarenite, 5. Arkosic volcarenite.

All of these sandstone petrofacies are defined on the basis of relative percentages of the following detrital grains: 1. Quartz (Qz, Qm + Qp), 2. Feldspar (Pl + Kf), 3. Volcanic rock fragments (Lv), 4. Ultramafic rock fragments (Lu) and 5. Bioclastic fragments + calcium carbonate content. The detail mineral and rock constituents in each petrofacies are listed in Table 6. Representative surface-cut view and photomicrograph of these rock-types are shown below.
1. Calcareous Ultramafarenite Petrofacies

The calcareous ultramafarenite is the most conspicuous and significant petrofacies within the Pamali Formation. Similar petrofacies has previously been described in the lowest lithofacies of the Riam Kanan Subbasin of the Manunggul Basin, as in the Sungai Pamali (cf. NS-853) and the Sungai Paau (cf. NS-587C, B and D). This particular petrofacies occurs in the conglomerate-sandstone association in the Sungai Paning-Paning (NS-782, Fig. 167) and in the upper Sungai Pitanak (i.e. NS-813, Figs. 168 and 169).

Megascopically, the rock is moderately hard, light grey (matrix) to dark grey or green (grains), calcium carbonate cemented, rounded to subrounded, and very poorly sorted granular or fine pebbly sandstone. It is seen to be matrix to grain-supported, consisting mainly of ultramafic (Lu, 20-48%) and CPX (2-10%). In sample NS-782, it contains significant amount of monocrystalline QZ (Qm, 7%), PL (4%), muscovite (Mv, 6%), epidote (Ep, 4%), schist (Lm, 12%) and unidentified bioclastic grains (15%). Subordinate constituents include limestone, chert and mafic fragments (Table 6).

There are various kinds of mafic and ultramafic detritus present. These include serpenitised peridotite, serpentinite, gabbro and dolerite. Observation on the clasts of the pebbly sandstone and pebbly conglomerate reveal that various kinds of mafic and ultramafic rocks contributed to the sandstone composition. Apart from serpenitised peridotite and serpentinite, granular faintly layered gabbro, schistose metagabbro, leucogabbro, pyroxenite and schistose pyroxenite were recognised. Fig. 170 to 172 show some of these rock fragments.
2. **Terrigenous Calcarenite Petrofacies**

Rocks included in the terrigenous calcarenite petrofacies have more than 50% of calcium carbonate content (i.e. carbonate grains and cement). Terrigenous grains are present as the most significant and striking constituents in the petrofacies. By definition they do not exceed 50% of the rock volume. These terrigenous grains are characterised by variable proportions of monocrystalline quartz (Qm, 6-16%), plagioclase (PL, 5-13%), volcanic fragments (Lv, Tr-13%) and in some samples ultramafic fragments (Lu, Tr-17%).

Both bioclastic and terrigenous detritus are characteristically poorly to moderately well sorted, subrounded to angular, and fine to coarse sand grade (Fig. 173, Table 6). All of these grains are set in a pale yellowish brown (10 YR 6/2) micritic matrix (i.e. a mixture of carbonate and terrigenous mud) or clear calcium carbonate. The grains are in contact with each other, with some of the grain edges having been diagenetically transformed to matrix.

**Quartz**

There are two kinds of QZ present in the terrigenous calcarenite petrofacies, mono and polycrystalline QZ. The latter forms less than 1% (Tr), whereas monocrystalline QZ averages 10% in the Sungai Paning-Paning and 6% in the Sungai Pitanak (Table 6). They are largely of uniform extinction, while grains with pronounced undulose extinction also occur in appreciable amounts.

**Lithic Detritus**

The most frequent lithic detritus present is volcanic and granitic fragments. The former occurs in all samples, making less than 1% to 17% of the thin section (Table 6), whereas the latter is present in trace amounts in NS-776E, NS-778 and NS-781A.
Fig. 167 Surface-cut view of calcareous ultramafarenite of the Pamali Formation from Sungai Paning-Paning (NS-782), southeastern Riam Kiwa Subbasin, showing very poorly sorted texture, consisting of ultramafic fragments with association of quartz, schist, feldspar, pyroxene, limestone and bioclastic grains.

Fig. 168 Surface-cut view of calcareous ultramafarenite of the Pamali Formation from Sungai Pitanak (NS-813), northern Riam Kiva Subbasin. It shows poor sorting, matrix-supporting, and consisting of various types of ultramafic rock fragments and clinopyroxene.
Fig. 169: Photomicrograph of calcareous ultramafarenite petrofacies of the Pamali Formation, showing texture and composition. Note serpentineite fragments and clinopyroxene grains are set in coarse-grained sparry calcite cement. XPL. Bar scale 1 mm.

Fig. 170: Photomicrograph of schistose metagabbro clast. XPL. Bar scale 1 mm.
Fig. 169 Photomicrograph of calcareous ultramafarenite petrofacies of the Pamali Formation, showing texture and composition. Note serpentinite fragments and clinopyroxene grains are set in coarse-grained sparry calcite cement. XPL. Bar scale 1 mm.

Fig. 170 Photomicrograph of schistose metagabbro clast. XPL. Bar scale 1 mm.
Fig. 171 Photomicrograph of quartz-muscovite-chlorite-epidote-garnet schist clast from the Pamalí Formation. XPL. Bar scale 1 mm.

Fig. 172 Photomicrograph of radiolarian micrite clast. XPL. Bar scale 1 mm.
Feldspar

Detrital feldspar is predominantly PL, averaging over 6% of thin sections from the Sungai Paning-Paning and 8% from the Sungai Pitanak. They are found as clear untwinned, simply twinned and multiple twinned PL. Some K-feldspar was also recognised. A reliable percentage of this feldspar cannot be given as the thin sections were not stained. In most cases the grains of feldspar are unaltered but minor alteration was observed, in particular along cleavages of some crystals.

3. Volcarenite Petrofacies

This is found only in the Sungai Tambulihin (i.e. NS-763). In hand specimen this rock is very much the same as that found in the Sungai Hananai in the northeastern Riam Kiwa Subbasin. It is fine to very coarse grained (0.2 - 1.6 mm), poorly sorted, and is composed almost entirely of volcaniclastic constituents. Non volcaniclastic detritus observed include a few grains of monocrystalline and polycrystalline QZ and some recrystallised bioclastic or limestone grains. The latter could easily be confused with pseudomorph of carbonate after PL.

Volcaniclastic constituents are characterised by abundance of chloritised and limonitised PL-phyric andesite, microlitic lava, glassy microlitic lava, chloritised glassy materials, and altered PL and PX phenocrysts (i.e. now as chlorite, magnetite and calcite) of porphyritic lava fragments. Crystal tuff fragments also contribute to the composition of the volcarenite petrofacies. All of these volcaniclastic grains are grain supported, with the spaces between grains normally occupied by pale brownish green chloritised cement.

Figs 174 and 175 to 177 show typical features of the volcanic-litharenite petrofacies and the most frequent volcanic rock types found in it. Note the volcanic lithic fragments are from the clasts of the conglomerate.
Fig. 173 Photomicrograph of terrigenous calcarenite facies of the Pamali Formation, showing texture and composition. Terrigenous detritus is composed mainly of altered volcanic fragments (black with white or grey needles), monocrystalline quartz (white), plagioclase (grey), ultramafic fragments (e.g. upper centre and central left and pyroxene (lower centre) and epidote (greyish-bluish yellow). Sungai Paning-Paning. XPL. Bar scale 1 mm. NS-781A.

Fig. 174 Photomicrograph of volcanite of the Pamali Formation, showing texture and composition. Note almost 100% of the constituents are of various types of volcanic fragments (see text). Locality NS-763. Sungai Tambulihin. XPL. Bar scale 1 mm.
Fig. 175  Photomicrograph of PL-PX phyric andesite clast in the Pamali Formation. Locality NS-765, Sungai Tambulihin. Bar scale 1mm.

Fig. 176  Photomicrograph of plagioclase-phyric andesite clast in the Pamali Formation. Sungai Tambulihin. XPL. Bar scale 1mm. NS-763(1)
Fig. 177 Photomicrograph of lath-shaped plagioclase-bearing lava andesite clast in the Pamali Formation, Sungai Paning-Paning. XPL. Bar scale 1mm. NS-763(2).

Fig. 178 Photomicrograph of calcareous arkosic volcanoclastite of the Pamali Formation, showing texture and composition. Volcanic rock fragments are mainly of altered microlitic lava, micro-porphyritic and amygdaloidal volcanic rocks. Quartz grains are in white. Sungai Paning-Paning. XPL. Bar scale 1mm.
4. Calcareous Arkosic Volcarenite Petrofacies

Calcareous arkosic volcarenite petrofacies (Fig. 178) is found in the Sungai Paning-Paning (e.g. NS-777) and the Sungai Pitanak (e.g. NS-789B and NS-785). The petrographic characters of this petrofacies is very much the same as the terrigenous calcarenite. The only difference is that the latter is higher in calcium carbonate content (>50%) or less than 50% terrigenous material, whilst the former is typically dominated by volcanic detritus which occupies about 22% to 45% of the thin section. Other significant constituents are monocystalline QZ (Qm, 9-10%) and PL (4-12%). Ultramafic detritus is found only in Sample NS-789B, whereas radiolarian chert and granite are present in all samples (Table 6). Minor but important constituents such as limestone, schist, K-feldspar and PX are found and listed in Table 6.

All samples included in this petrofacies are grain-supported, poorly to moderately well sorted, rounded to angular, and very hard as they have been cemented by calcium carbonate. The characteristics of all terrigenous detritus are very much the same as those found in the previous petrofacies.

5. Arkosic Volcarenite Petrofacies

Arkosic volcarenite is the dominant rock type or petrofacies found within the Pamali Formation throughout the Riam Kiwa Subbasin. It occurs, in SW-NE direction, from the Sungai Tambulihin (NS-765, NS-768, NS-769 and NS-766), the Sungai Pitanak (NS-788, NS-791 and NS-792B) and the Sungai Hananai (NS-796, NS-797, NS-798, DS-36 and DS-41). Nearly all sandstones from the former and the latter are made up of this petrofacies. Figs. 179, 180 and 181 display texture and compositional characteristics of the petrofacies from each of the above river sections.
Texturally, most of the samples from the arkosic volcarenite are subangular to very angular in shape, poorly to very poorly sorted in the Sungai Tambulihin and poorly to well sorted in the Sungai Pitanak and Hananai sections, moderately hard, and grain-supported. The terrigenous and bioclastic detritus are normally set in non calcareous mud or partially cemented either by Fe-oxide (haematite) or calcium carbonate. The latter is characteristically found near or around bioclastic and unidentified carbonate grains. Calcium carbonate or calcite also occur, as patches and micro-veins, in feldspar grains.

As is clear from the name, the arkosic volcarenite is typically dominated by various kinds of volcaniclastic detritus which occupies close to or more than half of the thin section (Table 6). The second major constituent is arkosic detritus, consisting of monocrystalline QZ (i.e. uniform and undulose extinction) and PL grains. Other constituents include CPX, granite, chert, K-feldspar, schist and recrystallised bioclastic detritus. Mafic and ultramafic rock and limestone fragments are present in some samples (Table 6).

In addition lithic volcanic fragments, as shown in Figs. 182 to 184 are the commonest volcaniclastic constituents in the petrofacies. These are described as amygdaloidal PL-CPX-phyric andesite, PX-andesite and HB-phyric andesite, respectively.

**B.4 Environment of Deposition**

The lithological and sedimentological characteristics present throughout the Sungai Pitanak-Hananai section suggest that the sedimentary strata there are redeposited sediments, accumulated by turbidity current processes. The occurrence of planktonic foraminifers in fine grained turbidite (limestone) interbeds are indicative of deposition in a deeper submarine environment, probably at bathyal depth.
Fig. 179 Photomicrograph of arkosic volcanocrenite of the Pamali Formation from the Sungai Tambulihi. It is composed mainly of lithic volcanic fragments, with association of quartz and plagioclase. XPL. Bar scale 1 mm. NS-765.

Fig. 180 Photomicrograph of arkosic volcanocrenite of the Pamali Formation from the Sungai Pitanak. XPL. Bar scale 1 mm. NS-810.
Fig. 181 Photomicrograph of arkosic volcanoclast of the Pamali Formation from the Sungai Hananai. XPL. Bar scale 1mm.

Fig. 182 Photomicrograph of plagioclase phryic andesite clast in the Pamali Formation, Sungai Pitanak. XPL. Bar scale 1mm. NS-792A.
Fig. 183 Photomicrograph of pyroxene andesite clast in the Pamali Formation, Sungai Pitanak. XPL. Bar scale 1mm. NS-792G.

Fig. 184 Photomicrograph of hornblende andesite clast in the Pamali Formation, Sungai Pitanak. XPL. Bar scale 1mm. NS-792D.
The sandstone beds display the following characteristics:

1. sharp and flat based beds;
2. regular with lateral continuity;
3. bed thicknesses range from 1.5 cm to 60 cm, but 1.5 cm to 12 cm are more common;
4. the sandstone : mudstone ratio is about 1 : 1 to 4 : 1;
5. grain size usually sand to silt;
6. amalgamation is very rare; and
7. the typical bed is an BE sequence, but AE and ABE divisions are also fairly common.

