GEOGRAPHICAL FACTORS INFLUENCING
THE DISTRIBUTION OF HEAVY METAL
TOLERANT INDICATOR SPECIES IN PARTS OF
THE UNITED KINGDOM AND EUROPE

Ph.D.

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1978
ABSTRACT

The distribution of the indicator species Minuartia verna, Thlaspi alpestre and Armeria maritima on metalliferous substrates has been the major focus of attention with mention also of Silene maritima and Cochlearia officinalis. The concept of the indicator species as developed in the literature has been considered and a comparison has been made between the vegetation communities of metalliferous areas and those of serpentine soils with which they have certain aspects in common. The geology and history of mining of British and European ore deposits, insofar as these affect the indicator species, have been investigated. Ecological data has been obtained for metalliferous communities involving the indicator species in Yorkshire, Gwynedd, Derbyshire, the Mendips, Belgium and other regions.

The relationship of Minuartia verna to substrate toxicity, competition and climate has been investigated and the implication of this relationship for succession on spoil materials has been considered. In terms of vegetation succession a parallel with British serpentine areas has been suggested.

The hypothesis of long distance dispersal of the indicator species to mine sites has been evaluated as have suggestions of "in situ" survival since the Late Glacial period. An explanation envisaging survival of the indicator species in heavy metal refugia within the orefields with subsequent spread to mine sites has been advanced and certain refugia have been identified. Some evidence for local disappearance of Minuartia verna and Thlaspi alpestre since the cessation of mining has been found. The sporadic occurrences of certain of the indicator species in metalliferous habitats have been investigated and explanations advanced for some of them. On substrates derived from ore deposits in the Carboniferous Limestone chemical parameters of the metalliferous environment have been found to explain only partially the distribution of the indicator species.
ACKNOWLEDGMENTS

Thanks are due to my supervisor, Professor M. M. Cole, for her advice on many occasions and to Mr. R. Brunsden for his help in the laboratory work. Many others provided assistance at various times; to them I also express my gratitude.
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**CHAPTER 11**

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PART 1

THE ECOLOGICAL AND GEOLOGICAL BACKGROUND, THE AIMS OF THE INVESTIGATION AND THE METHODS OF STUDY
CHAPTER 1

INDICATOR PLANTS,
THE ECOLOGY OF METALLIFEROUS HABITATS
AND
THE AIMS OF THE STUDY

1.1 The indicator concept

Indicator plants are essentially plants diagnostic of particular environmental conditions. They have been recognised in various contexts for a considerable period of time. Plant communities and species indicative of calcareous and saline areas have long been known and Chikisev (1965) mentions the use in Russia of indicator species to find water. Malyuga (1964) states that the inhabitants of Central Africa are guided to springs by the presence of *Acacia glandulifera* Schinz and Cannon (1971) outlines a water finding use for *Acacia greggii* A. Gray and *Prosopis juliflora* D.C. in the South Western United States. According to Cannon (1971) salt domes have been located by Russian workers using the saltwort, *Salsola nitraria* Pall. This species indicated salt domes at depths of 500 metres. There is also a considerable volume of literature on serpentine and gypsum indicators and claims have been made that certain species may indicate gold and diamonds (Cannon, 1971).

In certain areas species characteristic of heavy metal soils were noticed by early naturalists and other interested observers. According to Brooks (1972) the zinc flora of Belgium and Western Germany has been known for well over 100 years, and *Lychnis alpina* L., a copper indicator, appears to have been used by miners in medieval Scandinavia (Vogt, 1942). Farey (1811-17), quoted in Raistrick and Jennings (1965), writes of the association of
Campanula rotundifolia L. with mine hillocks and smelting sites in the Pennines. He describes the species as a "diminutive plant which my worthy patron, Sir Joseph Banks, has observed to be peculiar to spots where lead abounds in the soil." Minuartia verna (L.) Hiern was by 1588, already recognised as a metal indicator species in Europe (Thalius, 1588, cited by Ernst, 1965) and Henwood (1857) observed that at Dolfrwynog in Wales "Persons conversant with the copper turbaries consider the presence of metal in the soil indicated by the growth of the Sea Pink or Thrift (Armeria maritima (Miller) Willd), which appears to flourish there with remarkable luxuriance."

Indicator species have been employed more systematically in recent years. Becium homble (De Wild) Duvign and Plancke has been used in Zambia to discover copper deposits (Horizon 1959) and Pulou et al (1965) employed Armeria halleri Wallr. and Hutchinsia alpina (L.) R. Br. in the Pyrenees to find the sites of old mines and to discover new areas of mineralisation. Cole et al (1968) have used Polycarpaea synandra F. Muell var. gracilis Benth. in the Bulman area of Northern Australia to locate lead-zinc anomalies and Nicolls et al (1965) in the Dugald River area of Queensland showed Polycarpaea glabra C. T. White and Francis and a Tephrosia species to be indicative of mineralised areas. Cannon (1964) working in the Yellow Cat District Utah and using Astragalus spp., located uranium ore bodies missed by a drilling programme.

Cannon (1960, 1971) Malyuga (1964), Antonovics et al (1971) and Brooks (1972) have all produced tables of the various plant species employed as indicators around the world. Brooks (1972), like the other authors, makes a distinction between "universal" and "local" indicator species. He defines the universal indicators as species which will not grow in non-mineralised substrates and which can be used as indicators in any region in which they occur. He points out that the greatest successes in geobotany have been obtained with the aid of such species. The local indicators are, according to Brooks (1972), species adapted to tolerating mineralised ground but which will also grow elsewhere, providing the competition from other species is not too great.
Lambinon and Auquier (1964) introduced a similar classification for the metallophyte vegetation of the Aachen-Liege* area of North West Europe. They distinguish absolute metallophytes, taxa found on metal contaminated soils over all their distribution and Viola calaminaria Lej., Thlaspi alpestre L. ssp. calaminare (Lej.) Markgr. and Minuartia verna (L.) Hiern var. hercynica (Willk.) Friedr. are their examples. They also distinguish local metallophytes, found only on metal contaminated soil within a given region but also occurring in a phyto-geographically distinct non-contaminated area. Armor maritima is one of these.

The compilation of lists of universal and local indicator species appears to be a task fraught with difficulty, especially so in the case of the universal indicators. A critical assessment of the status of the universal indicators of the world will not be attempted here but examples will be selected from the literature to illustrate the types of problems which arise.

In the case of Becium hombleii, considered by some to be a universal indicator of copper, this impression seems to have resulted from insufficient knowledge of the distribution of the species. Recent work by Howard Williams (1970) has shown the plant to occur widely on non cupriferous soils in Zambia and to be not entirely restricted to cupriferous soils in Rhodesia.

A similar case is that of Lychnis alpina in Europe. Brooks (1972) lists the species as a universal indicator of copper citing Vogt (1942) as the authority. However in his paper Vogt (1942) notes the occurrence of the species on serpentine and dunite in addition to cupriferous pyrite deposits and Persson (1956) states that L. alpina, found

* The heavy metal communities of the Aachen-Liege area present a problem. In the 50 km from Aachen to Liege the communities occur in Belgium, Holland and Germany (Fig. 4.1). Heimans (1960) refers primarily to the communities in the Netherlands while Lambinon and Auquier (1964) dealt with the metalliferous sites in Belgium. In the account of the work of the various authors I shall refer to the particular area in which they were working but also take some of their statements to have a regional applicability. I shall generally refer to the mineral field as the Aachen-Liege area.
to be a good indicator of nickel in Northern Finland by Tanner (1930) is characteristic of, but not limited to, outcrops of copper, iron and zinc ores in Scandinavia. *L. alpina* is also known from serpentine rocks in Scotland (Proctor, 1969).

For certain other European species the problem of the designation of a species' universal or local indicator is aggravated by a confused taxonomic situation. In the case of the supposedly universal indicator species of zinc, *Viola calaminaria*, Flora Europaea (1968) suggests that the species is best regarded as a variety of *V. tricolor* L. ssp. *subalpina* Gaudin, a plant of meadows and screes in Southern and Central Europe. Heimans (1960) has also considered the taxonomic position of *V. calaminaria* and regards the plant to be more closely related to *V. alpestris* Becker (probably a synonym for *V. tricolor* ssp. *subalpina*) than to the species *V. lutea* Hudson with which earlier taxonomic opinion had associated it. Schwickerath (1931) was an adherent of the latter taxonomic viewpoint and *V. lutea* is included in certain listings of universal indicator plants, where it almost certainly should not be, with Schwickerath (1931) cited as the authority.

The case of the European universal indicator species of zinc, *Thlaspi calaminare* (Lej.) Lej. and Court, listed in the table in Brooks (1972) is very similar. The most modern taxonomic opinion, that of Flora Europaea (1964) suggests the "species" to be only a local variant, given specific rank, of the more widespread plant *T. alpestre* L.

It would appear therefore that, for certain species, factors such as confused taxonomy, restriction of investigation to one area or country and insufficient knowledge of distribution, dictate that there must be doubt about the claims that these plants are universal indicators.

On the other hand endemism on heavy metal soils has been reported by Duvigneaud and Denaeyer de Smet (1963) after extensive studies of the copper vegetation of Katanga, and their endemic species, which are of course universal indicators, appear soundly established.
Many plant species have forms adapted to the heavy metal environment. Schwanitz and Hahn (1954) showed heavy metal tolerant ecotypes of *Campanula rotundifolia*, *Linum catharticum* L., *Rumex acetosa* L. and *Plantago lanceolata* L. to occur on metalliferous localities near Blankenrode in Germany and Heimans (1960) mentions the occurrence of ecotypes of *Polygala vulgaris* L. and *Ranunculus acris* L. on toxic sites in Belgium.

Halliday (1960) reported *Linum catharticum*, *Galium sterneri* Ehrendorfer and *Briza media* L. from lead tips in the Northern Pennines and large numbers of species are known from soils elsewhere rich in heavy metal. In Rhodesia alone Wild (1968) identified 436 Angiosperms from copper soils, although he did not present much evidence relating to the copper concentration of these soils.

Many of the species of Wild (1968) and other workers are common constituents of the regional flora and cannot easily be used to prospect for ore deposits. Therefore, from a substantial global body of heavy metal tolerant species, investigators have selected a number of indicator plants; species which have been used or which they believed might be used in prospecting for ore deposits. The recent publications by Antonovics et al (1971) and Brooks (1972) contain tables of plants known to have been used in prospecting. The table in Antonovics et al (1971) contains 22 species, that in Brooks (1972) 62 species. The difference is partially explicable in that the table in Brooks (1972) includes selenium, iron and other substances not considered by Antonovics et al (1971) but there still occur in the table in Brooks (1972) a number of species which are not present in the list of Antonovics et al (1971). Of these some are included in a further table in Antonovics et al (1971) entitled "plants that have been cited as indicators but for which there is no clear cut evidence that they have been used in prospecting". Similar problems attend the comparison of the tables of Cannon (1960, 1971) and Malyuga (1964).
Brooks (1972) outlines the nature of the difficulty experienced by all the above workers.

"Numerous references to indicator plants have been made during the past 150 years, but the compiler of a table of them is immediately confronted with the problem of what to include in the listing. It is not particularly important to adopt as a criterion the fact that a plant has or has not been used in prospecting work or that the results have or have not been successful, since if a plant is a true indicator of mineralisation, the potential is always present. A far more serious problem is assessment of the credibility of an author's claims about a given species. Sometimes claims are lost in antiquity and are little more than folklore."

Heavy metal indicator plants, in terms of the conventional usage, appear generally to be species which occur over mineralisation and possess a disjunct distribution in respect of mineralisation, and, or, some form of morphological variation over mineralisation, these features enabling the investigator, or leading him to suppose that he would be able to locate ore bodies by the use of the plants.

Here the term indicator plant will be used as a shorthand style for certain species of plants of disjunct distribution on metalliferous soils in Britain and North West Europe. The past use and the potential use of the British indicator species in mineral exploration will ultimately be assessed; in some ways this is an assessment of the justification of the use of the term indicator species in relation to these plants.