All of these sedimentary attributes can be fitted and grouped into the criteria of Facies D, and partially into Facies C of Walker and Mutti (1973). Massive sandstone, pebbly sandstone and pebbly conglomerate that occur in the central part of the Sungai Pitanak section could also be included into Facies B2, A4 and A1 (Fig. 155) of Walker and Mutti (1973).

On the basis of the above facies association, which are dominated by Facies C and D, with additional Facies B2, A4 and A1, it is more likely that the sedimentary strata exposed in the Sungai Pitanak-Hananai traverses represent lobe-fringe deposits (Fig. 155) in a submarine fan (slope) environment (cf. lobe-fringe thin bedded turbidites of Mutti 1977). This interpretation is also supported by a detailed measured section in the Sungai Pitanak (see Figs. 158 and 159, and section at Locality NS-791), where it is characterised by a thickening and coarsening-upward sequence, started with Facies D at the base (NS-788A) and passing upward into medium-thin bedded turbidites (Facies C), and finally into B2 and A4 (cf. Walker and Mutti 1973 and Walker 1980).
6.5.3 Age of the Pamali Formation

The age of the Pamali Formation in the Manunggul Basin can be delineated by combining previous palaeontological data with that obtained during the present study (see Fig. 131 for all localities of paleontological and radiometric data).

In 1971, before the submergence of the Sungai Riam Kanan, Hashimoto collected and described a vast number of macrofossils (i.e. mainly molluscs) from various localities along the Sungai Riam Kanan and two of its tributaries, the Sungai Kalaan and the Sungai Pamali (see Hashimoto and Koike, 1973). The molluscan fossils which have been identified by Hashimoto and Koike (1973) include the following species (see Fig. 131 for approximate present localities).

<table>
<thead>
<tr>
<th>Locality</th>
<th>Species Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>HK* - 1</td>
<td>Nerinea sp.</td>
</tr>
<tr>
<td></td>
<td>Antiquilima sp.</td>
</tr>
<tr>
<td></td>
<td>cf. Cylindrites sp.</td>
</tr>
</tbody>
</table>

* HK is an abbreviation for Hashimoto and Koike

<table>
<thead>
<tr>
<th>Locality</th>
<th>Species Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>HK - 2</td>
<td>Inoceramus sp.</td>
</tr>
<tr>
<td></td>
<td>Reesidites (cf. R.elegans MATSUMOTO and INOMA)</td>
</tr>
</tbody>
</table>

Inoceramus terasakai MATSUMOTO and NODA or Inoceramus latus SOWERBY
Inoceramus labiatus SOWERBY

These fossils, according to Hashimoto and Koike (1973), are indicative of Middle to Upper Turonian age.

As mentioned in the preceding section, a new important fossil locality has been found by the writer in the Sungai Paau (see subsection A.2 for a list of fossil species). The occurrence of Actaeonella sp. and Actaeonella/cylindrites in this locality suggests a Turonian age (Drs. Morris and Cleevelly of the British Museum, pers.
Furthermore, the presence of Aptian to Early Albian Orbitolina-bearing limestone fragments (e.g. NS-591D, Orbitolina sp.) in the coarse grained sediments of the Pamali Formation is consistent with a Turonian age.

6.5.4 Synthesis for the Pamali Formation

The Pamali Formation is the largest, the thickest as well as the most continuous sedimentary fill of the Manunggul Basin. On the basis of lithological, sedimentological and paleontological characteristics, together with interpretation of sedimentary environments and sources, as presented in the preceding sections a synthesis of the depositional environments of the Pamali Formation has been constructed. This formation accumulated in two subbasins: 1. the Riam Kiwa in the NW, and 2. the Riam Kanan in the SE (see Fig. 131).

Geological observations along a number of key geological traverses (see Figs. 131, 132, 135, 136, 139, 140, 149, 158, 159 and 160), combined with petrographic studies on conglomerate and sandstone indicate that the Pamali Formation, as the lowest unit in the Manunggul Basin, is a wholly autochthonous unit of Pre-Tertiary rocks in the Meratus Mountains, deposited unconformably on and between rocks of the Meratus Ophiolite to the SE and the Tambak-Tamban volcanic-plutonic belt to the NW. The sediment was largely supplied by erosion of these highlands. The rocks of the Hauran Schist, the Paniungan Formation and the Alino Group, which lie to the SW of the basin also contributed to the Pamali sediment (see above for detail).

Sedimentological and structural characteristics of the Pamali Formation in the Riam Kanan and Riam Kiwa Subbasins, together with their interpretations (see above) provide a gross picture of regional sedimentation patterns. Fig. 185 was constructed on the basis of
lithological associations, coupled with the inferred surrounding interrelationships with the source terrains. It is suggested that the Pamali Formation in the Riam Kanan Subbasin was deposited in the alluvial coastal environment in the SW and shallow marine in the central and northeastern parts of the subbasin. The occurrence of molluscian bearing calcareous sandstone and oolitic calcareous sandstone/calcarenite, as was observed for instance in the Sunga Paau and Julung is consistent with lagoonal sedimentation.

The Bobaris and the Kusan Ranges are thought to have acted as barrier islands (Fig. 185). All of the sedimentary detritus in the formation can satisfactorily be matched with and must therefore have been derived from the surrounding terrains (see Fig. 131). The environment of deposition was controlled by the paleomorphology of the surrounding terrains.

In the Riam Kiwa Subbasin, on the basis of lithological associations, sedimentary structures, stratigraphic and paleontological characteristics, the Pamali Formation indicates two depositional settings, in shallow water fan delta to inner submarine fan and lobe-fringe submarine fan (see above). Inner submarine fan deposits are present to the north of the shallow water fan delta deposits. Lobe-fringe submarine fan strata occur in the northeastern part of the Riam Kiwa Subbasin. Here the sediments are dominated by alternating sandstone and mudstone, with interbeds of planktonic limestone turbidite which suggest that they were deposited by sediment gravity flows within a deeper submarine environment. The Pamali Formation in this subbasin, therefore, shows changes in facies from SW to NE, from shallow water fan delta to inner fan and to deep water environments in the NE.
FIG. 185 Schematic reconstruction of the depositional environment of the Pamali Formation in the Riam Kanan Basin.
6.6 Benuariam Volcanic Formation

6.6.1 Name and Type Section

The Benuariam Formation, from the village of Benuariam (now submerged), was first defined by Hashimoto and Koike (1973). It is here redefined as the volcanic rocks (pyroclastics and lavas) overlying the Pamali Formation in the Riam Kanan Subbasin (see Fig. 131).

As the original type locality is now submerged by the Riam Kanan, the writer has established a standard reference section in the Sungai Paau (Fig. 135) where the underlying and overlying contacts can be easily recognised. Here the formation conformably overlies the Pamali Formation, and in turn is overlain with angular unconformity by coarse sedimentary deposits belonging to the Tabatan Formation.

6.6.2 Lithological Characteristics

On the basis of lithological characteristics and volcanostratigraphy observed during systematic geological mapping in the Meratus Mountains and detailed geological traverse along the Sungai Paau, it is suggested that at least three major lithological divisions or members are present within the Benuariam Formation: 1. Paau Volcanic Breccia Member, 2. Malinau Basaltic Andesite Member, and 3. Mandiangin Rhyolite Member.

6.6.2.1 Paau Volcanic Breccia

The name Paau Volcanic Breccia Member is proposed for all PX-bearing volcanic breccias, with intercalations of tuffs and lava flows, which outcrop in the upper Sungai Paau (Fig. 186) in the southern Riam Kanan Subbasin. Graded and stratified lapilli tuff and tuff exposed in Bukit Batas and near the village of Artain (see Fig. 131) are also included within the member (Fig. 187). Other exposures occur in the following upper rivers: Mihak, Hajawa, Pihik, Pinang and in the vicinity of the submerged village of Benuariam (Fig. 131).
Fig. 186 Boulders of matrix-supported volcanic breccia of the Paau Volcanic Breccia (i.e. Benuarium Volcanic Formation) in the Sungai Paau.

Fig. 187 Stratified breccia tuff of the Paau Volcanic Breccia (i.e. Benuarium Volcanic Formation) exposed in a small area, about 1 km due south of Artain Village, southwest Riam Kanan Subbasin. This rock is intercalated with graded volcanic breccia conglomerate.
In the northern Riam Kanan Subbasin the rocks are exposed in the area between Gunung Pangkat and Sungai Paniungan. Although most of the rocks there are deeply weathered, their stratigraphic position can still be seen along the southern bank of the Sungai Paniungan where they are underlain by the Paniungan Formation.

The distribution of intermittent outcrops observed in the Sungai Paau is shown in Fig. 135. The rocks consist of medium to very coarse pebbly volcanic breccia, with interbeds of agglomeratic lapillistone and medium to coarse grained tuff. The thickness of the member is estimated to be in the order of 700 to 900 m.

The coarsest clasts occur in Locality NS-595 where the ten largest clasts have been measured: 20x30cm, 20x25cm, 19x23cm, 19x22cm, 18x23cm, 10x27cm, 16x18cm, 10x18 cm, 10x28 cm and 8x19cm. They are subangular to angular, matrix-supported, hard and poorly sorted and constitute about 30-60% of the rock volume. Vague bedding shows that the rocks are thickly bedded (80 cm - 1.2 m).

In the downstream part of the river (e.g. NS-598) the Paau Volcanic Breccia consists of rather deeply weathered pebbly volcanic sandstone. No structures such as cross-bedding, grading or other features were observed. In contrast, at Kalaan and Bukit Batas the Paau Member commonly comprises stratified, graded and poorly sorted lapilli tuff and breccia tuff. They are largely altered to palagonite, particularly in Kalaan area. These deposits are sub-rounded to angular and the matrix is relatively well sorted.

Nearly all of the breccia rock fragments are basic to intermediate in composition. They are mostly holocrystalline and porphyritic, consisting of PX-phyric basaltic andesite, PL-phyric andesite, PL-HB-phyric andesite, HB-phyric andesite and microlitic lava. Intermixed with these volcanic fragments are medium to coarse grained igneous and metamorphic rocks. These include metamorphic
fragments which are equivalent to the rocks of the Hauran Schist. Other fragments include mafic and ultramafic fragments and limestones.

Schist fragments in the volcanic breccia are thought to be accidental blocks in the sense of Williams et al., 1954. They have been blown out of the volcanoes. Metamorphic grade of the schist fragments is equivalent to that of the outcropping schist in the vicinity of Riam Kanan Reservoir. The schist blocks include porphyroblastic QZ-MV-CH schist and QZ-MV-CH-EP-GR (garnet) schist, both typical of the highest grade of the greenschist facies.

The lava intercalations within this member are commonly porphyritic, and show conspicuous flow-banding, defined by lath shaped crystals of plagioclase. They are fine to relatively coarse grained, dark grey, holocrystalline, and consisting of subhedral PL and CPX (i.e. some occur as chlorite pseudomorphs) phenocrysts set in a fine to very fine grained groundmass composed mainly of PL laths and CPX. Magnetite and chlorite or a combination of these two minerals occur in the coarser grains and in the groundmass.

6.6.2.2 Malinau Basaltic Andesite

The Malinau Basaltic Andesite is named after the Sungai Malinau in the northern Riam Kanan Subbasin (Fig. 135). The rocks include basaltic andesite lava flows and associated volcanic breccias. The occurrence of a sedimentary dyke in the Sungai Malinau (Fig. 188) indicates that the Malinau Basaltic Andesite overlies the sedimentary deposits of the Pamali Formation. Similar rocks are also found in the vicinity of Bukit Batubelaran. Here the rocks occur within the complex of ophiolite (Meratus Ophiolite), metamorphics (Hauran Schist) and submarine volcaniclastic deposits (Alino Group).

The rocks in the Sungai Malinau are altered, dark grey, medium to coarse grained, holocrystalline, porphyritic PX basic andesite. They consist largely of subhedral CPX and PL, with secondary quartz,
Fig. 188 Basaltic andesite lavas in the Sungai Malinau, showing sedimentary dyke, marked by a gap at waterfall, which crosses the lavas and the river.

Chlorite, magnetite, zeolite and epidote. Quartz (wavy extinction), albite and zeolite are commonly present in cavities or veinlets. Chlorite, epidote, unidentified clay minerals and opaque material form a sponge-like network in many of the PL crystals. Nearly all CPX grains are rimmed by thin zones of Fe-oxide.

In Bukit Batubelaran the rocks of the Malinau Basaltic Andesite are far fresher than those found in the Sungai Malinau. They are dark grey, fine to coarse grained, up to 5 mm in diameter, porphyritic and holocrystalline. Similarly, the phenocrysts and microphenocrysts are of PX and PL, with minor HB and magnetite. These are set in a very fine grained groundmass composed of PL microlites with intersertal grains of CPX and magnetite. CPX phenocrysts make up about 15% of the rock volume. Composition of PL ranges from andesine to labradorite. Chlorite and occasionally a mixture of quartz, epidote and chlorite occur in veins.
6.6.2.3 Mandiangin Rhyolite

The name Mandiangin Rhyolite is given to a sequence of porphyritic rhyolite lavas and pyroclastic rocks (tuffs and breccias) that overlies the Paau Volcanic Breccia.

The type section of this rhyolite member is in the small river near the road that leads to the Riam Kanan Reservoir, approximately 0.5 km S of Mandiangin (Fig 189). Good and important outcrops (Fig. 190), although small, and the exact contact with the underlying rocks are not exposed, are also found in the Sungai Paau (NS-606 A and B). As mentioned earlier, the Mandiangin Rhyolite is overlain by the Tabatan Formation with angular unconformity. Similar rocks are also exposed in Gunung Tampang, about 5 km SE of Pelaihari (see Geological Map).

Field and petrographic observations reveal that all the rocks from the Sungai Paau, Mandiangin and Bukit Tampang can be subdivided into four lithologies: 1. rhyolite, 2. ignimbrite or welded tuff, 3. tuff breccia, and 4. crystal tuff.

6.6.3 Age

Although the volcanic rocks of the Banuariam Volcanic Formation described above contain no fossils the age of the formation is closely constrained as Santonian (Lower Senonian) or middle Upper Cretaceous (87.5 - 83 Ma) by the following evidence:

1. At Bukit Butabelaran, 10 km NE of Pelaihari, porphyritic basaltic andesite has been dated (K/Ar dating on whole rock, determined by Dr N J Snelling, BGS), as Santonian (85.6 Ma) age.

2. Microdiorite of Danian or Early Paleocene (63.3 Ma, K/Ar dating on hornblende, Dr N J Snelling) age in the Sungai Julung, north of Riam Kanan Subbasin, is intrusive into basic andesite lavas and pyroclastics of the Benuariam Formation (see Fig. 139).
Fig. 189 Type section of the Mandiangin Rhyolite in the river near the village of Mandiangin. The rock exposure is made up of ignimbrite and tuff breccia. Flow-banding dips to the right.

Fig. 190 Exposure of rhyolite with intercalation of ignimbrite and crystal tuff in the Sungai Paau. Flow-banding steeply dips to the left.
3. **Stratigraphic position of the Benuariam Volcanic Formation** is between the Pamali and Tabatan Formations. Therefore its age must be younger than the Pamali Formation (Turonian-Coniacian) but older than the Tabatan Formation.

4. Basal coarse clastic deposits of the Campanian Tabatan Formation contain pebbles and granules of basic to rhyolitic volcanic rocks belonging to the Benuariam Formation.

6.6.4 **Source and Depositional Environment**

The presence of tuff, tuff breccia and lapilli tuff within the volcanic breccia sequence, dominated by porphyritic basaltic andesite and andesite to rhyolite, indicates that the Benuariam Volcanic Formation represents an influx of material from basic to intermediate through acid volcanoes.

The angularity and poor sorting of the volcanic breccia implies proximity to the volcanic source, which was possibly located in the present vicinity of the Sungai Malinau and Batubelaran. An alternative source to the NE is also probable, since the grain size of the volcanic breccia decreases, and the unit becomes stratified in the southwestward direction – Sungai Paau to Bukit Batas. The occurrence of intermediate volcanic vents within the Meratus Ophiolite suggest another possible source area. But further detailed mapping and petrographic work are needed before this suggestion can be accepted with confidence.

It is not certain whether the volcanic breccia is marine or non-marine. However, because the underlying formation is shallow marine and the overlying formation is an alluvial fan deposit, it is considered that the Benuariam Formation was deposited in a fairly shallow marine to subaerial environment.
6.7 Tabatan Formation

6.7.1 Name and Type Section

This name was proposed by Hashimoto and Koike (1973) who described the Tabatan Formation in the submerged area of the Sungai Tabatan and the Sungai Riam Kanan. The present writer extends its usage and includes all sediments which show similar characteristics to those described by Hashimoto and Koike (1973). The formation consists predominantly of well-rounded polymictic conglomerate, with intercalations of thick to thin sandstone beds.

The original type section of the formation (Hashimoto and Koike, 1973) is in the drowned part of the present Sungai Tabatan. To replace this locality, the writer has established a standard reference section in the Sungai Mihak (Fig. 191), about 8 km NE of the Sungai Tabatan.

6.7.2 Occurrence

The Tabatan Formation is distributed along the central axis of the Riam Kanan Subbasin, as shown in Fig. 131. The formation is well exposed in the Sungai Mihak and Paau, and Gunung Pahiyangan. Geological traverses in the two rivers above are shown in Figs. 135 and 191. It is possible that other exposures may occur to the NE of the Sungai Paau, for instance in the Sungai Pinang (see Fig. 137), but they were not visited during the present study.

The Mihak and Paau River sections are roughly perpendicular both to the axis of the subbasin and to the main structural trend of the Meratus Mountains. As the rocks of Tabatan Formation in these two traverses are not affected by folding and faulting, the thickness of the entire formation is relatively easy to determine. On the basis of the areal extent of the outcrops and distribution of the strike and dip of the beds in the Sungai Mihak, the thickness of the formation is estimated to be not less than 1800 m. The formation is considerably
FIG. 19. Geological traverse along Sungai Mihak, Riau Kanan, showing distribution of outcrops of the Resave Formation. Sedimentological attributes, including pebble count analyses, are shown in the figure.

**SAMPLE NS-650**

C-v.c peb.cgl.

**SAMPLE NS-691**

f.c. peb.cgl.

KEY TO SYMBOLS

- **Mudstone**
- **Sandstone**
- **Pebbley sandstone**
- **Conglomerate**
- **Granite**
- **Volcanics**

**CLAST TYPES**

- **Quartz**
- **Chert**
- **Schist**
- **Sandstone**
- **Gabbro**
- **Ultramafics**

**KEY MAP**

- **Sungai Mihak**
- **Uplifts**
- **Java Sea**

**LEGEND**

- **NS-650**
- **NS-691**
- **NS-693**
- **NS-695**

**NOTE**

- **C-v.c peb.cgl.** with some cobbles. It contains block of laminated calc-mudstone (60 x 100 cm)
- **msv** = massive
- **scl** = conglomerate
- **imbr** = imbricated
- **bd** = bedded
- **blc** = block
- **clst** = channelised
- **CS** = Clast-supported
- **MS** = Matrix-supported
thinner towards the SW in the Sungai Tabatan, which acted as the margin of the subbasin, but it is thicker in a northeastward direction.

The contacts of the Tabatan Formation with the underlying rock-unit are normally obscured by weathering, as in the Sungai Mihak, the Sungai Hajawa and the Sungai Paau. However, measurements on flow planes of rhyolitic lava of the Benuariam Formation at locality NS-606 in the Sungai Paau, which dips 53°-85° to the NNE (Fig. 135), and petrographic studies of the clasts from pebbly sandstone and conglomerate occurring just a few metres from the outcrop of the rhyolitic lava, reveal that the Tabatan Formation is separated by an angular unconformity (diastem) from the underlying Benuariam Formation.

6.7.3 Description of Lithology

Two main lithological units or members are recognised in the Tabatan Formation. The two members are (in ascending order): 1. Mihak Member and 2. Pahiyangan Member.

6.7.3.1 Mihak Member - Conglomerate and Sandstone

The Mihak Member occupies the lower part of the Tabatan Formation. Outcrops of this member can easily be reached on the banks of the Riam Kanan Reservoir, where local people are prospecting for diamonds and gold.

Good exposures are found along the Sungai Mihak (Fig. 191) and in the upper course of the Sungai Paau (Fig. 135). The rocks of the Mihak Member are represented by polymictic pebbly conglomerate, pebbly sandstone and sandstone. In addition, mudstone occurs as rare intercalations and also as blocks or ripped up beds in the conglomerate. Distribution of these lithologies, together with important sedimentological attributes, including pebble counts are shown in Figs. 135 and 191.
Based on the Mihak river section (Fig. 191), the Mihak Member contains approximately 60% conglomerate, 38% sandstone and 2% mudstone. The conglomerate diminishes in grain size and bed thickness downstream, and the sandstone beds become more frequent and thicker. Individual thicknesses range from a few tens of centimetres to a few metres. Scouring or channel structure is quite common at the base of the conglomerate beds (see field sketches in Fig. 191). The conglomerates are mainly clast-supported (Figs. 192 and 193), but matrix-supported conglomerates are also present (e.g. NS-691). Long axes of ten largest clasts in the Sungai Mihak average 11 x 16cm. The largest clast found so far is a block of laminated calcareous mudstone, with the size 60 x 100cm. Most conglomerate and pebbly sandstone beds observed are stratified, crudely to ungraded, thickly bedded or massive, and commonly intercalated with medium graded sandstone beds.

The clasts of these coarse clastic deposits are typically well rounded to rounded in shaped, poorly to very poorly sorted, fine to very coarse pebble sized, and are occasionally imbricated (e.g. Fig. 194). They are made up largely of intermediate to acid volcanic rocks, metamorphics, gabbros, granite and various kinds of sedimentary components such as chert, limestone, sandstone and mudstone, with minor ultramafic and leucocratic rocks. Pebble counts on conglomerate from two representative traverses are presented in Figs. 135 and 191. The matrix may be classified as coarse to medium and poorly sorted polymictic sands, commonly cemented by calcium carbonate, particularly in the central part of the Riam Kanan Subbasin.
Fig. 192 Poorly sorted, clast-supported to matrix-supported conglomerate of the Tabatan Formation showing heterogeneous clast composition (see Fig. 226 for pebble count analysis). Locality NS-650, Sungai Mihak.

Fig. 193 Pebbly conglomerate of the Tabatan Formation in the Sungai Faa. Locality NS-609.
Fig. 194  Imbricated pebbly conglomerate of the Tabatan Formation exposed at Locality NS-692 in the Sungai Mihak. Imbrication indicates that the paleocurrent was from the west (180/24 W).

Fig. 195  Cross-bed sets in sandstone interbed of conglomerate deposit, Tabatan Formation, Sungai Paau (Locality NS-603).
Sandstones occur as intercalations or forming the top part of the upward-fining conglomerate/pebbly sandstone sequence. They are commonly laminated, hard to semiconsolidated, dusky yellow (5 Y 6/4), greenish grey (5 GY 6/1) to medium grey (N 5/5), and calcium carbonate cemented in the lower and middle parts of the member. Sorting of the sandstones is poor to very poor. Crossbeds, planar type, are present in some of the sandstone beds (e.g. Fig. 195). In the Sungai Paau (NS-603), the thickness of individual sets generally ranges between 10 and 40 cm, but sets measuring 5 cm are also present.

In thin section, sandstone interbeds (e.g. NS-642, NS-693 and NS-694) are composed largely of monocrystalline (Qm, 25-41%) and polycrystalline (Qp, 5-10%) quartz, muscovite (Mv, 4-28%), plagioclase (PL, 2-9%), volcanic fragments (Lv, 3-28%) and schist (Lm, 4-10%). Accessory constituents are potassium feldspar, epidote, chlorite, magnetite and unidentified bioclastic fragments. They are commonly cemented by micritic or clear sparry calcite.

6.7.3.2 Pahiyangan Member - Sandstone

Stratigraphically, the Pahiyangan Member occurs immediately above the previous member. The contact between these two members of the Tabatan Formation has not been found.

The Pahiyangan Member is well exposed in the area of Gunung Pahiyangan (Figs. 196 and 197). It is approximately 80 m thick, consisting of sandstone, and is characterised by having stratification, medium grey (N 5/5) colour, coarse to fine sand size and poorly sorted. The sandstone is typically non-calcareous, comprising constituents similar to the underlying sandstone interbeds of the conglomerate sequence. The commonest detritus is QZ (45-55%) and muscovite (20-30%), with associated PL and QZ-MV schist fragments. Minor amounts of K-feldspar, radiolarian chert and intermediate volcanic rock fragments are also found. These framework grains are set in an oxidised muscovite-bearing mud-matrix.
Fig. 196 Gunung Pahiyangan (flat-topped mountain at the centre) viewed from the Riam Kanan Reservoir. The mountain is made up of thick bedded arkosic sandstone of the Mihak Member, Tabatan Formation.

Fig. 197 Close-view of the bedded sandstone section on the western flank of the Gunung Pahiyangan.
6.7.4 Age

As the sediments of the Tabatan Formation contain no fossils, its age can only be determined on the basis of the underlying and overlying rock-units. The underlying Benuariam Formation has been dated as Santonian or middle Upper Cretaceous (85.6 Ma by K/Ar dating on whole rock of basaltic andesite, determined by Dr N J Snelling, BGS) age. Whilst the overlying black shale, i.e. Rantaulajung Formation which contains abundant datable estherid fossils, is placed in Late Senonian (Hashimoto and Koike 1973). From the stratigraphic position and the above constraints, it can be suggested that the Tabatan Formation lies within Late Senonian, probably Campanian (83-73 Ma) in age.

6.7.5 Environment of Deposition

As described earlier, the rocks of the Tabatan Formation are sub-divided into two sedimentary units: 1. the Mihak Member and 2. the Pahiyangan Member. The former is represented by an association of conglomerate and sandstone, whereas the latter is composed entirely of sandstone.