1.2 The similarities between metalliferous and serpentine habitats

Rune (1953) noticed the floral similarity between certain metalliferous spoil heaps and serpentine areas in Scandinavia. He noted that Lychnis alpina was abundant on the nickel and zinc ores and was also a serpentine species. He writes of visiting the Stollberg Mines at Norrbarke and finding there L. alpina, Rumex acetosa and Agrostis canina L. growing together on the ore outcrops and slag heaps,
materials containing iron, lead and zinc. He states he encountered a plant community confusingly like one from serpentine. Rune (1953) cites certain characteristics of the serpentine flora of North Sweden which he feels are also "common to, at least all the northern serpentine floras".

1) The serpentine flora is relatively poor in individuals as well as in species.
2) In serpentine localities, several species are represented by certain races (ecotypes) differing ecologically and, sometimes, also morphologically from their original types.
3) Many plants appear very disjunctively in serpentine localities.
4) The serpentine flora contains basicolous as well as acidicolous plants which often grow together.
5) The serpentine flora has a relatively xerophytic character.
6) The serpentine flora is often dominated by certain families or genera e.g. Caryophyllaceae in North Europe and Eastern North America.

Other workers have remarked upon the similarities in both floral and ecological respects between serpentine and heavy metal rich soils and as some aspects of serpentine research seem relevant to heavy metal communities certain sections of the heavy metal plant literature will be reviewed in respect to the criteria of Rune (1953).

An initial difficulty is immediately apparent. European workers such as Schwickerath (1931), Lambinon and Auquier (1964) and Bradshaw (1952) have worked on mining spoil or in environments affected to varying degrees by mining and smelting operations and the pre-mining situation in many areas of Europe is uncertain. In contrast much of the work by Nicolls et al (1965), Wild (1968), Howard Williams (1970) and other investigators in Africa and Australia has been on undisturbed sites. On many mining spoils in Britain there is evidence that vegetation succession is occurring, this is probably also the case in Europe. A contrasting situation probably prevails on
African and Australian mineralisations and on many serpentine areas in that they appear stable in the long term. In terms of the comparison, it is intended to make, it is not thought that this difference is a major problem.

(1) The serpentine flora is relatively poor in individuals as well as in species.

Antonovics et al (1971) state that "the studies of species on metal contaminated soils have rarely been rigorous and are usually little more than incomplete species lists and that it is often possible that the species listed are not growing on metal contaminated soil but on distinctive, poor soils adjoining contaminated areas." Even so, there is a long established consensus of opinion that heavy metal sites are floristically poor. Ernst (1965) provides species lists which suggest this to be the case and the transects of Nicolls et al (1965) and Cole et al (1968) across metalliferous areas and into background vegetation in Australia demonstrate both floristic impoverishment and reduced cover. Wild (1968) recorded 436 species of Angiosperms on the copper soils of Rhodesia. He also recorded, (Wild 1970) 322 species on the serpentines of the Great Dyke, the latter covering a much larger area. He states that in Rhodesia trees and woody plants are generally more rigorously excluded by serpentine than by the copper, but he points out that copper flora of Rhodesia is an impoverished one.

(2) In serpentine localities several species are represented by certain races (ecotypes) differing ecologically and, sometimes, also morphologically from their original types.

Morphological and also colour variation has been noted in many heavy metal floras. Heimans (1960) states that *Polygala vulgaris* found on zinc soils in Belgium differs from ordinary *P. vulgaris* by its fine, dark blue flowers. Lefebvre (1967) demonstrated that the populations
of *Armeria maritima* on adjacent heavy metal sites in the Aachen-Liege area were very different in the repetition of floral characters and were also distinct from coastal populations of *A. maritima*. Malyuga (1964) showed floral variation in a poppy, *Papaver macrostomum* Boiss and Huet, and described changes in the flower form of *Pulsatilla patens* Mill., a change similar to the apetalal described by Rune (1953) for serpentine *Lychnis alpina* from Scandinavia. Dobrzanska (1955) observed that in plants growing on the calamine dumps near Boleslaw and Olkusz in Poland outward variations were frequent, dwarfishness being the most common. He found from growing experiments that morphological variations, including dwarfishness, were either transient and disappeared when environmental conditions were changed, as in *Ranunculus acris*, or were stabilized as a more or less hereditary character as in *Dianthus carthusianorum* L. and *Silene inflata* Sm.

Prat (1933) working on *Silene dioica* (L.) Clairv. from a copper deposit in Germany showed that seeds of the species from the copper rich area grew better in copper soil than seeds of *S. dioica* from other areas. Bradshaw (1952) demonstrated experimentally races of *Agrostis tenuis* Sibth. tolerant for lead and zinc, Halliday (1960) showed lead tolerant ecotypes for *Minuartia verna* and Lefebvre (1968) proved zinc tolerance in *Armeria maritima*. There is therefore considerable evidence for ecotypic variation, both morphological and physiological, on heavy metal soils.

(3) Many plants appear very disjunctively in serpentine localities.

This is the basis of the use of certain species of metal tolerant plants as indicators. *Minuartia verna*, *Thlaspi alpestre*, and *Armeria maritima* are present on lowland heavy metal sites in North West Europe, separated by often considerable distances from the alpine and coastal habitats in which they also occur. I have seen *Polycarpea glabra* in the Concurry District of Queensland occurring disjunctively in relation to the many small ore outc. ops of the area.
These discontinuous distributions have been interpreted by different authors in different ways. Schultz (1912) suggested that *Viola lutea* (*V. calammaria*) and *Minuartia verna* were formerly more widely distributed and that since the end of the last glaciation their distribution has been limited to metalliferous sites where the competitive situation is tolerable for the two species.

Heimans (1960) considering the distribution of *V. calammaria* and its relationship to *V. alpestris* (probably the *V. tricolor* ssp. *subalpina* of Southern Europe), suggests that the assumption must be made that the species spread in the Late Glacial Epoch from Alpine Europe to the Netherlands where it has maintained itself only on these sites where metallic ores are present in the soil. He further suggests that these metalliferous stations were not suitable for the establishment of trees and other plants which arrived in the succeeding periods of the Postglacial. This statement is in accord with the suggestions of Pigott and Walters (1952) in relation to species of discontinuous distribution in open habitats in Britain.

Auquier (1964) presenting a taxonomic interpretation describing a number of *Festuca* spp. from the heavy metal sites in the Liege area suggested that their relatives are now found in upland areas and from this he derived a relic conclusion similar to that of Heimans (1960). Antonovics et al (1971), however, are sceptical about the taxonomic validity of the fescues described by Auquier (1964).

Antonovics et al (1971) state that "the suggestions of Schultz, Auquier and Heimans are therefore that the species found on metal contaminated soils are usually paleo-endemic". They go on to say that "the situation is difficult to interpret: a simple paleo-endemic interpretation of the geographical distribution of all the species may often be inaccurate." The paper by Heimans (1960) dealing with the zinc flora of the Netherlands is in English and a relevant paragraph will be quoted:
"The fact that at least one of the species of our zinc flora, viz. our Armeria, occurred already in the older part of the late Glacial Epoch in this region and in a large area in its vicinity, lends plausibility to the assumption that the other species with subalpine alliance will have reached this country during the same period, and that the whole zinc flora therefore may be regarded as a relic from the late Glacial Epoch."

I disagree with the implication in Antonovics et al (1971) that Heimans (1960) is putting forward a suggestion that the distribution of most species of metal contaminated soils is to be interpreted from a paleo-endemic standpoint. Heimans (1960) is dealing only with the zinc flora of the Netherlands and in the section of the paper leading up to the above quotation mention only Viola calaminaria, Thlaspi alpestre, Minuartia verna and Armeria maritima.

At the end of a section discussing the work of Auquier (1964), this following on from a discussion of the work of Schultz (1912), both referred to here earlier, Antonovics et al (1971) state that "a similar interpretation (here they refer to the relic hypothesis) has been arrived at by Heimans (1960) studying the distribution of the zinc violet, Viola calaminaria, but he gives it only his tentative support."

I believe that the support of Heimans (1960) is rather more than tentative. There is the paragraph quoted above and earlier in the paper, having just discussed the possibility of long distance transport of the various species in question, which he believes unlikely, he writes "this implies that we will have to look for another explanation, and this is, in our opinion, to be found in the assumption that these zinc plants are relics of an older vegetation."
Antonovics et al (1971) point out that certain mine taxa may have arisen by recent evolution from relatives growing locally. They suggest that these are neo-endemics in the sense of Stebbins (1942). They consider the *Festuca* spp. of Auquier (1964) to be best interpreted as such. In the particular case of these Belgian fescues such an explanation appears very reasonable but a neo-endemic explanation will clearly not suffice in a situation where there are no relatives growing locally, for example in the case of *Thlaspi alpestre* in Belgium.

The response of Antonovics et al (1971) to this type of difficulty is to state that as contaminated soils are commonly associated with man's activities wide dispersion may be a man induced effect. They suggest that the transport of plants from upland to lowland regions could give the erroneous impression of relic status. They additionally claim that many metal mines are recent and in no way correlated with natural metal outcrops and they favour the suggestion that most mine species are neo-endemics. They cite the work of Duvigneaud and Denaeyer de Smet (1963) on natural copper vegetation in Katanga. These authors suggest that the majority of the cuprophyte species are close relatives of non-cuprophyte species found throughout the Zambesian region. Duvigneaud and Denaeyer de Smet (1963), however, also found some taxa with a relic character. It should also be noted that Wild (1971), working in Rhodesia, suggests that the metalliferous species *Dicoma niccdifera* Wild, is a relic species produced by biotype depletion and not a species produced by edaphic modification from a related species or a common ancestor.

Antonovics et al (1971) finally observe that "the last and very crucial point is that even if in some instances the evidence does favour the paleo-endemic hypothesis no plant is known that has an inherent or constitutional resistance to heavy metals throughout its distribution. In other words the plants on mines cannot be regarded as simple 'left overs' from a widespread distribution, the problem of evolution of tolerance is still there."
In relation therefore to the criterion of Rune (1953) it is true that plants with markedly disjunct distributions also occur on heavy metal soils. However the disturbed or totally man-created nature of some of these habitats results in problems in the interpretation of such distributions.

(4) The serpentine flora contains basicolous as well as acidiculous plants, which often grow together.

In contrast to the previous criteria this does not appear to be a commonly observed feature of heavy metal floras. Halliday (1960), however, in the Northern Pennines saw an association of the basicolous species, Linum catharticum and Galium sterneri, with acidiculous species such as Deschampsia flexuosa (L.) Trin. Association of calcicoles and calcifuges has long been known from Chalk heaths in the South of England (Tansley, 1939). Grubb et al (1969) working on Lullington Heath in Sussex investigated a community of calcicole and calcifuge species growing together in soils of pH between 5 and 7. They suggest that competition, together with other physical factors, is important in the exclusion of many calcicoles from soils of pH 5 to 7 in Britain. It must be observed that designations such as calcicole and calcifuge are often physiological inferences very much related to field observations of habitat. Certain habitats, Chalk heath and serpentine appear to allow some species to extend, due to reduced competition, beyond their normal, inferred, edaphic limitations but the phenomenon does not appear to have been widely observed in the case of calcicoles and calcifuges in the low competition conditions of heavy metal soils.

Dobrzanska (1955), however, working on zinc rich spoil heaps in Poland wrote of a heterogenous flora; he observed that "species needing or preferring calcareous soils appeared together with species from sandy soils." This juxtaposition of floral elements may be analogous to the association of calcicole and calcifuge species on serpentine areas.
(5) The serpentine flora has a relatively xerophytic character.

Dobrzanska (1955), working in Poland, states that plants from the calamine spoil heaps there are xeromorphic, plagiotropic, have small leaves and show other features such as growth type and rootlength, characteristic for vegetation growing on gravel, screes and, primarily on serpentine substrates. He is here describing xerophytic features.

It is generally apparent from the literature that many heavy metal sites which have been studied, with their poor vegetation cover and inhibited soil formation, are generally drier than the surrounding area and that their vegetation is more or less xerophytic in nature. Antonovics et al (1971) however observe that the xerophytic morphological features, especially small size, observed by many workers may in some instances be related to nutrient shortage in the habitat.