The Tabatan Formation occupies a distinctive stratigraphic position between an erosional surface and non-marine deposits (i.e. Rantaulajung Formation). The conglomerate and sandstone of the Mihak Member are interpreted as representing debris flow deposits that accumulated in an area of high relief and high flow energy condition. In such condition coarse clastic debris flows were probably deposited either in an alluvial fan or in a submarine fan which is in close proximity to the shoreline. The absence of "turbidites" as well as the common occurrence of channeling, cross-bedding and the absence of marine fossils all suggest that the Mihak Member is not part of such a submarine system, but instead it is an alluvial fan. The angular unconformity below the conglomerate and sandstone section of the
member indicates uplift, and therefore make an alluvial fan origin more likely. Furthermore, fresh water fossils in the overlying formation (Rantaulajung Formation) also favour an alluvial fan setting for deposition of the debris flow sediments of the Mihak Member.

The Mihak alluvial fan grades upward into fine-grained sediment of the Pahiyangan Member. It is characterised by fine to very fine terrigenous sandstone which is interpreted here to have been deposited in a series of sandy braided streams.

Overall, a significant vertical decrease in grain size is evident from the Mihak Member through the Pahiyangan Member of the Tabatan Formation. This suggests a change from high to low energy environmental conditions. Such sedimentary patterns, together with a close relation between sedimentation and volcanism, and the fault system in the southwestern Riam Kanan area are indicative of sediments deposited in or along a strike-slip margin or a pull-apart basin (see Chapter VIII).

6.7.6 Provenance

Field observation, including pebble count analyses, and petrographic examination, reveal that the coarse and fine grained clastic sediments of the Tabatan Formation were derived from a surrounding five main sources:

1. metamorphics,
2. ophiolite,
3. sedimentary rocks, (i.e. limestone, chert, sandstone and mudstone),
4. volcanics, and
5. granitic rocks (i.e. granite, diorite and granodiorite).

Greenschist, basic intermediate to acid volcanic rocks, limestone and chert form a very high proportion of the clasts and sand sized grains in the coarse clastic sedimentary unit of the Mihak Member of the
Tabatan Formation. The occurrence of plutonic material such as granite, uniform monocrystalline quartz and potassium feldspar implies that the magmatic arc was contributing to the sediments.

As mentioned above, the coarse clastic deposits of the Mihak Member pass upward into fine clastic deposits of the Pahiyangan Member, where quartz (45–55%) and muscovite (20–30%) with subordinate plagioclase and schist fragments are the most characteristic constituents. The source of detritus for these sediments may have lain to the southwest, probably from the area of the southwestern Riam Kanan. The sediments have been carried northeastward into the central part of the Riam Kanan Subbasin by braided streams.

6.8 Rantaulajung Formation – Estherid Bearing Black Shale

6.8.1 Name and Type Section

The Rantaulajung Formation used here is essentially the same unit proposed and described by Hashimoto and Koike (1973). The formation is defined as the sedimentary unit conformably overlying or interfingering with a fine-grained sandstone (cf. Pahiyangan Member) of the Tabatan Formation. Hashimoto and Koike (1973) designated the type section of the formation on the river bank in the drowned village of Rantaulajung (see Fig. 131). The formation is made up entirely of black shale which contains a number of important estherid fossils for age and environmental interpretation (see below).

Although the Rantaulajung Formation is no longer exposed, due to the submergence of the Sungai Riam Kanan, it is very important to retain this formation because its occurrence and application influence the stratigraphic framework and the interpretation of the tectonic history of the Manunggul Basin.
6.8.2 Occurrence and Description of Lithology

The Rantaulajung Formation occurs in a restricted part of the drowned Sungai Riam Kanan, forming the core of syncline of the Manunggul Basin (See Fig. 3, Hashimoto and Koike, 1973).

As mentioned above, the formation is composed of black shale. It contains the species of estherids which were identified by Kobayashi (1973) as:

- \textit{Pseudocyclograptus hashimotoi} KOBAYASHI, n.sp.
- \textit{Lioesteria} sp.

According to Kobayashi (1973) this is the first record of the estherid fossils from Indonesia. Detailed descriptions, historical background and regional correlation of these fossils is given in Kobayashi (1973).

6.8.3 Age

According to Kobayashi (1973) estheriid fossils are found only in deposits older than the Tertiary. As a result of the discovery of estheriids, as listed above, by Hashimoto and Koike (1973, described by Kobayashi, 1973), the age of the Rantaulajung Formation is no younger than Upper Cretaceous.

On the basis of the above age, combined with the age given for the underlying Tabatan Formation as well as radiometric data from the Julung microdiorite (see below), it can be suggested that the Rantaulajung Formation is most likely Maastrichtian.

6.8.4 Environment of Deposition

The estheriids-bearing black shale is interpreted as a non-marine or perhaps lake deposit that accumulated in a relatively flat and restricted area, and low energy environment.
6.9 Kayujohara Volcanic Formation (new)

6.9.1 Name and Type Section

The Kayujohara Volcanic Formation is proposed here to include all HB-phyric andesites and their pyroclastics (agglomerates and volcanic breccias). Stratigraphically this formation is the youngest rock-unit of the Manunggul Group. The formation is named from Kayujohara Mountains at the northeastern end of the Banjarmasin Quadrangle (Fig. 158).

The Kayujohara Volcanic Formation forms rugged mountains in the Kayujohara Range. Although flow surfaces are not well developed, identification of massive lava flows together with intercalations of volcanic breccia suggest that the volcanic igneous rocks of the Kayujohara Formation, at least in the vicinity of Kayujohara Mountains, may have developed as an extrusive dome. Similar rock type also occur as intrusive volcanics in a number of places in the Manunggul Basin, e.g. Sungai Julung and Bukit Keminting microdiorites. Agglomerates and their associated fine-grained pyroclastics occupy an elongated depression or synclinal axis near Pengaron, between the Sungai Paniungan and the Sungai Riam Kiwa (see Fig. 131). Present field observation suggests that the Kayujohara Volcanic Formation contains a member that is here informally defined as Alimukim Agglomerate.

6.9.2 Lithology and Petrography

The rocks are typically fine to medium-grained, olive grey (5 Y 4/1) and dusky brown (5 YR 3/2) when weathered, with striking prismatic or columnar HB crystals, lacking flow banding. Occasional volcanic breccias are found as intercalations within the lava flows.

In thin sections, these rocks are fine to medium-grained (0.2 mm - 2.5 mm), porphyritic and hyalopilitic texture. The most abundant phenocrysts and microphenocrysts are HB (30%) and columnar or lath-shaped PL (andesine, 20%). CPX phenocrysts occur in small amounts.
These phenocrysts and microphenocrysts are set in a very fine-grained groundmass composed mainly of the same composition (i.e. PL and HB) as the framework grains with which they are associated. Intermixed with these are altered glassy material and secondary opaques. The PL phenocrysts are heavily saussuritised, but HB, on the other hand, still remains largely unaltered.

Volcanic breccias, with which the volcanic lavas are associated exhibit similar texture (i.e. porphyritic or HB-phyric) and composition. The breccias are up to several tens of centimetres in length, and the thickness ranges from 40 cm up to about 2 m. Individual fragments are commonly surrounded by zones of reddish brown limonite, probably haematite.

6.9.3 Alimukim Agglomerate

The Alimukim Agglomerate, from the village of Alimukim, is the name given to pyroclastics, mainly agglomerates with minor volcanic breccias, overlying the sedimentary strata of the Pamali Formation in the area of Riam Kiwa Subbasin. The member is partially covered by the Tertiary deposits in the north (see Fig. 131).

A type section is proposed on the main road near Alimukim Village (NS-278). In this area, the member is well exposed almost continuously along the road. Good exposures, although weathered, are also found in the Sungai Tambulihin and road junction, 5 km ESE of Pengaron (Figs. 198 and 199).

Lithologically, the Alimukim Agglomerate contains blocks up to 40 cm in diameter in a HB-phyric andesitic matrix. Blocks include acid andesite, dacite and rhyolite. Accidental blocks of metamorphic rocks and limestones are occasionally found. The pyroclastic matrix consists of abundant subrounded to angular fragments of pumice, together with fragments of intermediate and acid volcanics. Broken phenocrysts of HB, PX and PL are commonly present.
Fig. 198 Alimukim Agglomerate exposed on the road bank, between the intersection of Sungai Tambulihin and Alimukim Village. The rocks are rounded to subrounded, matrix-supported and consisting of intermediate to acid volcanic rocks.

Fig. 199 Deeply weathered outcrops of the Alimukim Agglomerate exposed near the intersection of the Sungai Tambulihin and the main road leads to Alimukim Village. The rocks are seen closely resemble, in texture and composition, the rocks shown in Fig. 198.
6.10 Intrusive Volcanic Rocks

6.10.1 Julung Microdiorite

The name Julung Microdiorite is given here for all intermediate intrusive bodies, dykes and sills and plugs, which are found along and adjacent to the Sungai Julung (see Figs. 131 and 139). Volcano-stratigraphically, this is the youngest or the last stage of igneous rock-unit in the Meratus Mountains. As these intrusive bodies are both stratigraphically and compositionally closely related to the Kayujohara porphyritic andesitic lava flows, a contemporaneous origin is suggested. Note that other microdiorite bodies, exposed in Bukit Keminting and in the upper Sungai Pinang (see Fig. 131), have been mapped but are not described in this thesis.

Petrographically, the microdiorite is medium-grained, holocrystalline and composed largely of HB and PL phenocrysts and microphenocrysts. The HB phenocrysts are still fairly fresh, but in some grains secondary minerals such as calcite, epidote and magnetite occur in the core or along the margin of the crystal grains. Occasionally, secondary QZ together with epidote, twinned albite and reddish brown haematite substances are also seen to have replaced the HB grains. The PL pheno-and microphenocrysts are lath or columnar in shape, and many of them exhibit sponge-like texture, as the result of partial alteration to a mixture of sericite, epidote, chlorite, magnetite, reddish brown haematite, secondary quartz and possibly some albite. Small patches of clear calcite and micropolycrystalline quartz are present in the rock. In addition, veins which are filled with a mixture of zeolite, quartz, epidote and albite cross-cut the calcite patches or even phenocrysts of HB and PL.
6.10.2 Age

A sample of the microdiorite from the Sungai Julung was taken for radiometric dating. It indicates Danian (63.3 Ma K/Ar dating on hornblende determined by Dr N J Snelling of the British Geological Survey) or Lower Paleocene age. The similarity of the Kayujohara HB andesite to the Julung microdiorite (coarse porphyritic andesite) specimen suggests that a Danian or Lower Paleocene age is most likely for the Kayujohara Formation as a whole. The facts that the microdiorite intrudes pre-Julung microdiorite rocks are in good agreement with the above K/Ar dating result.
CHAPTER VII

PLUTONIC ROCKS

1. RIMUH PLUTON
2. KINTAP GRANITE
7.1 INTRODUCTION

Plutonic rocks in the Meratus Mountains have recently been systematically mapped by Sikumbang et al. (1982). They occur in two prominent northeast trending mountain ranges. The largest outcrop occurs in the Tambak - Tamban Range, on the northwestern side of the Meratus Mountains, and the other occurs to the southeast in the Kintap area, in the central portion of the Manjam Range, facing the Java Sea. The name for the former is Rimuh Plutonic Complex, whereas the latter is called the Kintap Granite. These two areas of plutonic rocks are separated by the Manunggul Basin. The distribution of the plutonic rocks over the area studied and their relationship to surrounding rock-units are shown in Fig. 200.

The plutonic rocks in the Rimuh area, Tambak-Tamban Range, are found to be intimately associated with the volcanic rocks of the Pitanak Formation (see description in Chapter IV). Whilst in the Kintap area, Manjam Range, the plutonic rocks are intrusive into both the Meratus Ophiolite and a sequence of the submarine volcaniclastic deposits of the Alino Group (Chapter V).

7.2 RIMUH PLUTONIC COMPLEX

7.2.1 Description

As mentioned earlier the Rimuh Plutonic Complex forms the core of the mountain ranges, as seen in Gunung Kandis and Gagaro in the Tamban Range and Gunung Ulin in the Tambak Range. The intrusions vary considerably in composition and shape, and they are surrounded by amygdaloidal porphyritic volcanic lava flows of the Pitanak Formation (see Chapter IV). There are at least four types of plutonic rocks present in the range (ascending order): 1. Gabbro, 2. Diorite, 3. Granodiorite, and 4. Granite. Detailed field observations and petrographic descriptions of these rock types are not given herein, because they are out of scope of the present study, and therefore reserved for
FIG. 200. Simplified geological map of the Banjarmasin Quadrangle, showing distribution of the plutonic rocks and adjacent rock-units (modified from Sikumbang et al. 1982).
future work. However, a brief description on field observations of relationships is given below.

Along the Sungai Rimuh and its surrounding area granite forms as dykes and sills or veins in a diorite to granodiorite belt which extends SW from Sungai Maan, N of Gunung Paringin, to the mountain range in the southern portion of the Amuntai Quadrangle. The most abundant rock type is granodiorite and diorite followed by granite.