(6) The serpentine flora is often dominated by certain families or genera e.g. Caryophyllaceae in North Europe and Eastern North America.

Rune (1953) is here referring to a numerical dominance in the flora.

Brooks (1972) writes that "the typical indicator will be a herb rather than a tree or shrub, and will probably be a member of the Labiatae or Carophyllaceae." Antonovics et al (1971), however, dealing with metal tolerant as opposed to indicator species, state that it is possible to get the impression that tolerance is restricted to certain families or genera. They cite the work of Wild (1968, 1970) which shows tolerance in many families with the largest families, the Leguminosae and the Graminae showing the greatest number of tolerant species.
Rune (1953) points out that in Central and Southern Europe the dominance of the Caryophyllaceae is less pronounced, the large families, the Leguminosae and the Compositae, assume increasing importance. Rune (1953) in stating his sixth criterion is dealing with a restricted geographical area, the situation globally on serpentine is as yet uncertain.

In relation to heavy metal soils there appears to be no explanation in the literature of the numerical dominance of the Caryophyllaceae and Labiatae among heavy metal indicators.

1.3 **Colonisation and plant growth on metalliferous soils**

Many open habitats, amongst which the great majority of metalliferous localities may be included, possess unusual environmental factors which tend to maintain the open condition. Pigott and Walters (1954) stress the importance of climate, rock type, instability and other factors in this process. Most extreme habitats show initial colonizing species which, by their presence, tend to ameliorate the environment and facilitate invasion by other species, the general process of colonization and plant succession. A disruptive environmental factor is necessary to halt this succession at some point, is heavy metal concentration such a factor?

The distinction outlined in the previous section between European and African and Australian heavy metal sites must again be borne in mind. On the natural sites of Africa and Australia the evaluation of plant distribution in relation to metal concentration and other parameters is probably an assessment of a relatively stable environmental situation, in Europe succession appears to be occurring on certain heavy metal soils.
Schwickerath (1931) showed a relationship between the various metal tolerant species in the colonization of the mine habitat and observed new species entering the developing *Festuca ovina* L. sward. Schubert (1954) working in the Bettendorf area of Germany, showed that *Silene vulgaris* (Moench) Garcke tended to invade the areas previously colonized by *Minuartia verna* and Ernst (1965) demonstrated that zinc levels were lower in the areas of increasing colonization.

As pointed out by Antonovics et al (1971) the latter situation could be one in which the plants themselves are alleviating toxicity, a situation in which weathering is reducing toxicity, or a situation of preferential colonization of areas of low zinc concentration.

The problem of age in relation to European mine site colonization does not appear to have been investigated in any depth. Schubert (1954) working on copper spoil in Germany found no incontrovertible evidence of succession between 1200 A.D. and the present day. However a Mr. Waldron, quoted in Gough (1930), wrote in 1875 of the reworking of Roman slag at Charterhouse in Mendip. Here scoria, charcoal and slag, some of the latter containing 20-26% lead, were covered by a foot to eighteen inches of peat and turf. This accumulation of organic matter was presumably accompanied by the development of a plant community differing from those found today in the area on younger substrates containing high concentrations of heavy metal.

Such accumulations of organic matter in the process of soil development seem to be an important factor in the amelioration of metal toxicity. There is a direct effect upon the availability of heavy metals to plants and also indirect effects on moisture capacity, soil structure and other factors. Lucas (1948) showed that copper may be chelated by the components of organic material and Hilton (1967) documenting the work of the Lower Swansea Valley project demonstrated that the mixing of organic matter, sewage sludge and sedge peat with copper and zinc tip material produced acceptable
levels of growth in experimental plantings. Dykeman and De Sousa (1966) working in New Brunswick showed concentrations of copper in a peat bog to 7% dry weight. These concentrations had no visible effect on the vegetation of the bog and they suggest that the immobilization of copper in the soil by chelation to natural organic compounds appears to be most important in preventing plant uptake of the metal in toxic amounts.

There are descriptions of soil development on serpentine substrates which may be of relevance to the process of succession on heavy metal rich soils. Many metalliferous sites in Europe are relatively recent and there has been little time for succession. In contrast many serpentine outcrops have remained undisturbed to any great extent since deglaciation.

Coombe and Frost (1956) working on The Lizard in Cornwall demonstrate that the vegetation of this area shows to only a limited extent the features described from other serpentine areas. In certain parts of The Lizard the soils are not wholly derived from serpentine. Some soils however are entirely produced by the weathering of serpentine and these soils too do not exhibit serpentine features. Proctor (1969) working on the west bank of Loch Lomond describes a serpentine bearing "a mundane heath vegetation". Superficial deposits which he investigated at Girvan and Glen Urquart showed a similar lack of distinctive vegetation. He states that even where serpentine provides some contribution to the soil, judging by its heavy metal content, the foreign matter seems to suppress any serpentine effects. He further observes that at many British sites the serpentine rock has weathered to produce a soil that covers a large area and he concludes that where there is extensive soil development, even when that soil is derived wholly from serpentine rock, there is suppression of the serpentine effect.
The effect of the accumulation of organic matter in heavy metal soils has already been mentioned. Other soil factors have been investigated by certain workers in attempts to assess their importance in the colonization by, and the distribution of, plants on metalliferous soils.

Lambinon and Auquier (1964) have shown variations in the preferences of certain species in relation to soil moisture. They report that in Belgium Festuca ovina occupies both dry and moist sites and that Armeria maritima occurs on fairly moist soils. They found Minuartia verna to be a species of the drier sites and in the wetter areas of the zinc rich spoil heaps Molinia caerulea (L.) Moench, Scirpus sylvaticus L. and Eriophorum angustifolium Honckeny were present.

Nicolls et al (1965) working in the Dugald River Lode area of Queensland suggested, on the basis, as they point out, of a relatively small number of samples, that of the major soil nutrients phosphorous may have an important influence over the distribution of the lode assemblage. Other major soil nutrients showed little variation. However, they state that, while variations of lithology, relief, drainage, texture and major nutrient status of the soil may have some effect on plant distribution, trace element anomalies in the soil exert the controlling influence.

Poor major nutrient status of the spoil heap soils appears to be an important element in the sum of difficulties which plants experience in colonizing such areas and beneficial effects have been observed following the addition of fertilizer to spoil materials. Generally mine spoils are low in nitrogen, phosphorous and potassium (Smith and Bradshaw, 1970).

Calcium status is a major factor influencing the distribution and type of the heavy metal flora. Varying concentrations appear to affect the availability of certain heavy metals (Schwickerath, 1931, Halliday, 1960) and additionally calcium has an effect upon soil pH, the latter also influencing the availability of the heavy metals.
The contrast between the relatively species rich floras of the calcareous spoil heaps of the Pennines and the impoverished floras of the siliceous debris of Wales has been recognised for some time. Ferreira (1959) noted the contrast between calcium rich and calcium poor tips on Benn Laoigh in the North of Scotland. The calcareous tip supported species of Saxifraga, Silene acaulis (L.) Jacq. and Festuca rubra L., while the other tips showed a scattered community of Agrostis spp. and Cerastium vulgatum L. Both tips had a pH of 6.4.

In relation to the mitigation of toxicity by calcium Halliday (1960) felt that lead toxicity on limestone tips could be expected to be uncommon and difficult to detect. Halliday (1960) looked at the exchangeable Pb/Ca ratio and the zinc concentration of tip soils, mainly in the Northern Pennines, and demonstrated that the metalliferous sites poor in species could be related to the parameters 1300 ppm. zinc and a Pb/Ca value of 1. He states that there is no evidence of toxicity in any soil with more than 2.5 m-equiv. of calcium and it is therefore unlikely to occur in soils possessing free calcium carbonate. The general impression given by Halliday (1960) is one of scepticism in relation to the possibility of metal toxicity on many of the sites he surveyed. He writes of the coarse nature of tip soils, the difficulties inherent in the colonization of such soils and the susceptibility to erosion of the unstable tipped material.

Factors other than heavy metal concentration clearly do have an effect upon the vegetation of heavy metal soils. Even in Britain metalliferous habitats range from peat bogs and contaminated alluvial areas to arid tips and limestone scarps. With this diversity of habitat it would be surprising if heavy metal concentration was the only ecological factor influencing the plants of metalliferous soils.
Minuaria versus: World distribution of all subspecies. (After Mettler, 1929)

Figure 1.2
1.4 The British indicator plants

There are several candidates for inclusion in a list of British indicator plants. *Minuartia verna* and *Thlaspi alpestre* are widespread on mineralized areas in England and Wales, and *Armeria maritima*, *Silene maritima* With. and *Cochlearia officinalis* L. occur disjunctively on heavy metal sites in certain areas. *Lychnis alpina* is apparently associated with a pyrite mineralisation on Hobcarton Crag in the Lake District. Raven and Walters (1956) and Pearsall and Pennington (1973) refer to this site but no analytical data appears to be available. *Viola lutea* occurs on metalliferous areas in Derbyshire and Balme (1954) observed the species growing abundantly on the disturbed ground associated with mining in the county. Cole (1975) has suggested that the species *V. lutea* and *Saxifraga hypnoides* L. are indicators in Derbyshire.

Of these species investigations have been confined to the first five, *Minuartia verna*, *Thlaspi alpestre*, *Armeria maritima*, *Silene maritima* and *Cochlearia officinalis*, and have concentrated on the widespread species *M. verna* and *T. alpestre*.

*M. verna* is an arctic alpine species while *T. alpestre* is a plant of alpine affinities, (Matthews, 1937). Figure 1.1 adapted from Mattfeld (1929), shows the distribution of the highly variable species *M. verna*. *T. alpestre* too is a variable species, occurring in the uplands of South, West and Central Europe and is naturalized in parts of Scandinavia. Fig. 1.2 shows the distribution of *T. alpestre* in northern Europe and the species also occurs in North America (Rochow, 1970).

*A. maritima* (Fig. 1.3) is a widespread and often discontinuously distributed species of Europe, Asia, North and South America (Baker, 1948). *S. maritima* is considered in *Flora Europaea* (1964) to be a subspecies of *S. vulgaris*, the subspecies ranges along the coast of Western Europe from the Azores to Murmansk. *C. officinalis*

Figure 1.4
The European Heavy Metal Flora is at its maximum development in the Aachen-Liege region. Here M. vernia, T. alpestre, S. cucubalus, A. maritima and Viola calaminaria occur in association. According to Dobrzanska (1955) of the North West European metal assemblage only Armeria elongata Hoffm. var. halleri (closely related to A. maritima) occurs in the Boleslaw-Olkusz area of Poland. The lists of Ernst (1966) for Southern France show T. alpestre, Silene cucubalus, Armeria halleri and M. vernia. V. calaminaria is absent. M. vernia is absent from many metalliferous areas between North West Europe and The Alps.

1.6 The aims of the study

Even though within the British Isles there are heavy metal plants closely related to the European forms, with the exception of the genus Viola in which our metal tolerant species appears to be V. lutea, nowhere do they come together at one site to form a complete heavy metal assemblage. However, as shown later, even in the Aachen-Liege area a fully expressed association appears to be the exception rather than the rule.

This is just one of the problems of distribution associated with these heavy metal species. The heavy metal plants characteristically in Britain and Europe show markedly disjunct distribution in relation to metalliferous sites. On superficial examination there appear to be many heavy metal habitats suitable for these species in which they do not occur. Certain of these anomalies are already explained. Calcium status of the soil, for example, is known to be very significant in the British Isles. Other features of distribution remain unsolved. For example A. maritima occurs in a few areas in the Northern Pennines but not on all metalliferous sites in the region. T. alpestre in Derbyshire occurs on heavy metal sites in the southern part of the county but not in the major mining area between Youlgrave, Buxton and Castleton. These anomalies of distribution have been investigated.
As outlined earlier in other parts of the world the claim has been made for certain plants as "universal indicators". This has never been suggested for the British species with the exception of *Lychnis alpina*, but very strong associations have been noted in certain areas between some of the species and heavy metal sites. The comment of Henwood (1857) about *A. maritima* in the Dolgellau area has already been mentioned and Williams (1830) noted the association of *T. alpestr* with mines in the Llanwrst-Betws-y-Coed area. *M. verna* has the local name of leadwort in the Northern Pennines (Halliday, 1960).

For all the British species of indicator plant the heavy metal site is one habitat component in their total range. The importance of this component varies from one area to another and an attempt has been made to evaluate its contribution to the total distribution of the various species.

Halliday (1960) points out that the recognition of toxicity in the field is far from easy. In the collection of some specimens even mine sites appear to have been unrecognised or unremarked upon. A specimen of *M. verna* at Kew collected on the Heights of Abraham, Matlock in 1865 bore the habitat description, "short turfed stony bank above deep cleft in rock, with *Thlaspi alpestr*". This seems to be a description of an excavated vein and associated mine dump. Undisturbed mineralisations can also be overlooked. In a widespread species such as *Minuartia verna* the interpretation of available records is an important part of the distribution study and this tendency for past observers to fail to recognise toxic sites must be taken into account.

For more than 2,000 years heavy metal mining activity has had the side effect of exposing for plant colonization areas of metal rich material. In certain regions at least there appears to have been no surface expression of mineralisation before mining activity, this was especially the case in the Northern Pennines where a continuous peat cover in
many areas necessitated the use of hushing, a destructive prospecting technique involving the removal of peat by rushing water. Spoil heaps produced by mining activity are now habitats for the indicator species and extensions of range in the course of mining activity may be presumed. British mining has tended to be cyclical in nature with periods of intense activity followed by, in certain areas, centuries of relative quiescence. At the moment mining is in total recession, a recession from which it will probably not, in its previous form at least, recover. Succession seems to be occurring at present on waste materials and British indicator plants may now be in a phase of range contraction. An attempt has therefore been made to assess the effects of extension and contraction of range in the distribution of the indicator species and to gain some idea of the rate of the process of succession on spoil heaps.

Earlier in the discussion of the disjunct distributions shown by many indicator species the views of Antonovics et al (1971), Heimans (1960) and Schultz (1912) were referred to. The possibility of long distance dispersal, the effect of man on dispersal generally, and the problem of development of tolerance are all involved. If long distance dispersal is rejected then credible survival sites, either for metal resistant populations or populations from which tolerant individuals could have arisen, must be postulated.

Long distance dispersal is, as a generally operating process, not widely supported at present. Cain (1944) summarizes his view, "that long distance dispersal has resulted in migration and accounted for discontinuous areas seems rarely to have been the case. This conclusion is based primarily upon existing distributions which largely show symmetrical replicate patterns mostly unrelated to chance and other elements of dissemination, and upon evolutionary phenomena, such as endemism in general and the occurrence of local races in particular."
Any discussion of the likelihood of long distance dispersal of the indicator species is made more complicated by the possibility of the effect of man. There is evidence for long distance transport of Minuartia verna by human agency. Rune (1953) cites Nordhagen (1930) who recorded _M. verna_ at Odda, South West Norway. Apparently the plant had arrived in fluorspar imported from Derbyshire. Halliday (1960) quotes Nordhagen (verb. comm.) who states that _M. verna_ arrived in Norway subsequent to the importation of a cargo of Derbyshire ore but appears to have since become extinct. Hilton (1967) recorded _Silene maritima_ from a copper tip in the lower Swansea Valley. The plant may have arrived with imported ore, there being no natural metalliferous outcrops in the area, or may be derived from a local maritime population.

According to Antonovics et al (1971) no species of metal resistant plant is known to show inherent tolerance of heavy metals throughout its range. This is relevant to the possibility of long distance dispersal between non-resistant populations and heavy metal sites. Abbot and Misir (no reference), quoted in Antonovics et al (1971) from Antonovics (1966), showed that about one in 7,000 _Agrostis tenuis_ plants showed inherent resistance to copper rich soil, there was selection for tolerance in one generation. If other species generate tolerant individuals with a similar frequency the small chance of long distance dispersal from a non-tolerant population is further reduced by the remote possibility of the dispersed individual showing tolerance. As an example, Halliday (1960) states that for _M. verna_ the origin of the population near Dolgellan in Wales is puzzling as there are no nearby natural habitats. The nearest substantial mine populations are in Flintshire, an unlikely source he believes. He also expresses the opinion that scarcely more plausible is an origin from a now extinct population on Cader Idris, 11 km. to the south.
In the course of the study it was therefore decided to consider the potential of dispersal by man and also to evaluate the possibility of survival in naturally occurring metalliferous areas until mining activity made available new sites for colonisation.

My attitude to the possibility of long distance dispersal is generally one of scepticism. Belief in the widespread effectiveness of long distance dispersal is in many cases, and the European heavy metal species may be included here, a matter of individual conviction. From a pragmatic standpoint, and because there is no evidence for it in the literature, it is not thought that the old miners would transport ore from one orefield to another, and transport in ore is the way M. verna arrived in Norway. To prove or refute dispersal by birds or transport in the mud on miners' boots is impossible. I believe that suggestions for discontinuous distribution which involve long distance dispersal before all other explanations have been found wanting are inherently unsatisfactory and a search has therefore been made for natural or relatively undisturbed heavy metal populations in an attempt to postulate the ecological conditions under which heavy metal communities could survive until the onset of mining.

Godwin (1956) believes that the habitats of the immediate Post Glacial period were ones of rocky base rich soils, especially in the upland areas, occupied by species of the arctic alpine type. Where the covering of glacially derived material was not too great the metalliferous veins were presumably exposed at the surface and may have had some effect on the species composition of such areas. With the passage of time the rocky, base rich soils gradually changed; they were covered by peat in the upland areas, and nearly everywhere with ameliorating climatic conditions and soil development, other species arrived to oust the arctic-alpine flora. The extent to which this occurred on metalliferous areas is obviously of considerable importance in any attempt to postulate refuge sites for the indicator species and this problem has been investigated.
A major part of the study has been the collection of quantitative data on the vegetation and soils of heavy metal areas with the aim of correlating vegetation pattern and process with environmental and soil factors. Low competition is an important and generally recognised factor in the occurrence of the indicator species on heavy metal soils and, as the competitive ability of a species may vary throughout its range, related to its own capabilities and those of its competitors, it was hoped to investigate this aspect in the distribution of the indicator species. A final aim was to assess the potential of the British metal tolerant species as indicators of mineralisation.
CHAPTER 2.

THE MINERAL DEPOSITS, MINING
AND
THE LEGACY OF MINING ACTIVITY

2.1 The general situation

Mining activity has proceeded in the United Kingdom since the Bronze Age. Most counties of upland England, Wales and Scotland have had, at some time, small scale mining activity within their boundaries, but the areas of major importance have been Cornwall, Devon, Somerset, Central and North Wales, the Pennines, the Lake District and the Southern Uplands of Scotland. Mineralisation within the Palaeozoic rocks of these areas has generally been of the fissure type involving the impregnation of faults and fractures in the country rock by hydrothermal solutions dispersing from deep seated emanative centres. The country rocks, the modes of occurrence of ore bodies, mining history, and mining methods have all had considerable effects upon the distribution of the indicator species, both spatially and temporally, and they will therefore be briefly reviewed here.

2.2 The ore bodies and their modes of occurrence

The mineralisations may be conveniently divided into two groups, those in the calcareous sediments of the Lower Carboniferous, and those in the rocks, very occasionally calcareous, of other periods. It is on substrates derived from the former that the indicator plant communities show their greatest expression, and these will be described first.

Mineralisation in the Lower Carboniferous

Lead, in the form of the primary mineral galena, is the most abundant metallic mineral in the lodes of this formation. Zinc is abundant and widespread and silver is often present in quantities sufficient to have justified extraction. Copper is present in economic quantities in only a few areas. Common primary gangue minerals are calcite, quartz,
barytes and fluor spar. Secondary minerals occur in the oxidation zones and on the spoil heaps in all areas. Considerable variation in the relative abundance of the various primary and secondary minerals occurs both from orefield to orefield and within the orefields themselves, often adjacent veins have quantitatively different mineral assemblages.

Mineralisation in the Mendips is widespread and surface workings occur over much of the area. Mineralisation occurs in both the Carboniferous Limestone and the overlying beds of the Permian Dolomitic Conglomerate, a calcareous rock containing much Carboniferous Limestone material. The economic deposits were found at Shipton and Charterhouse and near East Harptree, Chewton Mendip and Priddy. Zinc, in the form of calamine, was predominant in the Dolomitic Conglomerate at Shipton, occurring in many small veins 15-60 cm wide. Galena occurred in larger veins in the other mines, accompanied by the gangue minerals calcite and quartz (Green, 1958).

In North Wales the lead and zinc ores are restricted mainly to the Carboniferous Limestone Series and the Cefn-y-Fedw Sandstone series. The veins in this area were far more productive than in Mendip and some flats were exploited. The economic minerals of the veins were galena and blende with some secondary calamine. The gangue mineral is predominantly calcite spar; some quartz is also present (Smith, 1921).

The Derbyshire field shows a greater diversity of mode of occurrence than Mendip and a greater diversity of gangue mineral than North Wales. The pipe or pipe vein formed by the widening of a vein in one or more beds of limestone, was important in Derbyshire ore production. The flat, essentially a lateral development of the pipe, is less common in Derbyshire. In the orefield galena and blende occur with fluor spar, calcite and barytes. The gangue minerals may differ widely in parallel veins or even vary laterally along the same vein (Carruthers and Strahan, 1923).
Such mineral assemblages occur throughout the Pennines. Metasomatic replacement deposits are peculiar to Weardale and were economically extremely important. Barytes, fluor spar, and the uniquely Northern Pennine mineral, with erite, are predominant in the northern orefield. Calcite here plays a subordinate role. Within this orefield zinc was important to the west of the Burtreesford Disturbance, but not in the eastern parts of the field (Dunham, 1948).

Copper is rarely important in the mineralisation of the Carboniferous Limestone, although the copper deposit at Ecton Hill in Staffordshire was, for a period, nationally predominant in the production of copper ore. Copper associated with the Carboniferous Limestone also occurs at Great Orme, Malham, and near Richmond in Yorkshire (Dewey and Eastwood, 1925).

**Mineralisation in other formations**

Major fissure type mineralisations in rocks other than Carboniferous in age occurred in parts of Cornwall, very importantly in Mid-Wales, in the Betws-y-Coed region, in the Lake District and the Southern Uplands of Scotland. The country rocks range from the Devonian and Carboniferous Killas slates of Cornwall to the Palaeozoic siliceous grits, mudstones and shales of Mid-Wales. Here the main constituents of the lodes were quartz, lead, zinc, copper and iron sulphides, calcite was rare (Jones, 1922). In the Lake District lead ores are found in the rocks of the Ordovician Borrowdale Volcanic Series (Eastwood, 1921). Copper was important in the intrusive and associated sedimentary rocks of Devon and Cornwall. The lodes were characteristically gossanous near the outcrop (Dewey, 1923).
2.3 British mining, the historical scene

Evidence for pre-Roman mining is scarce and generally indirect. Mining tends to destroy, by its progress, indications of previous exploitive activity. The metal for the Iron and Bronze Age cultures may have been derived from near at hand. For instance in the excavation of the Glastonbury lake village lead artefacts were unearthed, this lead was probably obtained from shallow workings in the Mendip Hills (Gough, 1930).