Field observation along the Sungai Rimuh and Maan, eastern tributaries of the northeast trending Sungai Mangkauk, in the western foothills of Tamban Range, indicate that granite (leucogranite) is associated with fine-grained (aplite). These acid igneous rocks are intrusive into gabbro and diorite, as shown by the occurrence of gabbro and diorite roof pendants and xenoliths within the granitic bodies. Diorite and gabbro also commonly occur in the outer zone of granitic complex (e.g. NS-427 and RH-01 to 14). Some fine-grained basalt occurs as xenoliths in the granitic rocks. Contacts of gabbro and diorite with the granite are sharply defined. The granite also cross-cuts the gabbro and diorite.

On the basis of the above field relationships, the diorites and gabbros are therefore regarded either as an early batholith related to the Rimuh Pluton or perhaps as remnants of leuco-melanocratic rocks of the Meratus Ophiolite. Similar features, where the granites contain xenoliths or inclusions of diorite and gabbro are found within the ophiolite of the Manjam Range. Furthermore, on the basis of field evidence given above, the leucogranitic rocks in the Rimuh Pluton can be considered as the last phase of igneous intrusion.

There are two more important features to be noted herein. Lower Cretaceous limestone (i.e. Batununggul Formation), occurs as a sedimentary xenolith, within the dioritic rocks in the upstream part of the Sungai Mangkauk (NS-423), about 1 km W of Liangkuraku Village.
This indicates that the diorite is post-limestone deposition. The other, the diorite is intrusive into the porphyritic volcanics (amygdaloidal basalt-andesite) of the Pitanak Formation. Similar diorite is also found in Gunung Ulin in the Tambak Range, forming the core of the range.

7.2.2 Age

On the basis of structural relationships and petrographical observations, it is suggested that there are two stages of the formation of the Rimuh Pluton; diorite and granodiorite assemblage, and granite. Due to deuteration of samples for radiometric dating, the precise age of these plutons cannot be given here. However, they are considered to be early Upper Cretaceous or pre-Upper Turonian in age.

The age determination for the Rimuh Pluton is based on the following evidence:

1. Diorite is intrusive into Lower Cretaceous (Barremian-Aptian) limestone of the Batununggal Formation.

2. Field observations and petrographic studies indicate that components of the diorite, granodiorite and granite together with detritus of the Pitanak Volcanic Formation are found in the Upper Turonian-Coniacian conglomerate of the Pamali Formation of the Mangunggul Group, thus suggesting the intrusions to be older than Upper Turonian.

7.3 KINTAP GRANITE

7.3.1 Description

The Kintap Granite is found to be intrusive into the volcanioclastic sedimentary strata of the Alino Group and also cuts the gabbro and dolerite of the Meratus Ophiolite. As mentioned early, this granite is comparable to the Rimuh granite, where it cuts the diorite and gabbro in the Tamban Range (see above).
The granite is found in large outcrops, as shown on the 1:250,000 geological map of the Banjarmasin Quadrangle (Fig. 200), in the village of Riam Adungan, Sungai Kintap. It is massive and shows little variation over the outcrop. However, dykes of a fine-grained granite (aplite) occurs to the north of the main granite body where the intrusion cuts the limestone block set in the coarse volcanoclastic deposit of the Pudak Formation (i.e. lower unit of the Alino Group).

Similar intrusions of granitic rocks in the ophiolitic complex were observed in several localities in the Manjam Range, particularly seen in the upper Sungai Hajawa (Figs. 201 and 202). The granitic rocks here occur as small intrusive plugs or dykes in the ophiolite complex. They seem to cut the dyke complex that consists of metagabbro (NS-576A and NS-576B), metadolerite (NS-576E, NS-576G1 and NS-576G2) and peridotite (NS-576E, see Figs. 201 and 202). The conversion of gabbroic rocks to metagabbroics (epidiorite) is probably related to these granite intrusions.

The granitic rocks from Kintap (NS-0352) and Sungai Hajawa (NS-576C) were both examined petrographically (i.e. unstained thin section) and stained for potassium feldspar and PL feldspar (i.e. the staining method used follows the procedures of Bailey and Stevens 1960 and Laniz et al 1964). These granites are greyish pink (5 R 8/2 to greyish yellow green (5 GY 7/2) with greyish black (N22) small patches, holocrystalline, hypidiomorphic granular, and micrographic or granophyric texture, with the grain size ranging from 0.4mm to over 4mm in diameter (medium-grained). Rock exposures show typical massive fabric. However, they are cross-cut by joints, fractures and veins, and altered to some extent. Fresh rock samples, for radiometric dating, can only be obtained by excavating the outcrop for about 3m from the surface.
Fig. 201 Exposure of metagabbro, metadolerite and ultramafics with granite intrusion, upstream of Sungai Hajawa. Close-up of the granite with its hostrock is shown below.

Fig. 202 Granite ("adamellite") intruded into metagabbro and metadiorite in the ultramafic complex. Upper Sungai Hajawa (NS-576). Note ultrabasic xenoliths (dark grey) within the metagabbro.
The rocks contain essentially PL, QZ, with minor biotite (now largely chloritized). Crystal boundaries are normally straight, but irregular and curved intercrystal boundaries are also present. QZ crystals are strained, showing very strong undulatory extinction. They vary in size, ranging from 2mm - 4.6mm, but they are equant. Many PL crystals are now sericitized or partially replaced by clear calcium carbonate. Similar carbonate aggregates are commonly present along fractures within or in spaces between the crystal grains of QZ and PL (NS-0352). Furthermore, in sample NS-0352, the PL is frequently intergrown with K-feldspar (perthite), and some intergrown with QZ (myrmekite).

Point-count analysis from a stained granitic sample (NS-576C) indicates that the rock consists principally of QZ (30%), PL (32%) and potassium feldspar (35%). Accessory minerals include chlorite (i.e. pseudomorph of biotite, 2%) and magnetite which forms 1% of the rock volume. This rock is classified as adamellite (Hatch et al, 1980) and falls into the "granite" category of Streckeisen (1976).

7.3.2 Age

The granite, which forms the Kintap pluton, was dated by Dr N J Snelling of the British Geological Survey on the basis of whole rock by the potassium-argon (K/Ar) method. It was determined to be 95.3 m.y. This dating figure falls within the early Upper Cretaceous or Cenomanian. The Cenomanian age for the Kintap Granite is also supported by the evidence below:

1. Clasts of granite are found in the Turonian Pamali Formation of the Manunggul Group.

2. Similar granitic intrusions, forming as dykes or sills or even veins cut the gabbro and dolerite of the Meratus Ophiolite in the Sungai Hajawa. This indicates that the Kintap Granite must have been intruded after the emplacement of the Meratus Ophiolite.
3. The granite cuts the late Lower Cretaceous (Albian-Cenomanian) volcaniclastic deposits of the Alino Group in the Sungai Kintap.

4. No granite of the same textural and petrographical characteristics was found as detritus within the Alino Group.

The evidence above confirms the result of radiometric dating (95.3 m.y.), so that the Kintap Granite is of Cenomanian (early Upper Cretaceous) age.
CHAPTER VIII

DISCUSSION AND CONCLUSIONS

GEOLOGICAL AND TECTONIC EVOLUTION OF THE MERATUS MOUNTAINS
8.1 INTRODUCTION

This chapter is an attempt to integrate all units of the Pre-Tertiary rocks in the Meratus Mountains, in order to understand their origins and interrelations. They are interpreted in the context of plate tectonics and the geological evolution of the western Indonesian region.

The Pre-Tertiary rocks in the area studied, which forms the southwestern portion of the Meratus Mountains in the Banjarmasin 1:250,000 Quadrangle, consist of fifteen rock-units (Table 7, Geological Map). Each of these has been defined and placed in a proper stratigraphic framework and setting.

Chapter III presents field and petrographic descriptions, age and possible origin of the dismembered Meratus Ophiolite, and the Hauran Schist and Pelaihari Phyllite. Chapter IV describes the Lower Cretaceous sedimentary rocks consisted of Paniungan and Batununggal Formations. They are preserved as tectonic slices and are the oldest dated strata in the Meratus Mountains. Chapter V deals with the coarse volcanoclastic strata, turbidite deposits and associated cherts (Alino Group) which form the NW and SE flanks of the Meratus Ophiolite. Chapter VI describes sediments and associated volcanics which form a sedimentary basin (Manunggul Group) superimposed on the ophiolite and associated rocks. Chapter VII presents volcanoplutonic rocks which form the Tambak-Tamban Range and Kintap Granite in the southern foothills of the Manjam Range.

From these chapters, five major sequence of geological events can be identified in the evolution of the Meratus Mountains. Each event is characterised by a specific rock sequence and/or tectonic setting. They are summarised in a schematic chronological tectonic history in Figs. 203, 204 and 205. A synthesis of each even is given below.
<table>
<thead>
<tr>
<th>Period</th>
<th>Age (m.y.)</th>
<th>ROCK UNIT</th>
<th>GEOLOGICAL EVENTS</th>
<th>PALEO-ENVIRONMENT</th>
<th>VOLCANOPLUTONIC EVENTS</th>
<th>METAMORPHIC GRADE</th>
<th>TECTONIC EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRETACEOUS</td>
<td>138</td>
<td>BERRIASIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>131</td>
<td>VALANGINIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>125</td>
<td>HAUTERIVIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>119</td>
<td>BARREMIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>113</td>
<td>ALBIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>97.5</td>
<td>CENOMANIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strike, slip</td>
</tr>
<tr>
<td></td>
<td>95</td>
<td>TURONIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>88.5</td>
<td>CONIACIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>87.5</td>
<td>SANTONIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>83</td>
<td>CAMPANIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>MAASTRICHTIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>DANIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>MAASTRICHTIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Subsidence</td>
</tr>
<tr>
<td></td>
<td>54.9</td>
<td>YPRESIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Stretching of lithosphere</td>
</tr>
<tr>
<td></td>
<td>50.5</td>
<td>LUTETIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>50.0</td>
<td>BARTONIAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 7. Summary of stratigraphic framework and geological evolution of the Meratus Mountains, SE Kalimantan.*

*† position of dated sample.*
8.2 EARLY CRETACEOUS (BERRIASIAN-EARLY APTIAN, 144-116 Ma, FIGS. 203, 204 AND 205): SHELF TO SLOPE SEDIMENTATION

The geological history during Early Cretaceous in the Meratus Mountains is based on evidence presented in Chapter IV. From this evidence and published reports (e.g. Koolhoven 1933 and 1935; Hashimoto and Koike 1973; Situmorang 1982 and Priyomarsono 1984), the writer considers that the oldest sedimentary strata in the Meratus Mountains are represented by two litho (tectono) stratigraphic units:

1. Paniungan Formation (Berriasian-Barremian), and
2. Batununggal Formation (Barremian-Aptian).

8.2.1 The Paniungan Formation

The Paniungan Formation is made up largely of mudstone with intercalations of calcareous sandstone and minor limestone exposed in small tectonic windows in two separated sedimentary belts (Fig. 31). Although these two belts are now separated, approximately 40 km from each other, the rocks of the Paniungan Formation are of the same age (see Section 4.1.5, Chapter IV) and exhibit similar depositional environments in both areas. The finely laminated character, poor sorting, lack of burrowing infauna, dark grey to black colour, and the sparse population of benthic fossils found in the mudstone suggest that the Paniungan sediments were deposited in a restricted, relatively low energy, oxygen depleted environment, within an extensive shallow marine shelf. Low energy conditions predominated with occasional higher energy conditions generated either by storms or tides. These currents were responsible for transporting bioclastic grains such as bryozoans, bivalves and coralline algae.

Gradual deepening from near to outer shelf is suggested by decreasing grain size and increasing carbonate content. Terrigenous detritus was derived from the Sunda continent.
Field, sedimentological and paleontological evidence (Chapter IV) indicate that the Paniungan Formation grades upward into, and in some instances even interfingers with, the Barremian-Aptian Batununggal Formation.

8.2.2 The Batununggal Formation

This sedimentary sequence, prior to tectonic disturbances, may represent a regional transgression in the SE, offshore of Sunda continent (Figs. 203 to 205). The strata both here and also elsewhere in Kalimantan comprises bioclastic limestone and now occurs in three different tectonostratigraphic units:

1. autochthonous (intact limestone),
2. parautochthonous (thrust sheets), and
3. allochthonous (exotic blocks).

Detailed descriptions and depositional environmental interpretations of these units can be found in Chapters IV and V.

The Batununggal Formation crops out sporadically. In the northern part of the study area, in the Tambak and Tamban Ranges, the sequence is autochthonous because the limestones there are not disrupted and redeposited, and do not show any deformational features such as cleavage, complicated calcite and quartz veining, shear planes and pressure solution. The occurrence of granite and granodiorite pebbles, quartz and plagioclase suggests that the formation was deposited directly on the granitic basement complex of the Sunda continent. This autochthonous sequence comprises bryozoan lime packstone-boundstone and Orbitina-wackestone, deposited in a subtidal shelf environment; under aerobic, moderate to low energy conditions. The sequence is largely obscured by overlying PL-phyric lava flows and diorite and granite intrusions. Further north, i.e. in the southern
FIG. 203. Paleo geological and tectonic sketches showing evolution of southeastern Kalimantan and adjacent areas from Early Cretaceous (Barremian, 144 Ma) to Early Paleocene (Danian, 63 Ma).
FIG. 204. Series of diagrams showing tectonic evolution of South-East Kalimantan.
part of the Amuntai Quadrangle (Heryanto et al in prep.), the Batununggal Formation was deposited closer to the shore, under higher energy conditions. The energy conditions of deposition were higher than those of the southern part of the study area.