With the coming of the Romans and the importation of expertise derived from their mines in Spain, mining increased in both scale and extent. The Mendips were occupied and mining organised with alacrity, lead being produced there by A.D. 50, in Flintshire by A.D. 69 and in Yorkshire by A.D. 81 (Raistrick and Jennings, 1965). Lead proved easy to produce in Britain and very quickly the mines of Spain were in decline, Pliny the Elder wrote in A.D. 77 of the restriction of British production by statute (Raistrick and Jennings, 1965). Roman influence extended even to the remote areas of the Northern Pennines, a site, Chesters, in the valley of the South Tyne above Garrigill, is supposedly of Roman origin (Raistrick and Jennings, 1965). The Romans apparently did little in the way of mineral exploration, veins previously exposed by the Britons were present in abundance. They appear to have mined by open cast methods and also by shallow level and introduced improved methods of ore extraction, washing and smelting. Furnaces, slag and washing debris attributable to the Romans were seen at Pentre Halkyn (Lewis, 1967) and in the Townfield at Charterhouse (Gough, 1930). In the latter they left a stratum of scoria, earth and charcoal two feet in thickness (Waldron, in Gough, 1930). Roman methods of smelting, for technical or perhaps economic reasons, were apparently inefficient, some of their waste material contained from 20-26% lead.
Mining declined upon the departure of the Romans and the tempo was slow until the upsurgence of demand for lead brought about by the great ecclesiastical constructions of the early Middle Ages (Lewis, 1967). Lead was exported to Europe from the Pennine orefields in the Twelfth Century, transport being by cart or pack pony to a convenient river or sea port, and then by sea to the ultimate destination (Raistrick and Jennings, 1965).

Later in the Middle Ages the record is of slow, and often interrupted, progress until the reign of Elizabeth brought a renaissance to British mining. The importation of German expertise and the establishment of the Society of Mines Royal, although not immediately successful, eventually produced dividends in the fields of both exploration and development (Lewis, 1967). By the late Seventeenth Century the Society of Mines Royal had outlived its usefulness and a test case in 1693 removed its restrictive influence. The financial basis of mining now underwent a change with the founding of the Company of Mine Adventurers and, importantly, the Quaker Lead Company, later the London Lead Company (Raistrick and Jennings, 1965). Unsystematic exploitation was now increasingly replaced by pragmatic development. The latter part of the Seventeenth Century was an age of technical innovation. The drainage adit, the introduction of gunpowder and the use of coal in the reverberatory furnace removed many restrictions on the mining operation and the way was now open to large scale exploitation of the metallic ores of England and Wales.

The Industrial Revolution produced improvements in ore-dressing and engines became available for dewatering mines, an ever present problem. Rationalisation of the operations of the London Lead Company assured its profitability in the Nineteenth Century, joint stock companies were floated elsewhere, sometimes with unjustified optimism. In Derbyshire, however, the system of small scale finance largely prevailed, there was little cooperation between neighbouring miners or partnerships, and this affected the development of the industry in the area (Raistrick and Jennings, 1965).
A decline in the fortunes of the industry set in towards the close of the Nineteenth Century. With the opening of rich mines overseas British heavy metal extraction rapidly became uneconomic. Impoverishment of the ore bodies in depth was a problem in certain mines as was the cost of dewatering but the major reason for the decline of the industry was the effect of foreign competition. Depression and depopulation in many districts of lead mining Britain ensued.

2.4 Exploration and the extractive process

Mining exploration in Britain seems, largely, to have been an unscientific and speculative process. There is little evidence in the literature of vegetation being a recognised prospecting tool and no evidence to show that any particular species of plant was used as an indicator. In the Mendips, however, miners associated poor plant growth with ore deposits; in 1666 the Rev. Joseph Glanvil of Frome (cited in Gough, 1930) stated that there were, to his knowledge, "no certain signs above ground that afforded the probability of a mine, but that sometimes, when an ore body was very near the surface, the grass was yellow and discoloured". Over much of the Pennines the exploration problem was exacerbated by peat, the Romans may have introduced hushing to surmount this difficulty. Even in the Nineteenth Century in this region speculative cross cuts were driven in anticipation of intersecting veins at depth, all too often with no result (Raistrick and Jennings, 1965).

The extractive processes in mining are important in the production and maintenance of the indicator plant habitat. The history has been one of steady improvement in extractive procedures, and this has led to the important practice of reworking old waste material.

Ore, until the advent of gunpowder, was got by pick and wedge. In stubborn cases of hard rock, fire setting would be resorted to. In Roman times and the early Middle Ages the large lumps of ore were removed by hand, the remainder was crushed and washed super-
ficially, and much ore material went onto the waste heap. In the Sixteenth Century the simple buddle was introduced, followed by, in 1565, the sieve and tub (Raistrick and Jennings, 1965). This latter development provided employment for 2,000 people who were engaged in reworking the waste hillocks of Derbyshire; an indication, perhaps, of the inefficiency of earlier methods of ore extraction.

The early Nineteenth Century brought further improvements in ore dressing procedures. Water separation methods require, for maximum efficiency, a material of uniform size; crushing rollers were therefore increasingly employed. Such innovations enabled the agent at Dufton Mine in Westmoreland to report, in the 1820's, that he was able profitably to employ a number of boys to wash spoil produced half a century before (Raistrick and Jennings, 1965).

The extractive phase of the industry was over in Mendip by 1800. Here, in the Nineteenth Century, there was concentration on the remelting of the slags of previous periods. In the four mineries of Mendip this activity was pursued for varying times and with varying success until St. Cuthbert’s, the last smelter, closed in 1908 (Gough, 1930).

2.5 The mining landscape

The character of the mining landscape is a reflection of the topography of the mining area and the methods of mining used, the latter dependent upon the physical and geological conditions prevailing in the orefield, together with the technological possibilities at the period of maximum mining activity and, to a certain extent, the social and economic conditions prevailing within the orefield.

In the earliest periods of mining abundant near surface mineralisation was available for exploitation. The simplest mining methods were therefore employed. Opencast techniques were favoured, the vein was trenched and ore, and sufficient country rock as necessary to retain freedom of operation, was removed. Waste material was
often thrown up along the side of the trench after sorting and these early techniques involved little spatial displacement of excavated material. In certain areas trenched veins, extending often for some distance and perhaps modified by later activity, are a feature of this mining style. Trenching was effective to a depth of six metres or so. At this stage the sides of the workings became unstable and this precluded further excavation (Raistrick and Jennings, 1965).

The bell pit was a development to cope with this problem. A shaft was sunk on the line of the vein to a depth of about 10 metres and the vein was then worked laterally from the foot of the shaft. Such methods produced lines of small spoil heaps of ore seen in many mining areas. There was a tendency to carry out some of the sorting in these earlier, and indeed in later, mines below ground. Only ore, with some associated gangue material, would be brought to the surface. For this reason workings historically recorded as quite extensive may leave little surface expression. At High Low near Sheldon in Derbyshire only small heaps of waste material are visible on the surface today, even though mining here was on quite a considerable scale. Such heaps are probably of material excavated in the course of construction of the shafts. Larger pieces of limestone may also have been carried away and used for various purposes.

The heaps produced by bell pitting are small in area and generally not steep sided. The physical forces of slope degradation have had considerable time to operate on these heaps, thus further subduing their relief. Such heaps tend to be relatively stable in nature and often are extensively vegetated.

As mining proceeded surface reserves became exhausted and it was necessary to extend the search to greater depth and to fresh areas. New techniques therefore evolved. Deep shafts were employed in Derbyshire and the Mendips; in the Northern Pennines the dissected topography favoured the level. Mining was now on a greater scale with greater capitalisation of the industry, greater amounts of spoil
were produced, and the nature of disposal of waste material changed also. Much larger tips became characteristic features of mining areas. Such tips are often flat topped and steep sided, in the Northern Pennines frequently extending from the mouth of the level in the manner of a railway embankment. The flat surfaces of these tips are often compacted and the steep sides are highly unstable and poorly vegetated. During the Nineteenth Century extraction procedures became more sophisticated, crushing processes produced waste of finer grade and such material, especially when deposited on steep slopes, can be extremely unstable and inimical to plant colonization.

Carboniferous Limestone is the main component of the tips of the Pennines. In certain areas there is an admixture of Yoredale shales and sandstones. Some of the spoil material was excavated in the course of driving access or speculative levels and is of country rock, non toxic in nature. Many of the spoil heaps are heterogenous in origin, materials from different veins or different parts of the same vein may end up in association on the tip. This is seen often in the analyses of heavy metal concentrations; not only do concentrations of one metal change greatly over short distance but the relative proportions of the various metals may change also.

In certain areas smelted materials occur on the tips. At Plombieres in Belgium the predominant waste is a cindery type of slag, at Charterhouse in Mendip a more glassy slag is seen, and at Slagmill Plantation in Derbyshire slag is in evidence on the small waste heaps. Generally, however, slag is not a common waste material in the mining areas. In the later period of mining ore was often carried to the coalfields for smelting, to the Lower Swansea Valley for example. The small scale smelters in the mining fields have generally left little evidence of their former presence.
At the height of mining activity there appears to have been considerable pollution associated with the extraction and, especially, the smelting of ore. Gough (1930) quotes Beaumont who in writing about the Mendips, stated that "if people living near the places where ore was washed tried to keep cats or dogs, or any kind of fowl, they always found that they died in a short time." Water was short on Mendip and there was a constant risk of cattle being "minded" when their drinking water was poisoned by mining operations.

Smelting was an especially injurious activity. Grass was regularly poisoned and in the middle of the last century fish in the river at Cheddar suffered from the effects of the smelters and associated operations at Charterhouse (Gough, 1930). An involved lawsuit in the 1860's concerned the right to unpolluted water for paper making at Wookey Hole, the water being affected by the smelting activity at Priddy, two miles upstream. In Flintshire too similar problems occurred (Lewis, 1967).

Pollution of water courses and the production of suitable habitat for indicator species is known at present. In Belgium the flood plain of the River Gheul between La Calamine and the Dutch Border harboured, until recently, extensive communities of heavy metal vegetation. Heimans (1960) states that the area occupied by the Zinc Plants in this valley extended to the highest level of flooding and Kurris and Pagnier (1955), cited by Heimans, showed concentrations of zinc in the soil of the floodplain area. The floodplain of the lower Afon Ystwyth in Wales is contaminated by lead and the banks of Eller Beck in Wensleydale show evidence of considerable lead and zinc deposition.

The miners made use of waste material for road building. Damp hollows on the course of the bridleway from Malham to Settle in Yorkshire appear to have been filled with spoil. Considerable quantities of ore were transported along tracks in many mining areas, spillage appears to have occurred and this has led to isolated areas of toxic soil.
2.6 The future of British mining

Mining in Britain has in the past concentrated on the extraction of the high grade ores of fissure type deposits. In certain areas of the northern Pennines and in the remoter regions of Wales unexploited mineralisations of this type still exist. Many mines were abandoned as a matter of economics rather than for reasons of shortage of ore and these could be reopened if economically feasible. The forseeable future probably lies in the exploitation of low grade ore bodies of considerable extent. One such deposit has been proved near Dolgellau in Wales, and the intensive exploration of Highland Britain now in progress holds hopes of others. Such large scale operations, involving the efficient extraction of metals from large amounts of country rock, will have an effect on the British landscape far in excess of that produced in the past 2,000 years of British mining.
CHAPTER 3
FIELD AND ANALYTICAL METHODS

3.1 The data on the distribution of the indicator species

Information on the distribution of the indicator species has been assembled from a variety of sources. Place of collection data was obtained for specimens in the Herbarium at Kew and the records collected under the auspices of the Botanical Society of the British Isles (B.S.B.I.) mapping programme, held by the Nature Conservancy Biological Records Centre, were also used. Various county floras provided further information and certain popular natural histories (Raven and Walters 1956, Condry 1966, Hervey and Barnes, 1970) were useful to a limited extent. Some papers, either referring to a specific indicator plant (Riley, 1956) or to an area in which the species occurred (Pigott, 1956) were also useful. Generally the more modern the record the more precise is the location of the site of collection or observation. The modern floras (Clapham, 1969) and the B.S.B.I. records are especially good in this respect, often providing four or six figure grid references.

3.2 Field methods

An initial reconnaissance was undertaken on the basis of the distributional data and additionally further areas were visited where mining was known to have been undertaken in the past. In the Northern Pennines where there are many small mine workings on the Carboniferous Limestone additional sites, especially for Minuartia verna and Thlaspi alpestre, were found, but in areas such as the Mendips and Derbyshire the distribution data reflected accurately the actual distribution of the indicator species. In short there appears to be no reason to doubt the overall picture of distribution compiled from the various sources.
In the areas where the indicator species are relatively scarce, for example Belgium and the Mendips, an attempt has been made to visit all the known sites, in other regions this was impracticable. The general aim in the search for areas for further study was to identify sites which appeared typical for a particular orefield and also to find areas with considerable environmental heterogeneity and offering opportunities for studying heavy metal rich habitats other than spoil heaps.