In the southern part of the study area, the sequence is paraautochthonous or allochthonous. In the Sungai Kintap, at least five limestone lithofacies can be recognised: 1. echinoderm, molluscan and coraline algae-rich packstone (mass-flow); 2. planktonic-ammonite-bearing lime mudstone; 3. massive bioclastic wackestone and packstone (mass-flow); 4. Orbitolina-bearing lime mudstone; and 5. sponge spicular lime mudstone. They were probably deposited in outer shelf to slope environment dominated by turbidity current generation but interspersed with low energy, anoxic, suspension sedimentation.

In the Sungai Batubeguntur, three carbonate lithofacies are recognised: 1. massive bioclastic lime mudstone and wackestone; 2. bedded Orbitolina-bearing lime mudstone-wackestone; and 3. graded bioclastic lime wackestone-packstone. They were also deposited in a slope environment but with reef-derived coral fragments.

The sponge spicular limestone lithofacies which appears to be the uppermost lithofacies of the Batununggal Formation in the Sungai Kintap is significant. It contains fresh crystals of plagioclase, clinopyroxene and hornblende, volcanic lithic grains (i.e. microlithic and porphyritic volcanics) and ash; but no continental derived grains. This suggests that the onset of volcanic activity was contemporaneous with sedimentation. Similar crystals and lithic clasts are the main constituents of the overlying Alino Volcaniclastic Group which contains blocks of spicular limestone (Pudak Formation, see Chapter V). The environmental changes between the Lower Cretaceous sedimentary strata (Paniungan and Batununggal Formations) and the
Alino Group are probably related to the development of subduction in the Tethys Ocean (Figs. 203 and 204).

From the foregoing discussion there can be little doubt that the Paniungan and Batununggal Formations were closely related in time and space. A reconstructed facies model for these two formations is shown in Fig. 205. It shows the inferred lateral facies variation on the southeastern Sunda continental margin. Further southeast, the carbonates are more likely to have been underlain by oceanic crust of the Tethys Ocean.

On a regional scale, the Lower Cretaceous sedimentary strata, in particular the Orbitolina-bearing limestones and associated carbonates are widely distributed and therefore are very characteristic in Kalimantan, flanking the island on the southeast, northeast, north and northwest (Fig. 203A). In the Segama Valley and Darvel Bay areas and in Sarawak the carbonates (Madai-Baturong Formation, Barremian-Albian) are largely represented by oolitic and molluscan limestones with subordinate Orbitolina-bearing limestones deposited in clear, shallow shoals or lagoons (e.g. Adams and Kirk 1962; Kirk 1962; Adams 1963; Leong 1974). Slope carbonates, as found in the Batununggal Formation of the Meratus Mountains, have not been reported in these areas. Note that the oolitic and molluscan limestones which represent lagoonal or shoal carbonates are only present in the form of redeposited fragments in the Batununggal Formation.

According to Fitch (1955), the limestones in the Segama Valley and Darvel Bay are closely associated with submarine volcanic rocks and cherts (Chert-Spilite Formation here correlated with the Alino Volcaniclastic Group). This association is similar to that in the Batununggal Formation in the Meratus Mountains where the limestones are unconformably overlain by volcaniclastic deposits and associated
FIG. 205. Facies model for carbonates of the Batununggal Formation
A. Model after Coogan (1969). B. Inferred lateral facies distribution on the southeastern Sunda continental margin. In the southeast, the carbonates are more likely to have underlain by oceanic crust.
cherts of the Alino Group (Sikumbang, in this thesis). Batununggal type limestones occur as one of the most conspicuous components in the submarine volcanic debris flows of the overlying Pudak Formation (i.e. basal unit of Alino Group).

*Orbitolina*-limestones and associated carbonates also occur in neighbouring islands, such as in western part of Sulawesi, central Java and South Sumatra (cf. Bemmelen 1949; Hashimoto and Koike 1973; Asikin 1974; Hashimoto 1975).

All the evidence above offers a firm basis for regional correlations, and therefore will lead to the conclusion that the Lower Cretaceous carbonate sedimentation and associated rocks were widely distributed around the margins of the Sunda continent (Fig. 203A).

The occurrence of dismembered ophiolitic slices within the tectonic complex of the Meratus Mountains indicates that the Tethys oceanic lithosphere was present to the southeast of the Sunda continental margin, as can be seen in Fig. 203. If this is the case, the Lower Cretaceous strata, in particular the offshore part of the Batununggal Formation, were probably deposited on the Tethys oceanic crust (Figs. 203A and 204A). At the end of Early Cretaceous sedimentation, the shelf-slope basin had been filled, and by that time major submarine volcanic eruptions had begun producing the volcanlastic components of the Alino Group.

8.3 **EARLY CRETACEOUS (LATE APTIAN-EARLY ALBIAN, 116-108 Ma, FIG. 206A AND B): SUBDUCTION AND OPHIOLITE EMLACEMENT**

8.3.1 **Subduction**

As mentioned above the Tethys oceanic crust was already present to the southeast of Sundaland during deposition of the Late Barremian-Early Aptian Batununggal Formation. This oceanic crust was subducted westwards and northwestwards beneath the east and southeast Sunda
FIG. 206. Block diagrams showing the original (first) emplacement of the Meratus Ophiolite along the margin of Sunda continent. During this stage a number of oceanic slices is being tectonically inserted and incorporated with shelf to slope continental margin strata. (cf. North Sumatra at the present time, see Page et al 1979 and Karig, et al 1980).
continental margin giving rise to an island arc (Fig. 203B and 204B), the Alino Volcaniclastic Group. It is assumed that the subduction zone, together with the volcanic arc extended northwards as far as North-East Kalimantan, and to the southwest, west and then northwest. The arc and its associated rocks are preserved as allochthonous terranes in Central Java, West Java and the western margin of Sumatra (cf. Katili 1973; Hamilton 1979).

An active subduction zone to the southeast of the Sunda continental margin in the late Early Cretaceous time (Figs. 203B, 204B, 206A and B) is evidenced by:

1. the Alino Group, Albian to Early Cenomanian in age, represents the remnant (accreted terrane) of a volcanic island arc.

2. rocks of the Hauran Schist and Pelaihari Phyllite have been metamorphosed to greenschist and amphibolite facies; a grade of metamorphism often ascribed in the literature to subduction processes. The metamorphic event has been dated at 108.4 Ma (K/Ar). Possible extension of this subduction are suggested by the occurrence of high P blueschist metamorphic rocks to the northeast of the study area (Sampanahan Quadrangle, Supriatna 1982) and so also to the southwest where metamorphic rocks of similar age have been encountered in offshore wells (Ben-Avraham 1973; Bishop 1980). In the south arm of Sulawesi, blueschists and eclogites, with K/Ar date of 111 Ma on muscovite, have been reported by Sukamto (1975). Blueschists have been recorded at Lok-Ulo, Central Java (Dr A J Barber, pers. comm. 1986). It has also been suggested that comparable rocks in the Lolotoi Complex are a part of the same Cretaceous subduction trend (Barber 1976 and 1977; Earle 1979).
3. Plutonic rocks of early Late Cretaceous age (95.3 Ma or Early Cenomanian) intrude the Alino Volcaniclastic Group in the Sungai Kintap. This indicates that the development of the Alino island arc was completed by the intrusion of early Cenomanian granite. Comparable granitic rocks, averaging 100 Ma have long been reported by Katili (1971 and 1973) and Ben-Avraham (1973) in the offshore area of Java. These have been regarded as Cretaceous plutonic belt, produced by subduction in the southeast, that runs from the Meratus Mountains, passing the offshore area of Java, to the western side of Sumatra.

4. the northwestward subduction of the Tethys oceanic crust beneath the Sunda continental margin is consistent with magnetic lineation patterns in the Wharton Basin (south of subduction zone) where Johnson (1976) suggested that active spreading occurred in the late Early Cretaceous (130-100 Ma), with the northeast-southwest trending basin representing the extinct spreading centre.

From the above evidence it can be concluded that the late Early Cretaceous event involved deformation, low to high grade metamorphism, volcanic activity and granite intrusion.

8.3.2 Emplacement of Ophiolite

The dismembered nature of the Meratus Ophiolite has been described in Chapter III. The rock sequence now exposed compares very favourably to well documented cross-sections of the oceanic crust and upper mantle (see Fig. 30). Noted that mafic sheeted dyke complex, mafic volcanic pillow lavas and pelagic sedimentary cover (i.e. radiolarian chert and pelagic limestone) are missing in the ophiolite section.
One of the most important pieces of field evidence is that these ophiolitic rocks are flanked on the northwest and southeast of the Meratus Mountains by an assemblage of coarse to fine volcanioclastic turbidites of the Alino Group, which also contains intercalated cherts and radiolarians. This evidence undoubtedly indicates island arc activity occurred after the original emplacement of the Meratus Ophiolite. The development of volcanic arc above the ophiolite and associated tectonic slices will be interpreted and discussed in the following section.

In an attempt to deduce the ophiolite emplacement in the Meratus Mountains, many papers from various examples in the world, e.g. the Oman Mountains, Cyprus, New Guinea and Newfoundland have been consulted. The most comprehensive references are in Dewey and Bird (1971), Church and Stevens (1971), Coleman and Irwin (1977), Panayiotou (1980) and Gass et al (1984).

One of the major problems in deciding how and when the ophiolite was emplaced is that after its formation it has frequently been involved in additional tectonic movements. Interpretation of the tectonic events leading to the emplacement of ophiolite in the Meratus Mountains is much more complex than was originally envisaged (e.g. Priyomarsono 1984), and unlikely to have occurred as a single event.

Based on field relations between the ophiolite and adjacent rock units, regional geology and petrographic examinations of volcanioclastic deposits of the Alino Group (see Chapter V) and calcareous terrigenous strata of the Manunggul Group, I suggest that the Meratus Ophiolite has undergone at least two periods of tectonism in its emplacement to its present position. These are:
1. one phase during or shortly after its formation, prior to or concurrent with onset of volcanic arc activity (the Alino Group deposition), and
2. a second phase, post arc formation but prior to the Manunggul Group deposition, when it was emplaced in its present position.

These periods of tectonism are based on the following evidence:

1. ophiolitic detritus is found both in the Albian-Cenomanian Alino Volcaniclastic Group and the lowest unit (Late Turonian-Coniacian Pamali Formation) of the Manunggul Group;

2. the Alino Group also contains components from the Lower Cretaceous sedimentary strata (i.e. Paniungan and Batununggal Formations), therefore both the ophiolite and the Batununggal Formation must have been emergent near to the onset of volcanic arc development.

The two phases of tectonism related to the emplacement of ophiolite mentioned above fit well with the arc - continent collision model (cf. Jaques and Robinson 1977), as will be discussed below (see Figs. 203C and 204C). The first phase tectonism affecting the original emplacement of the ophiolite is discussed below, whereas the emplacement to its present position will be discussed later.

8.3.3 Emplacement after Ophiolite Formation (first emplacement)

As initial relations of the ophiolite with adjacent rock units have been completely destroyed, it is extremely difficult to interpret the tectonic events affecting the ophiolite. However, the presence of ophiolitic detritus (e.g. gabbro, leucocratic and ultramafic rocks and radiolarian chert) together with detritus from the Batununggal Formation in the volcaniclastic deposits of the Alino Group, strongly
suggest that both the Batununggal Formation and the ophiolite were emergent at the onset of arc development. The ophiolite and the Batununggal Formation were both providing detritus contemporaneously with the deposition of the Alino Group. This may suggest that the ophiolite and Paniungan and Batununggal Formations were juxtaposed by the onset of Alino island arc development.

It is postulated here that the tectonic juxtaposition of two unrelated rock assemblage was probably due to a transcurrent fault along the southeastern Sunda continental shelf-slope. This is in agreement with transcurrent faulting being an important mechanism for ophiolite emplacement (Brookfield 1977; Saleeby 1977). If this is correct then the northern margin of the Tethys oceanic lithosphere would have been juxtaposed by transcurrent faulting against southeastern margin of the Sunda continent (Fig. 206A). As a result the Paniungan Formation and the Batununggal Formation were segmented, sliced and tectonically dispersed and incorporated into the highly deformed Meratus Ophiolite. It has been proposed that such tectonism including disruption and tectonic mixing (dispersing) processes can occur during a change in plate motions where two lithospheric plates move at an oblique angle (e.g. Page et al 1979; Karig et al 1980; Coney et al. 1980 and Barber 1985).

As the transcurrent movement changed its direction, due to oblique convergence, the slices of ophiolite and Lower Cretaceous sedimentary rocks (Paniungan and Batununggal Formations) formed a sequence of imbricate structures. Such tectonic slices might be incorporated in the accretionary prism, prior to the formation of the Alino arc (Karig et al 1979; Moore et al 1980). The change of transcurrent faulting to an oblique subduction regime is believed to have been in response to a northwest-southeast spreading ridge, south of Kalimantan. The presence of a spreading ridge is supported by
magnetic lineation patterns in the Wharton Basin (see Johnson et al. 1976). As stated earlier, the Alino submarine volcanioclastic deposits were built upon a complex of accreted material from both oceanic crust and associated rocks and the continental shelf to slope sedimentary strata (Fig. 206B), as discussed below.


Detailed mapping together with thorough sedimentological, petrographic and paleontological observations in the pre-Tertiary rocks of the Meratus Mountains (Chapter V) have provided invaluable information on the distribution of the volcanioclastic sedimentary sequence that makes up the Pudak (lower) and Keramaian (upper) Formations of the Alino Group. The deposition of the Alino Group was taking place during late Early–Cretaceous to early Late–Cretaceous (Albian to Early Cenomanian). The time required for this deposition is about 13 m.y. (Table 7).

The lithology, sedimentary structures and paleontological evidence examined in the Alino Group (Chapter V) are suggestive of gravity flow deposits (i.e. debris flows and turbidites) largely derived from arc and subordinate adjacent basement rocks. Both formations of the Alino Group are considered to have been deposited around an active volcanic arc during late Early Cretaceous. The occurrence of slope to basinal limestone clasts and blocks together with subordinate detritus from ophiolitic rocks including rare foliated radiolarian chert suggest that the rear and fore-arc basins were bounded and/or partly floored by slices of oceanic crust and deep-marine carbonate sediments. A similar submarine phase of arc volcanism has been suggested for the origin of the Lesser Antilles arc (Sigurdson 1980), the New Hebrides arc (Mitchell 1970), the Mariana
arc (Hussong et al. 1982) and Jasper Point Formation, Mariposa, California (Bogen 1985).

To the southeast of the Meratus Mountains, beyond the study area, outcrops of radiolarian chert with association of volcanioclastic sandstones are also found. They occur in the vicinity of Gunung Kukusan, southeastern coast of South-East Kalimantan, and on the western coast of the island of Pulau Laut (Rustandi et al. 1982). If island arc model for the Alino Group in the Meratus Mountains could be accepted, thus the cherts and volcanic sandstones further southeast, as exposed in the two areas mentioned above, may have also been a part of the island arc related basins deposited further offshore perhaps in an inner slope or trench slope break setting. The setting of these volcanioclastic deposits with radiolarian cherts association can closely be compared with those found in the rear and fore-arcs of the Marina island (Hussong et al. 1982).

One of the most interesting correlation to be made is that of the occurrence of radiolarian cherts and associated terrigenous sandstones in the Pangkajene Valley in South Sulawesi (Haile et al. 1979); the occurrence of the Noni Formation at Booi, Lalan Asu, Noil Noni and Noil Toko in West Timor (Barber et al. 1977; Rosidi et al. 1979; Haile et al. 1979 and Earle 1983). Volcanioclastic deposits, which can be compared to those of the Alino Group, have been reported to occur in Sumba (Chamalaun et al. 1981 and von der Borch et al. 1983). Both the age of the radiolarian chert succession as well as the volcanioclastic deposits above is either of Late Jurassic or Early Cretaceous (e.g. Haile et al. 1979; Chamalaun et al. 1981; von der Borch et al. 1983 and Earle 1983). It has been suggested by a number of workers the radiolarian chert succession in South Sulawesi, Timor and volcanioclastic strata in Sumba could represent parts of a fore-arc basin formed along
the margin of the southeastern Sunda continent (Hamilton 1977, 1979; Earle 1983 and Audley-Charles 1985). This suggestion is in good agreement with the present study in the Meratus Mountains where they can be satisfactorily correlated with that of the late Early Cretaceous Keramaian Formation of the Alino Group.

8.5 EARLY LATE CRETAUCEOUS (LATE CENOMANIAN-EARLY TURONIAN, 95-90 Ma, FIGS 203C, 204C AND 207): ARC-CONTINENT COLLISION, OPHIOLITE EMMPLACEMENT RENEWED SUBDUCTION (WITH MAGMATIC ARC) AND STRIKE-SLIP MOVEMENT

Four main tectonic events have been recognised during Late Cenomanian-Early Turonian, between 95 and about 90 Ma B.P. These are as follows (Figs. 203C, 204C, 207 and Table 7): 1. arc-continent collision; 2. final emplacement of ophiolite (obduction); 3. renewed subduction; and 4. strike-slip movement.

8.5.1 Arc-Continent Collision

Stratigraphical, sedimentological and structural constraints together with paleontological and radiometric data and interpretation of pre-Tertiary rock units present in the Meratus Mountains strongly suggest that the Alino island arc (see above) had collided with the southeastern margin of the Sunda continent by early Late Cretaceous, post-dating the Kintap Granite (95 Ma) but prior to the renewed subduction and strike-slip movement. During this arc-continent collision the Alino island arc with a narrow slab of oceanic crust and mantle on its northern end was overthrusted or obducted onto the leading edge of the Sunda continent, which probably consisted of pre-Cretaceous volcano-plutonic rocks and/or metamorphics (craton), with a cover of Lower Cretaceous continental shelf sediment (cf. Paniungan and Batunuggal Formations).

The collision is thought to have developed in response to Late Cretaceous (100-80 Ma) spreading in the Wharton Basin (Johnson et al 1976). This arc-continent collision, in some respects, can be

375
compared with that of Papua New Guinea (Jaques and Robinson 1977) where the collision has produced shortening at the continental margin, emplacement of the ophiolite, and uplift and segmentation or fracturing of the accreted arc.

8.5.2 Emplacement of Ophiolite to its Present Position (final emplacement (Fig 207)

As mentioned above, the Meratus Ophiolite was emplaced or obducted in response to the arc-continent collision. There are good stratigraphic, sedimentological, paleontological and radiometric evidence to constrain the timing of the emplacement of the Meratus Ophiolite and the Alino arc against the Sunda continental margin to the northwest.

Using the sandstone composition and paleontological data from the Pamali Formation which represents the basal unit of Manunggul Group, together with structural and stratigraphic relations of the Meratus Mountains, a model for the emplacement of ophiolite to its present position can be constructed, as shown in Fig. 207. It has been stated in Chapter VI that the Pamali Formation contains significant amount of ophiolitic sandstone (ultramafarenite petrofacies), occurring adjacent to the margins of the Manunggul Basin.

As the age of the formation is almost the same everywhere in the basin, i.e. Late Turonian to Coniacian (Chapter VI), therefore it can be concluded that the emplacement (obduction) of the Meratus Ophiolite, including its associated rocks, to its present geological and tectonic setting was completed by Early Turonian time, contemporaneous with the obduction of the Alino arc. At this time, ophiolitic detritus was being shed into the Manunggul Basin. Sediments derived from the Manjam and the Bobaris Ranges nearly filled the Manunggul Basin to sea level by the end of the Late Cretaceous. At the same time the Tambak-Tamban volcano-plutonic arc, formed during
FIG. 207. Block diagram showing obduction of the Meratus Ophiolite and associated rocks (e.g. Alino arc volcanics) onto Sunda continental margin. During this tectonic event the Manunggul pull-apart basin was initiated.
or very shortly after the arc-continent collision, supplied sediments from the north.

8.5.3 Renewed Subduction and Volcano-Magmatic Arc

It has been indicated in the previous subsection that a volcano-plutonic arc, represented by the Pitanak Volcanic Formation and Rimuh Granite (Chapter VII), was also formed during or shortly after the Alino arc-continent collision. This is interpreted as a result of northwestward subduction of the Tethys oceanic crust which was developed in response to the closure of a narrow strip of oceanic lithosphere behind the Alino arc along the site of the present Meratus collision zone.

If this can be accepted the Pitanak Volcanic Formation and Rimuh Granite in the Tambak-Tamban volcano-plutonic complex may have been a southeastward facing magmatic arc with the earlier accreted Meratus Mountains being reheated by rising of magma from the reactivation of a previously already active subduction zone.

8.5.4 Strike-slip Faulting

A sequence of alluvial fan, marginal marine to submarine fan of Late Cretaceous to Early Tertiary (Late Turonian - Early Danian) age has been included in the Manunggul Group (see below). The group was accumulated in an elongated basin in the central part of the Meratus Mountains (Chapter VI). A detailed sedimentological description and interpretation of all rock units present in the group indicates that the geometry and evolution of the Manunggul Basin requires a structural explanation.

This Manunggul Basin is thought to have been developed within a zone of strike-slip faulting, as a pull-apart basin, which opened during Late Cenomanian-Early Turonian deformation (Table 7).
Sedimentological evidence indicates that strike-slip faulting began during or shortly after the arc-continent collision (see above, Fig. 203C, 204D and 206), in a tectonic regime characterised by oblique convergence. The development of the basin was contemporaneous with and terminated by volcanic activity (Table 7).

The above interpretation is supported by the following evidence. As shown in the geological map (see back pocket), two major northeast-southwest trending strike-slip faults have been recognised in the field. These are inferred to be sinistral strike-slip faults which bound the Manunggul Basin to the north, the Bukit Besar Fault, and in the south the Kintap Fault. There is ample evidence of sinistral strike-slip faulting along the Kintap Fault. It is found in adjacent fault zones and in the Pudak Volcaniclastic Formation (Chapter V). These include: 1. shearing and slickensides along the fault zone, with occasional inclusion of highly tectonised ophiolitic slices within the adjacent highly deformed Pudak Formation; 2. structural disruption or slicing of the cleavage and rigid clasts (e.g. limestone and gabbro); 3. subparallel to oblique extension in the cleavage plane; 4. veins are displayed along sinistral faults; 5. common occurrence of strike-slip faults at various scales; and 6. common occurrence of steep faults and thrusts (Chapter V). The Bukit Besar Fault, on the other hand, is inferred on the basis of the following evidence: 1. shearing and slickensides near the fault zone, but less intense than that of the Kintap Fault; 2. sudden change in lithology, from calcareous ophiolitic sandstone (ultramafarenite) of the Pamali Formation (i.e. Manunggul Group) to PL-phyric basaltic andesite flows of the Pitanak Formation to the north; and 3. the Tertiary sequence exposed south of Gunung Tamban was cut by straight fault, more likely displaced from the Tertiary outcrops exposed in the southeast. (Chapter VI).
Furthermore, the traces of the NNE-SSW faults cross-cut the two major strike-slip faults. It is suggested that the fault patterns seen in the basin are a reflection of faulting in the basement.

8.6 LATE CRETACEOUS-EARLY TERTIARY (LATE TURONIAN-EARLY DANIAN, 90-63 Ma FIGS. 203C, 204D AND 206): PULL-APART BASIN

The Manunggul Basin was developed as two subbasins. The Sungai Riam Kanan Subbasin in the south was partly separated from the Riam Kiwa Subbasin in the north by an uplifted mid-basin thrust sheet (horst) composed of the Bobaris Ophiolite Range and associated rocks, with slices of the Paniungan Formation (Fig. 131 in Chapter VI). The basin is bounded in part by rocks of the Hauran Schist and the Alino Group.

The sedimentology, tectonic style, and the regional setting, suggest that the Manunggul Group accumulated in a pull-apart basin similar to those found along the San Andreas Fault, California (Crowell 1974 a and b). The development of the basin can be divided into five main stages. They are: 1. Turonian-Coniacian Pamali Formation; 2. Santonian Benuarium Formation; 3. Campanian Tabatan Formation; 4. Maastrichtian Rantauajung Formation; and 5. Paleocene Kayujohara Formation. The Benuarium and Kayujohara Formations are both volcanogenic, indicating that arc volcanism was still active during the development of the basin (Table 7).

8.6.1 Turonian-Coniacian

The basal Pamali Formation forms the major basinal fill (see Figs. 155 and 185, Chapter VI). In the Riam Kanan Subbasin conglomerates, pebbly sandstones and sandstones derived from the surrounding terrains accumulated in alluvial, coastal and shallow marine environments. Source terrains include the highly deformed Meratus Ophiolite, Hauran Schist, Alino Volcaniclastic Group and Paniungan and Batununggal Formations.
At the southern margin of the Riam Kiwa Subbasin, thick bedded alluvial fan conglomerates and sandstones (1500-2000m) pass northeastward into a thick (5000m) sequence of submarine fan deposits as superimposed fan lobes.

8.6.2 Santonian

In Santonian time, subaerial to very shallow submarine basic through intermediate to acid volcanism produced the Benuarium Formation in the Riam Kanan Subbasin. The occurrence of this volcanic formation indicates that arc volcanic activity have also played as an important role in the development of the Manunggul Basin. The arc volcanism was more likely formed simultaneously with strike-slip fault (Figs. 203C and 207). The combination of arc volcanism and strike-slip components, which apparently controlled the evolution of the Manunggul Basin, bears great similarity to Sumatra where such processes dominated the geology of Sumatra during Late Cretaceous-Early Tertiary and Late Oligocene-Early Miocene (e.g. Karig et al 1979 and 1980).