In the course of the reconnaissance spot samples were taken from sites which were not to be the subject of more detailed work. Such samples were generally collected from an area of fairly bare spoil occupied by the indicator species. Wherever possible a flat site was selected for sampling. While these samples were not randomly secured it is felt that they provide additional useful information when used in conjunction with samples from the same region collected in a more controlled manner.

Transects were used for more detailed study. The general method was to record vegetation in metre square quadrats along a transect line and to sample soil or spoil at regular, usually one or two metre, intervals. On certain spoil heaps the transects were located randomly but generally the relatively small areal extent of the metalliferous habitats and the particular environmental gradients being considered tended to dictate the location and direction of the transect line. Sometimes the transects are very short and this is generally due to the very restricted extent of the metalliferous site.

Most transects have been plotted in diagrammatic form. The diagrams are generally self explanatory but where the diagram contains a relief profile this is illustrative rather than completely accurate. On many diagrams there is a considerable amount of vertical exaggeration.
3.3 The collection and initial treatment of soil samples

Samples were taken of surface spoil or soil where it was exposed or, where a root mat was present, of material just below the mat. All samples were therefore obtained from the top 10cm of the substrate. About 100g of soil, sometimes more, was collected and air dried as soon as practicable. On the return to the laboratories all samples were dried in a drying cabinet at 25°C and all analyses were carried out on soil which had been thus dried. There was often some delay, however, between drying and actual analysis and it is possible that certain samples took up some atmospheric moisture at this stage. This is believed to be relatively unimportant.

3.4 The analyses for heavy metals and the bases calcium, magnesium, sodium and potassium

All the analyses were made for total concentrations of the heavy metals and bases. Antonivics et al (1971) point out that as far as heavy metal analysis is concerned there is no evidence that the methods which purport to measure plant available heavy metal in fact reflect more accurately the amount of heavy metal available to plants. Total metal concentration apparently relates in a reasonably constant way to the concentration affecting the plants, has been used with success by a number of workers (Nicolls et al, 1965, Cole et al, 1968) and is easy to measure. In addition in this study other soil parameters, calcium concentration, organic matter content and pH, known to affect heavy metal availability have been determined and have been used in an inferential way to predict actual soil toxicity.

Total analysis was also performed for the bases calcium, magnesium, sodium and potassium. This method was used because again it is rapid and could produce a large number of analyses, especially for calcium, for use in the computation of the calcium to heavy metal ratio (this ratio is discussed later in this chapter). As with total metal determinations it is probable that the results produced by this
method of analysis reflect in a relative way the amounts of the bases available to plants, especially in relation to, as here, a relatively uniform environment. It must also be pointed out that exchangeable calcium and magnesium are difficult to determine in soils containing free carbonates, Heald (in Black, 1965) does not recommend their estimation in such soils.

All analyses were carried out in a -80 mesh sieve fraction. Samples of 0.1g were digested in 3ml of 8N nitric acid for 95 minutes in a water bath at 95°C. 7ml of distilled water were then added to each sample, the samples were shaken and allowed to settle before analysis. Analysis was performed for the heavy metals and calcium and magnesium using a Shandon Southern A3000 atomic absorption spectrophotometer while sodium and potassium were determined using a Gallenkamp flame photometer. Dilution where necessary was made with 2.4N nitric acid. Solutions of 500 ppm and 1000 ppm strontium in 2.4N nitric acid were used to suppress interference in the analyses for calcium and magnesium respectively.

Determination of copper in the peaty soils from Dolfrwynog (Chapter 9) was carried out both by the above method and on ashed soil. A weighed amount of peaty soil was ashed at 420°C, the weight loss on ashing was calculated and then the ashed sample was sieved to -80 mesh and analysed by the previously outlined method. The copper concentration in the peaty soil was then calculated using the percentage weight loss on ashing. The two methods gave reasonably comparable results, both sets of analyses have been plotted on the diagrams in Chapter 9 but generally the determinations made on ashed soil have been used in the interpretation of the relationships between vegetation and soil toxicity. Exceptions are noted in the text.
3.5 The determination of total phosphorous concentrations

The concentration of total phosphorous was determined in a ground-80 mesh sieve fraction. 0.5g of potassium bisulphate was added to 0.1g of ground soil and mixed and fused until a quiescent melt was obtained. 2ml of 4N nitric acid was then added and the sample placed in a water bath for one hour at 90°C. The samples were then diluted to 10ml with distilled water, mixed and allowed to settle. A 5ml aliquot was then pipetted into a colourimeter tube and 2ml of vanadate-molybdate solution and 3ml of distilled water were added. An Evans Electro Selenium 222 Concentration Colourimeter was used to determine the phosphorous concentration.

3.6 The determination of pH

pH was measured using 20g of soil which had passed through a 2mm sieve. A 1-1 soil-distilled water mixture was generally employed but certain organic samples, mainly from Dolfrwynog, required a 1-2 mixture. A Pye pH meter and glass electrode were used.

3.7 The determination of organic carbon

Organic carbon was determined in a -2mm sieved fraction using the Walkley and Black rapid titration method (Piper, 1947). The value has been reported throughout as organic carbon.

3.8 The determination of soil texture

The determinations were made on samples of 20g which had passed through a 2mm sieve. Particle size analysis for silt and clay was by the pipette sampling method (Day, in Black, 1965) following the destruction of organic matter by hydrogen peroxide and dispersal using Calgon. The sand fractions were analysed by sieving. The analyses are presented throughout in the categories coarse sand, medium sand, fine sand, silt and clay. Table 3.1 shows the size fractions.
to which these categories correspond. The categories are a modification of the United States Department of Agriculture system (Soil Survey Staff, 1951). The U.S.D.A. system is included in Table 3.1 for comparison.

<table>
<thead>
<tr>
<th>Table 3.1 Diameter ranges of soil separates employed in particle size analysis.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used in this study</td>
</tr>
<tr>
<td>Diameter range</td>
</tr>
<tr>
<td>mm</td>
</tr>
<tr>
<td>Coarse sand</td>
</tr>
<tr>
<td>Medium sand</td>
</tr>
<tr>
<td>Fine sand</td>
</tr>
<tr>
<td>Silt</td>
</tr>
<tr>
<td>Clay</td>
</tr>
</tbody>
</table>

United States Dept. of Agriculture system

| Diameter range                                |
| mm                                             |
| Very coarse sand                              | 2.00 - 1.00 |
| Coarse sand                                    | 1.00 - 0.5  |
| Medium sand                                    | 0.5 - 0.25  |
| Fine sand                                      | 0.25 - 0.10 |
| Very fine sand                                 | 0.10 - 0.05 |
| Silt                                           | 0.05 - 0.002 |
| Clay                                           | Below 0.002 |

3.8 The determination of organic matter

As pointed out in Section 3.4 the peaty soils from Dolfrynog bog in Wales were analysed for copper in two ways, one of which involved ashing at 420°C. This produced data on the percentage weight loss on ashing and this has been assumed to correspond to the organic matter content of the soil and has been expressed as such in the text. Methods of organic matter determination involving ignition of soil
at high temperatures are not as accurate as other methods of organic matter determination (Black, 1965) due to loss of water from the minerals of the clay fraction but in relation to the peaty soils from Dolfrwynog this is not thought to be a source of serious inaccuracy.

3.9 The calcium-heavy metal (Ca/HM) ratio

Schwickerath (1931) working on calcareous spoil heaps in Europe showed a better correlation between the vegetation and a calcium-zinc ratio than between the nature of the vegetation and total zinc concentrations. Halliday (1960) used a lead-calcium ratio which he found accounted well for the distribution of Minuartia verna on the spoil heaps of the Northern Pennines.

Schwickerath (1931) was dealing with spoil heaps containing predominantly zinc and Halliday (1960) with ones containing mainly lead but in a wide ranging comparison of toxicity on spoil heaps an immediate problem is that toxicity may be the result of high copper, lead and zinc levels, in isolation or in any combination. Little investigation appears to have been made of the effects of heavy metals in combination or of the relative toxicities of the heavy metals.

The flora of the calcium rich spoil heaps considered in the course of this study is essentially constant, there are no major changes between metalliferous areas which might be ascribed to the presence or absence of a particular heavy metal and for the indicator species Minuartia verna, Thlaspi alpestre, Armeria maritima and Silene maritima ecotypes for the three heavy metals, copper, lead and zinc appear to occur. Inspection of the analyses from various areas suggests that combinations of two heavy metals at moderate concentrations result in a vegetation similar to that produced by a high concentration of one heavy metal alone. To take an example the La Calamine and Theux spot samples (Fig. 4.2) with lead and zinc levels in the ranges (with some exceptions) 30-60,000 ppm and 10-30,000 ppm respectively supported vegetation essentially similar to that in the last few metres of La Calamine Transect 1 (Fig. 4.5) where zinc occurred in concentrations around 100,000 ppm and lead was virtually absent. In addition at Malham Tr. 8b (Chapter 8.8) where
copper, lead and zinc occurred in combination at high concentrations vegetation was virtually non existent, the impression was of an extremely toxic soil.

The field evidence therefore suggests that the heavy metals may act in combination or individually to produce a certain level of toxicity but before such combined effects may be taken into account the relative toxicities of the heavy metals must be known.

Jeffrey et al (1975) designed an experiment to simulate a calcareous nutrient poor site. They grew the grass Festuca rubra ssp. commutata and a legume, white clover, in their culture medium and measured the reduction in the dry weight production of the two species at various heavy metal concentrations. The results showed that 320 ppm of copper produced a reduction of 80-90% in the dry weight of both species while 3,000 ppm of lead was necessary to have the same effect. 4,000 ppm of zinc produced a reduction of 80% in the legume's dry weight but had relatively little effect on the grass. 30,000 ppm of zinc was necessary to reduce the dry weight of the grass by 80%.

The results of this experiment suggest that in calcareous environments for a given concentration copper is more toxic than lead and lead more toxic than zinc. The results suggest that copper has several times the toxicity of lead and field observations support this. Metaliferous sites with just a few thousand ppm of copper and not much more lead and zinc (Grizedale Copper Mine Tr. 9, Chapter 8) support vegetation similar to that of neighbouring sites with relatively little copper but tens of thousands of ppm lead and zinc (Malham, Calamine Mine Tr. 8, Fig. 8.8).

The relationship between lead and zinc suggested by the experiments of Jeffrey et al (1975) is somewhat more equivocal. For the legume zinc appears to be marginally less toxic than lead but for the grass considerably less so. To return to the La Calamine Tr. 1 (Fig. 4.5)
and assuming that *Festuca ovina*, the resident grass, will behave in a similar way to the *F. rubra* ssp. *commutata* of the Jeffrey et al (1975) experiment it is difficult to see how the latter part of the transect, with little lead and predominantly zinc toxicity, can be as toxic for *F. ovina* growth as it apparently is.

Weighing the evidence based on field observations and on the experiments of Jeffrey et al (1975) it was decided, in order to compare calcareous metalliferous environments, to construct a calcium to heavy metal ratio (Ca/HM ratio) as a measure of toxicity based on the assumption that one "unit" of copper will have the same effect on the vegetation as ten "units" of lead or twenty "units" of zinc and also that combinations of these heavy metals have an effect on vegetation which is similar to that of a single heavy metal.