8.6.3 Campanian

The Tabatan Formation accumulated in alluvial fan and sandy braided stream environments after the cessation of Benuarium volcanic activity. Coarse alluvial conglomerates and pebbly sandstones occur in the lower part of the sequence (Mihak Member), giving way to lower energy braided stream sandstones in the upper part (Pahiyangan Member). They were derived from the uplifted metamorphic, igneous and sedimentary terrains and from the volcano-plutonic arc. A formation thickness of 1800m has been estimated along the central axis of the Riam Kanan Subbasin, thickening northward.
8.6.4 Maastrichtian

Non marine or lacustrine black estheriid shales of the Rantaulajung Formation interfinger with the fine grained sediments of the Tabatan Formation and are exposed in the core of a syncline in Manunggul Basin, Riam Kanan. They reflect stable tectonic conditions during the Maastrichtian.

8.6.5 Danian (Paleocene)

Regional uplift accompanied commencement of volcanic activity during the Paleocene, characterised by subaerially extruded hornblende-phyric andesites and pyroclastics of the Kayujohara Formation (Table 7). At the same time, microdiorites were intruded into earlier units of the Manunggul Group. These intermediate igneous intrusions, together with volcanic extrusions and explosions mark the final phase of magmatic activity in the Meratus Mountains. Their occurrence suggests that renewed subduction in the southeast occurred during the Early Paleocene (Fig. 208). This igneous activity may correspond to the enlargement of the Wharton Basin, prior to the formation of marginal seas in the Makassar Strait and the Java Sea.

Shortly after the cessation of magmatic activity, probably in the Late Paleocene or Early Eocene, South-East Kalimantan on the southeastern margin of Sunda continent was rifted and drifted and its fragments moved east and southeastwards (Fig. 208). Fragments showing a strong affinity to the Meratus Mountains are now found in South Sulawesi, Timor and Sumba islands. The rifting stage was subsequently accompanied by subsidence (Situmorang 1982). At the same time, the Tertiary basins of Barito, Asem-Asem and Kutai were developed, which now flank the Meratus Mountains in the west, southeast and north, respectively. In the Makassar Strait a Tertiary basin was also formed as explained in detail by Situmorang (1982), by stretching of the lithosphere in the Early-Middle Eocene time.
FIG. 208. Paleogeographical and tectonic sketches showing evolution of South-East Kalimantan and adjacent areas from Early Paleocene to Present Day.
At present the Tertiary sedimentary basins of the southern and eastern Kalimantan act as wide back-arc or marginal basins (with continental basement) of the present islands of Java and Sulawesi. Similar sedimentary patterns also originated in or adjacent islands of Sulawesi, Java and Sumatra. From the present configuration of these islands it is clear that the pre-Tertiary subduction system migrated outward or away from the Sunda region. As a result, magmatic arcs with fore-arc basins and trenches have been developed and are still being developed along the islands of Sumatra and Java (e.g. Karig et al 1980; Moore et al 1980; Pulonggono and Cameron 1984). To the southeast, northward drift of the Australian continent during the Miocene and continuing into the present day is complicated by the development of arc and fore-arc basins and trough or trench sequences in the eastern Sunda Arc and the Banda Arc (Katili 1973; Hamilton 1979; Barber 1985). Because of this, the Meratus Mountains have since the Eocene been protected from direct tectonic activity by the intervening oceanic fragments, continental blocks and magmatic arcs from the interaction of three major plates lying in the south, east and northeast, i.e. the Indian-Australian, Pacific and the Philippines, respectively.

CONCLUSIONS

Table 7 (see above) gives a summary of the pre-Tertiary stratigraphic framework as well as sedimentary, igneous, metamorphic and tectonic events in the Meratus Mountains. From the foregoing descriptions and discussions, the following conclusions can be reached:

1. The pre-Tertiary stratigraphic framework, together with age, composition and environment of each unit, and the relationships between units, as shown in Table 7, has been modified in accord with the light of modern stratigraphic principles.
2. The Paniungan Formation is the oldest sedimentary unit that has been dated, ranging from Berriasian to Early Barremian age. The overlying Batununggal Formation ranges from Late Barremian to Early Aptian age.

3. During the Berriasian to Early Aptian, a continuous sedimentary succession, i.e. Paniungan and Batununggal Formations, was laid down in a shallow marine to slope setting on the southeastern margin of Sunda continent. Sedimentation was terminated by the onset of volcanism, as shown by fresh volcanic material (e.g. plagioclase and clinopyroxene) in the uppermost lithofacies of the Batununggal Formation.

4. The Berriasian-Early Aptian Basin was partly underlain by the Tethys oceanic lithosphere.

5. Three events are recognised in the Meratus Ophiolite: 1. its formation; 2. its displacement (strike-slip) from its original position; and 3. its emplacement (obduction) onto the continental margin, which later strike-slipped, to form a pull-apart basin.

6. A submarine island arc, represented by the Alino Group (Albian-Early Cenomanian age), developed within a complex of heterogeneous tectonic slices (allochthonous terranes) composed of oceanic crust and associated rocks and Early Cretaceous sedimentary strata.

7. Metamorphic rocks (i.e. Hauran Schist and Pelaihari Phyllite) have been dated at 108 Ma. The grade of metamorphism ranges from greenschist to amphibolite. High pressure blueschist metamorphic rocks occur only to the northeast of the area studied (i.e. Sampanahan Quadrangle, Supriatna et al 1982).
8. Two granites are recognised:
   1. Kintap Granite in the south is in the Manjam Range, dated as 95.3 Ma. It is intimately associated with the Alino sub-marine volcanic arc.
   2. Rimuh Granite in the north is in the Tambak-Tamban Range. It occurs in close association with the Pitanak Volcanic Formation.

9. Alino arc-Sunda continent collision occurred in the Late Cenomanian-Early Turonian times.

10. Manunggul Group, Late Turonian-Danian age, is interpreted as a pull-apart basin. It was generated by strike-slip displacement.

11. Four phases of volcanic activity are recognised. They are represented by the following units: 1. Albian-Cenomanian Alino Group; 2. Early Turonian Pitanak Formation; 3. Santonian Benuarlam Formation; and 4. Maastrichtian-Danian Kayujohara Formation. The latter two were developed during the formation of Manunggul Basin. Phase 2, 3 and 4 were associated with the cycle of Late Cretaceous orogeny in the present Meratus Mountains.

12. Parts of the Meratus Mountains (SE Kalimantan) were rifted and drifted and their fragments moved eastward and southeastwards in Late Paleocene time, and now form allochthonous terranes of southwest Sulawesi, Timor and Sumba islands.
RECOMMENDATIONS FOR FUTURE RESEARCH

Although the Pre-Tertiary rocks in the Banjarmasin 1:250,000 Quadrangle are the key to resolving the geology and tectonics of the Meratus Mountains, and have been thoroughly studied by the writer, further studies are still needed. The area studied should be extended northeast and eastward of the Banjarmasin Quadrangle to include the remaining parts of the Meratus Mountains, Pulau Laut and Sebuku.

Recommendations for future research are:

1. Further studies of the Meratus Ophiolite, to include detailed lithological and structural mapping; combined with petrological, geochemical, paleomagnetic and geochronological (i.e. K/Ar and Rb/Sr dating from gabbro, dolerite, diorite and trondhjemite) studies, in order to prove or disprove the present interpretation of the origin and original position of the Meratus Mountains. These studies should be integrated with other research activities, as outlined below.

2. Further studies on the granite intrusions in the Sungai Kintap in the southeast (Manjam Range) and the Sungai Rimuh in the northwest (Tambak-Tamban Range) are needed in order to elucidate their absolute age, petrogenesis and their geological and tectonic setting. These studies should be undertaken in conjunction with detailed mapping of the granites and their paleomagnetic analysis.

3. Further studies on two major outcrops of the Paniungan Formation, as exposed in the Sungai Paniungan and Sungai Satui, should be continued and concentrated on detailed microstructures and clay mineralogy of the mudstone and heavy minerals from the sandstone intercalations. Since the Paniungan Formation has been
successfully dated by palynomorphs, the study of fossil spores should be expanded, by collecting more samples from various localities. This study is very important for regional correlation and also for determining paleoclimate.

4. **Studies on mineralogy and geochemistry of the volcaniclastic deposits of the Alino Group.** These should be combined with microstructural analysis.

5. **Further studies on radiolarian cherts,** focusing on detailed lithological mapping and geochemistry. Studies on radiolarian chert dating from clasts of the sedimentary units of the Alino and Manunggul Groups are also necessary in order to locate the missing oceanic sedimentary cover of the Meratus Ophiolite.

6. **Detailed structural and petrological studies of the Pelaihari Phyllite and the Hauran Schist.** It is important to establish type sections for these two metamorphic units.

7. **Further studies on petrography, mineralogy, geochemistry and geochronology of the volcanic rocks from the Benuariam and Kayujohara Formations of the Manunggul Group and Pitanak Formation of the Tambak-Tamban Range** are required.

8. **Studies on the estheriid black shale of the Rantaulajung Formation.** The main problem with this study is that the shale outcrop is now submerged by the Riam Kanan Reservoir. However, for a short term, it is recommended that future worker(s) should contact and discuss the matter with Professor W. Hashimoto.
9. Studies on marine geology and geophysics are also vital to determine deep crustal structure in the offshore area of South-East Kalimantan in order to clarify the tectonic evolution of the Meratus Mountains.

10. All of the studies recommended above should also be undertaken in adjacent islands in order to obtain data from the whole of the Southeastern Sunda continental margin. These include the Pre-Tertiary rocks of South Sulawesi, Java and Western Sumatra. Suspected Sundaland terranes in Sumba and Timor must also be investigated.

These recommendations are designed to provide a full understanding of the geology and tectonic evolution of the Meratus Mountains and the Sunda continental margin as a whole. The success of this very ambitious project largely depends on how specialists in different earth science disciplines combine their information to contribute to a comprehensive multi-disciplinary study.
BIBLIOGRAPHY


HUSSONG D.M., UYEDA S. and others (eds), 1982. DSDP Initial Reports, LX.


KROL L.H., 1918. Topografische en geologische schetskaart van de onderafdeelingen Martapoera en Pleihari.


**RESULTS OF POTASSIUM-ARGON AGE DATING FROM SOUTH-EAST KALIMANTAN, INDONESIA**

<table>
<thead>
<tr>
<th>SAMPLE No</th>
<th>ROCK TYPE</th>
<th>% K</th>
<th>n_{40}Ar/m</th>
<th>%\text{atmos} 40Ar</th>
<th>Age ± error</th>
<th>DATED MINERAL/ROCK</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS-670</td>
<td>Microdiorite</td>
<td>0.372</td>
<td>0.8882</td>
<td>88.76</td>
<td>60.45±5.44</td>
<td>Hornblende</td>
</tr>
<tr>
<td>NS-670</td>
<td>Microdiorite</td>
<td>0.372</td>
<td>0.8682</td>
<td>48.36</td>
<td>59.12±1.67</td>
<td>Hornblende</td>
</tr>
<tr>
<td><strong>Average and error</strong></td>
<td></td>
<td></td>
<td></td>
<td>59.78±3.55</td>
<td>Paleocene (63.3 m.y)</td>
<td></td>
</tr>
<tr>
<td>NS-834</td>
<td>Basic andesite</td>
<td>1.2080</td>
<td>4.2306</td>
<td>25.27</td>
<td>87.93±2.31</td>
<td>Whole rock Santonian (85.6 m.y)</td>
</tr>
<tr>
<td>NS-0352</td>
<td>Granite</td>
<td>0.4553</td>
<td>1.6999</td>
<td>39.58</td>
<td>97.79±2.53</td>
<td>Whole rock Mid Cenomanian (95 m.y)</td>
</tr>
<tr>
<td>NS-527</td>
<td>Metadolerite</td>
<td>1.4360</td>
<td>6.4777</td>
<td>49.74</td>
<td>112.48±3.01</td>
<td>Hornblende</td>
</tr>
<tr>
<td>NS-527</td>
<td>Metadolerite</td>
<td>1.3527</td>
<td>6.8048</td>
<td>04.00</td>
<td>125.00±3.15</td>
<td>Hornblende</td>
</tr>
<tr>
<td><strong>Average and error</strong></td>
<td></td>
<td></td>
<td></td>
<td>118.74±3.07</td>
<td>Mid Aptian (115.7 m.y)</td>
<td></td>
</tr>
<tr>
<td>NS-857</td>
<td>Hb Schist</td>
<td>0.2100</td>
<td>1.0302</td>
<td>87.32</td>
<td>122.00±10.2</td>
<td>Whole rock</td>
</tr>
<tr>
<td>NS-857</td>
<td>Hb Schist</td>
<td>0.2100</td>
<td>1.0049</td>
<td>91.55</td>
<td>119.10±14.17</td>
<td>Whole rock</td>
</tr>
<tr>
<td><strong>Average and error</strong></td>
<td></td>
<td></td>
<td></td>
<td>120.55±12.18</td>
<td>Lower Albian (108.4 m.y)</td>
<td></td>
</tr>
</tbody>
</table>