The Ca/HM ratio is thus a derivation of previous ratios which accounted for toxicity in respect of a relationship between calcium and zinc or calcium and lead. In the majority of British situations where lead is in high concentration and zinc at fairly low levels the Ca/HM ratio is essentially a Ca/Pb ratio. Thus many of the general relationships between plant cover and the Ca/HM ratio which will be demonstrated could be produced using a Ca/Pb ratio alone. The inclusion of zinc in the Ca/HM ratio however allows sites in which zinc predominates to be compared with the majority of sites in which lead is the important heavy metal. The Ca/HM ratio has been arrived at by means which are mainly empirical but the ratio also has an empirical justification in that it appears to work. While a high degree of accuracy is not claimed for the assumption that zinc has for a given concentration half the toxicity of lead the Ca/HM ratio calculated on this assumption appears in many cases to account satisfactorily for the distribution of the indicator and other species.
One of the best examples of this is on the floodplain of the stream Eller Beck in Wensleydale (Chapter 7.2). There, downstream from the area of The Straits the relative importance of the heavy metals lead and zinc in the soils changes, lead is in higher concentration near The Straits but zinc is at higher levels than lead farther downstream. Other aspects of the environment along the stream remain relatively constant however and in consequence lead and zinc are the major variables. Because of this environmental homogeneity in variables other than the heavy metals it is possible to consider alternatives to the Ca/HM ratio as just described. This exercise has been carried out in Chapter 7.2 and it will be seen that the Ca/HM ratio based on the assumptions that lead and zinc act in combination to produce toxicity and that lead for a given concentration is about twice as toxic as zinc appears to account adequately for the distribution of the indicator species when the alternatives do not.

Little mention has been made of copper in the above account of the Ca/HM ratio. In the vast majority of British metalliferous sites copper is unimportant, generally being around 100 ppm. Even at these small concentrations copper may be having a slight effect on soil toxicity but this effect has been assumed to be constant and copper has not been included in the calculation of ratio. Where copper was at a concentration in excess of 300 ppm it has been included in the calculation of the Ca/HM ratio using the assumption that copper has ten times the toxicity of lead as suggested by the experiments of Jeffrey et al (1975). In effect copper has only been included in the calculation of the Ca/HM ratio in certain sites in the Malham area, (Chapter 8).

Table 3.2 shows hypothetical examples of the calculation of the Ca/HM ratio, first for a substrate containing lead and zinc and subsequently for one containing copper at a concentration in excess of 300 ppm. As the examples show copper and zinc are converted to a "lead standard".
### Table 3.2 The method of calculation of the Ca/HM ratio

**Example 1: a soil with less than 300 ppm copper**

<table>
<thead>
<tr>
<th>Lead  (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40,000</td>
<td>20,000</td>
<td>100,000</td>
</tr>
</tbody>
</table>

\[
HM = \frac{Zn}{2} + Pb
\]

\[
HM = 10,000 + 40,000
\]

\[
HM = 50,000
\]

\[
Ca/HM = \frac{100,000}{50,000}
\]

\[
Ca/HM = 2/1
\]

Expressed as \(Ca/HM = 2\).

**Example 2: a soil with over 300 ppm copper**

<table>
<thead>
<tr>
<th>Copper (ppm)</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000</td>
<td>30,000</td>
<td>20,000</td>
<td>100,000</td>
</tr>
</tbody>
</table>

\[
HM = 10 \cdot Cu + Pb + \frac{Zn}{2}
\]

\[
HM = 10,000 + 30,000 + 10,000
\]

\[
HM = 50,000
\]

\[
Ca/HM = \frac{100,000}{50,000}
\]

\[
Ca/HM = 2/1
\]

Expressed as \(Ca/HM = 2\).
3.10 The copper-organic matter ratio

At Dolfrwynog bog in Wales copper is present in high concentrations in peaty soils. As has been discussed in Chapter 1 there is considerable evidence that quantities of organic matter in a soil affect the availability and hence the toxicity of heavy metals. Accordingly it was decided to calculate a copper-organic matter ratio (Cu/OM ratio) for the soils at Dolfrwynog bog. The figure for percentage weight loss onashing has been taken to represent the amount of organic matter in the soil. The ratio is a simple division of copper concentration by the percentage of organic matter. Thus a soil with 1,000 ppm copper and 10% organic matter will have a Cu/OM ratio of 100.

The Cu/OM ratio is very similar in rationale to the Ca/HM ratio and as will be shown in Chapter 9 appears to account more satisfactorily for the distribution of the indicator species at Dolfrwynog than measurements of copper concentration alone.

3.11 Accumulated day degrees and their method of calculation

Temperature is considered to be an important factor influencing the distribution of plant communities and species (Good, 1974). Various parameters of temperature have been used in relation to explanations of the distribution of plants, among them measurements of accumulated temperature. Opinions have varied on the usefulness of accumulated temperature as a determinant of the physiological conditions of plant growth. Klages (1949) has suggested that the assumption that a linear relationship exists between temperature and plant growth is fallacious. He felt that this was especially the case when the temperature exceeded optimum conditions. Wulff (1943) however has pointed out that the most important cause of altitudinal climatic boundaries is insufficient warmth.
Accumulated temperatures expressed in day degrees above 42°F (5.6°C) have been used in preference to, for instance, a simple measurement of the mean of the warmest month in the belief that they convey more information about the deterioration of climate northwards and with increase in altitude in the study areas. Table 3.3 shows July mean temperature and accumulated day degree totals for four British orefields.

Table 3.3 shows that while the mean July temperatures of the orefields fall from the Mendips to the Malham region in fairly equal steps of around 1°F (0.6°C) the day degree totals do not follow the same pattern. The change in day degree totals between the Mendips and Halkyn Mountain suggest a greater climatic disparity than might be supposed on the basis of a difference in mean July temperature of 0.8°F (0.5°C). The difference in day degree totals probably provides the better indication of the actual climatic changes, reflecting as it does the longer growing season in the Mendips.

The method used is that of Thom (1954) employing the necessary data of Shellard (1959). The most precise method of calculating accumulated day degree totals involves the use of daily values of maximum and minimum temperature but this is obviously time consuming and requires a large amount of data. The more simple method involving the use of averages of monthly mean temperature suffers from the difficulty that where monthly means are around the base temperature normal day to day temperature variation will not be satisfactorily taken into account. For example using a base temperature of 42°F a month with an average mean of 41.5°F would not "score" any accumulated day degrees, clearly in error for some days are sure to show maximum temperatures in excess of 42°F. More sophisticated methods have been evolved to cope with this problem, the method of Thom (1954) as Shellard (1959) demonstrates with worked examples seems to be the best. In Shellard's example the figure produced by Thom's method
Table 3.3  July mean temperatures and accumulated day degree totals for four British orefields.

<table>
<thead>
<tr>
<th>Orefield</th>
<th>Altitude</th>
<th>July mean</th>
<th>Day degrees (°F)</th>
<th>Climatic station</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Mendips</td>
<td>243m</td>
<td>59.7°F(15.4°C)</td>
<td>2949</td>
<td>Weston super Mare</td>
</tr>
<tr>
<td>Halkyn Mountain</td>
<td>274m</td>
<td>58.9°F(14.9°C)</td>
<td>2510</td>
<td>Rhyl</td>
</tr>
<tr>
<td>The Southern Pennines</td>
<td>307m</td>
<td>57.7°F(14.3°C)</td>
<td>2370</td>
<td>Buxton</td>
</tr>
<tr>
<td>The Malham area</td>
<td>366m</td>
<td>56.6°F(13.7°C)</td>
<td>2120</td>
<td>Malham Tarn House</td>
</tr>
</tbody>
</table>
differs by only one day degree from the precise computation. Thom's method uses the standard deviation of monthly mean temperatures combined with monthly means to produce a statistical estimate of the additional day-degrees in months when the use of the average temperature alone would indicate the accumulated temperature to be small or zero. The method is not particularly complicated but its application requires the use of an empirically derived curve contained in the paper of Thom (1954) and the maps of standard derivation of monthly mean temperatures for the British Isles in Shellard (1959). There is thus little point in reproducing the mathematical expression alone here. Where necessary data for mean temperatures has been adjusted using the environmental lapse rate of $1^\circ F$ for every 270 feet suggested by Manley (1952). The accumulated day degree totals have been left expressed in $^\circ F$. 
PART 2

INVESTIGATIONS OF THE PLANT COMMUNITIES IN SELECTED METALLIFEROUS REGIONS
CHAPTER 4

THE AACHEN-LIEGE OREFIELD OF BELGIUM, GERMANY AND THE NETHERLANDS

4.1 Introduction

Between Aachen in West Germany and Liege in Belgium lies the formerly very important zinc mining region which will be referred to as the Aachen-Liege orefield. The orefield lies on the northern flanks of the Ardennes and Haut Fagnes in the dissected countryside of the pre-Ardennes region. The area ranges in altitude between 150 and 350m and the geological basement is mainly of Devonian and Carboniferous age. The rocks here are less intensely folded than in the region of the Ardennes to the south.

The orefield is drained by the rivers Vesdre, Cheul and Inde. The Vesdre flows westwards in a deep valley from Eupen (Fig. 4.1) to meet the Meuse at Liege while the Cheul flows northwards from the Lontzen-Welkenraedt area to reach the Meuse to the north of Maastricht. The Inde, again with headwaters near to Eupen, flows north-eastwards towards the Rhine.

The climate of the area is greatly influenced by the regular passage of depressions but is somewhat more continental than that of most parts of the British Isles. Maximum and minimum mean temperatures are more extreme than those of Britain, Maastricht, a little to the north of the region, has a July mean of 20°C and a January mean of 2°C. The first frost in the area is experienced in late October, somewhat earlier than at Brussels to the north. Although rainfall totals are not as high as those of the Haut Fagnes and Ardennes they are considerably greater than in most regions of Belgium. The rainfall stations at Thimister (268m) and Aachen (204m) are both within the orefield and record annual precipitation totals of 1044mm and 844mm respectively.
The mineralisations of the orefield are associated with limestones or dolomites of Carboniferous or Devonian age. They are believed to be the result of segregation from hydrothermal solutions originating from a deep seated abyssal intrusion and rising along weaknesses in the country rocks (Dewez and Lespineux, 1947). Zinc was generally the predominant mineral, accompanied by galena, pyrite and marcasite. Calcite was an important gangue mineral.

Mining in the area, as in the British Isles, appears to have had a long history. At Prayon in the valley of the Vesdre a mine is believed to have been worked by the Romans, mainly for iron ore, but the period of maximum mining activity was during the Nineteenth Century. By the latter part of that period the industry was beginning to decline, production figures for a mine at Kinkerapois near to Liege show that it was unimportant in 1871.

Other mines in the area were productive for somewhat longer. The Bleiberg mines at Plombieres worked veins containing haematite, galena, blende and pyrite. The Bleiberg vein was filled with a brecciated mixture of grits, shales and sandstones, cemented by ore (Admiralty, 1918). The period of greatest activity at Plombieres was from 1833 to 1870 when 60,000 tonnes of lead and 20,000 tonnes of zinc were produced. This mine was unusual in the orefield in the particular predominance of lead in the deposit and as will be seen later this is reflected in the composition of the spoil heaps today. The waste heaps at Plombieres were reworked during the Second World War.

The Vielle Montagne mines in the La Calamine area were once the most important of the whole mining region, being predominant at their zenith in total world production of zinc. The ore bodies consisted of masses of calamine with red clay, lying in a dolomitic pocket in the Carboniferous Limestone (Admiralty, 1918).
As was stated earlier the latter decades of the Nineteenth Century were the period of decline of the Belgian zinc mining industry. Production figures for Belgium for 1912 indicate that 488,030 tonnes of foreign ore and 840 tonnes of Belgian ore were processed in that year, the Belgian ore was won from the mines at Welkenraedt. Clearly by 1912 Belgian mining had virtually ceased. The mines in the Aachen area appear to have been worked for longer. The Admiralty report of 1918 records that the mines at Stolberg were being actively exploited at that time.

4.2 The heavy metal tolerant communities

In Chapter 1 the taxonomic confusion surrounding the heavy metal species of the Aachen-Liege area was outlined. It was pointed out that, according to Flora Europaea (1964, 1968), certain of the "species" and "varieties" of the heavy metal tolerant plants of the region were no more than local variants and ecotypes. For this reason, although the nomenclature which is used here closely follows that of Lambinon and Auquier (1964) and other recent accounts of the flora of these metalliferous areas, varieties and subspecies have been omitted.

The Aachen-Liege region is one of considerable diversity of metalliferous habitats. To the east of Aachen, around La Calamine and near Theux in the valley of the Hoegne (Fig. 4.1) the heavy metal plant communities occur on spoil derived from mining operations while in the valley of the Gheul, flowing northwards to the Netherlands, the communities are associated with toxic material washed downstream from the La Calamine and Plombieres district. At Prayon metal tolerant species occupy areas polluted in the course of smelting operations and at Angleur smelter waste provides sites of considerable toxicity.
The Aachen-Liege area was visited for a short period in July 1972 and for a longer period in August 1973. An attempt was made to visit as many sites as possible of those mentioned by Heimans (1960), Lambinon and Auquier (1964) and Lefebvre (1967). The general aim of the study in the orefield was to obtain a comparison with the British situation.

Fig. 4.1 which shows the distribution of the indicator species in the area has been prepared from personal observation and a variety of published sources. The map outlines the distribution of four species Minuartia verna, Thlaspi alpestre, Armeria maritima and Viola calaminaria. Other metal tolerant species such as Silene cucubalus and Campanula rotundifolia are generally present and have not been included.

As in Britain the metal tolerant species do not occur everywhere in a fully expressed association. Only at La Calamine do the four indicator species, *M. verna*, *T. alpestre*, *A. maritima* and *V. calaminaria* combine with other metal tolerant forbs and grasses to produce the "classical" north west European heavy metal assemblage. At Angleur and Plombieres *M. verna* is absent and at Breinigeberg near Aachen *T. alpestre* does not appear to occur.

4.3 The minor sites

In the course of reconnaissance a number of sites were visited. At these localities soil samples were taken and floristic lists, concentrating on the indicator species, made. Fig. 4.2 shows the heavy metal levels at these various sites, the concentrations of lead and zinc on the transects at La Calamine are also included in the figure for comparative purposes. Other analyses were also carried out and these are included in the text.
Figure 4.2
Angleur

Fig. 4.2 shows the concentrations of copper, lead and zinc in spoil from Angleur. Table 4.1 presents further analyses of the spoil from Angleur.

Table 4.1 Calcium concentrations in and the pH of certain samples from Angleur.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Calcium (ppm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 1</td>
<td>nd*</td>
<td>6.8</td>
</tr>
<tr>
<td>S 2</td>
<td>5,750</td>
<td>6.7</td>
</tr>
<tr>
<td>Tr 1/2m</td>
<td>13,300</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Much of the metalliferous spoil at Angleur appears to contain an admixture of smelted material. As is evident from inspection of Fig. 4.2 and Table 4.1, with the exception of Sample 1, heavy metal and calcium concentrations and pH of the spoil from Angleur appear reasonably uniform. Sample 1 was from an atypical site, the area appeared to have been levelled by bulldozing, presumably in the course of reclamation.

Viola calamaria, Silene cucubalus, Agrostis tenuis and Rumex acetosa were present at all the sampled sites but Thalassia alpestre and Armeria maritima were absent from the disturbed site at which Sample 1 was taken. Minuartia verna was not seen at Angleur and does not appear to have been recorded from the locality.

Prayon

Mining is known to have taken place at Prayon but the main cause of contamination of the environment by heavy metals appears to be emission from a zinc smelting plant. Ramaut (1964) has documented the effects of this pollution and mentions Thalassia alpestre growing

* nd - not determined, abbreviation used throughout
here on soil containing 0.28 - 0.5% zinc. In this study *T. alpestre* was found growing in soil of pH 6.6 and zinc concentrations of 4,000 to 8,000 ppm (Prayon S1 and S2, Fig. 4.2). The calcium level in Prayon S2 was 5,500 ppm.

**Theux**

Fig. 4.2 shows heavy metal concentrations in the four samples taken from Le Rocheux near Theux and Table 4.2 contains the results of additional analyses of the spoil.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Calcium (ppm)</th>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorus (ppm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>7,950</td>
<td>350</td>
<td>810</td>
<td>nd</td>
<td>nd</td>
<td>7.2</td>
</tr>
<tr>
<td>S2</td>
<td>10,950</td>
<td>275</td>
<td>810</td>
<td>nd</td>
<td>nd</td>
<td>7.1</td>
</tr>
<tr>
<td>S3</td>
<td>7,500</td>
<td>275</td>
<td>765</td>
<td>2,700</td>
<td>480</td>
<td>7.0</td>
</tr>
<tr>
<td>S4</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>6.7</td>
</tr>
</tbody>
</table>

It is clear from the analyses in Table 4.2 and Fig. 4.2 that the spoil from Theux is very uniform in its chemical composition. Nevertheless there was some variability in the incidence of the metal tolerant species from site to site.

*Minuartia verna* was present only at the site from which Sample 3 was taken and was there represented by only a few individuals. The site was one of more or less bare spoil and appeared to have been affected by recent erosion. Isolated clumps of the grasses *Festuca ovina* and *Agrostis tenuis* stood above the general level of the spoil, holding what appeared to be the remnants of a formerly more extensive organic surface horizon at their bases.
Viola calaminaria occurred only at the site of Sample 4 and grew in an organic layer overlying spoil. This mixture of organic material and spoil was between 7 and 10 cm thick. The slightly lower pH (Table 4, 2) of the sample from this site is probably related to the organic matter accumulation at the surface. A tendency for V. calaminaria to be associated with sites with organic matter accumulation in the surface horizon has also been noticed elsewhere in the Aachen-Liege orefield and this will be discussed more fully later.

Silene cucubalus, Thymus pulegioides L., Euphrasia officinalis L., Campanula rotundifolia, Lotus corniculatus L., and Linum catharticum were also seen on the spoil heaps at Theux. Armeria maritima was not found.

Lontzen

Lambinon and Auquier (1964) list sites at Montzen, Lontzen and Welkenraedt (Fig. 4.1). Of these only the metalliferous plant community at Lontzen was located. As Fig. 4.2 shows heavy metal levels at the site were, in terms of some elsewhere in the orefield, not particularly high. Of the species considered typical of the metalliferous flora of the region only Silene cucubalus and Campanula rotundifolia were present. The pH of the spoil was 7.

River Gheul

Heimans (1960) has described the heavy metal vegetation of the floodplain of the River Gheul. He mentioned that the application of lime to the floodplain soils was leading to the disappearance of the indicator plant communities. It proved impossible to find plant communities as described by Heimans (1960). This may have been because only a limited area of the floodplain was searched but it may be that in the decade since Heimans (1960) described the communities they have been very greatly reduced in extent by the liming of the floodplain soils.
Of the species of the metallic flora only *Silene cucubalus* was found. This plant grew in two places (River Gheul Sl and S2, Fig. 4.2) where undercutting of the river bank had occurred. Zinc levels in the soil at these sites were between 4,000 and 10,000 ppm and the values for lead were similar. The pH of the alluvium was 7.2 at both sites.

**Stolberg**

The large spoil heaps at Stolberg are composed of slag material derived from smelting and are poorly vegetated. The slopes of the spoil heaps are, to a certain extent, unstable, the angle of slope of much of the spoil is between 30° and 36°. Information on the heavy metal content of the spoil is presented in Fig. 4.2 and Table 4.3 shows the results of other analyses.

**Table 4.3** Calcium, sodium, potassium, magnesium and pH determinations of spoil from Stolberg

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Calcium (ppm)</th>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>6.5</td>
</tr>
<tr>
<td>S2</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>5.8</td>
</tr>
<tr>
<td>S3</td>
<td>8,950</td>
<td>175</td>
<td>1,100</td>
<td>2,210</td>
<td>6.7</td>
</tr>
</tbody>
</table>

*Thlaspi alpestre, Armeria maritima* and *Viola calaminaria* were present in places on the spoil at Stolberg but *Minuartia verna* does not appear to occur at this site.

**Breinigeberg**

At Breinigeberg there appears to have been much less disturbance due to mining activity than at many other sites of mineralisation in the Aachen-Liege orefield.
Two discrete areas were sampled and the results of the analyses are shown in Fig. 4.2 and Table 4.4.

Table 4.4 Calcium, sodium, potassium, magnesium and pH determinations of soil from metalliferous areas at Breinigeberg

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Calcium (ppm)</th>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>6,950</td>
<td>105</td>
<td>810</td>
<td>2,170</td>
<td>6.5</td>
</tr>
<tr>
<td>Tr 1/2m</td>
<td>295,000</td>
<td>765</td>
<td>1,300</td>
<td>1,990</td>
<td>8.0</td>
</tr>
<tr>
<td>Tr 1/6m</td>
<td>240,000</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>7.8</td>
</tr>
</tbody>
</table>

The samples Tr 1/2m and Tr 1/6m are representative of the chemical characteristics of the soil along a short transect which ran through a Minuartia verna community on the side of an excavated vein at Breinigeberg. The slope along much of the transect line was in excess of 30°. M. verna occurred in the first 2m of the transect line at cover values of 2% and was associated with other calcicole species such as Hieracium pilosella L., Thymus pulegioides L. and Linum catharticum. M. verna was absent from the area of 6m. As Fig. 4.2 shows zinc levels are lower in the 6m region than in the vicinity of 2m where M. verna occurred. Although calcium levels at 6m are lower also (Table 4.4) it appears probable that the absence of M. verna from the 6m region is due to lower toxicity. The occurrence of M. verna at Breinigeberg is discussed more fully later.

Both samples on this transect line are unusual in respect of their very high calcium concentrations. These have been verified by replicate analysis and are in accordance with the high pH values of the samples.
The situation at the site from which Breinigeberg Sample 1 (Fig. 4.2 and Table 4.4) was obtained was very different. This was an area of short grass, mainly *Festuca ovina*, and appeared to be undisturbed although nearby was some hummocky ground, perhaps indicative of former mineral workings. *Armeria maritima* and *Viola calaminaria* occurred at this site in soils with an insignificant zinc level but a lead concentration of around 10,000 ppm.

### 4.4 The major sites

**Plombieres**

Mining operations ceased in the La Calamine-Plombieres region around the turn of the Nineteenth Century. At Plombieres, however, as previously mentioned, there was some reworking of the spoil during the Second World War. Because of this it is even more difficult than normal to form an impression of site history.

Fig. 4.3 refers to Transect 2 which crossed a flat area of spoil, the spoil being predominantly composed of smelted slag material. The transect appears to be divisible into two sections, an initial area to 22m with much bare ground and the subsequent part beyond. These sections will be referred to as Zone 1 and Zone 2 respectively.

In Zone 1 lead and zinc show a fairly constant relationship with lead concentrations being about twice those of zinc. In Zone 2 there is far greater variability in the concentrations of the two heavy metals and in their relationship one to the other. Table 4.5 shows the means and standard deviations for lead and zinc concentrations in the two zones.
GEOBOTANY

Campanula rotundifolia

Agrostis tenuis

Festuca ovina

Viola calaminaria

Armeria maritima

Bare Ground

GEOCHEMISTRY

60,000
50,000
40,000
30,000
ppm
20,000
10,000
0

Pb

Zn

Cu

RELIEF

PLOMBIERES: TRANSECT 2.

Figure 4.3
Table 4.5 The means and standard deviations of lead and zinc concentrations in Zones 1 and 2 on Plombières Tr. 2.

<table>
<thead>
<tr>
<th></th>
<th>0 - 22m.</th>
<th>24 - 40m.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lead</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ppm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>24,183</td>
<td>20,772</td>
</tr>
<tr>
<td>S. D.</td>
<td>3,976</td>
<td>14,599</td>
</tr>
<tr>
<td><strong>Zinc</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ppm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>10,058</td>
<td>21,433</td>
</tr>
<tr>
<td>S. D.</td>
<td>3,193</td>
<td>14,683</td>
</tr>
</tbody>
</table>

Table 4.5 demonstrates that while the mean concentration of lead is slightly lower in Zone 1 than in Zone 2 mean concentrations of zinc are more than doubled. Although there is more variability in lead and zinc concentrations in Zone 2 it is clear from Fig. 4.3 that many samples from Zone 2 show heavy metal concentrations equal to or exceeding those of Zone 1. It is evident from Fig. 4.3 that the only species of any importance in Zone 1 are Festuca ovina and Armeria maritima and that bare ground in many quadrats approaches 100%. In Zone 2, however, Agrostis tenuis greatly increases in cover values as also does F. ovina. A. maritima and Viola calaminaria too become more important and Campanula rotundifolia appears in the community. Differences in metal concentrations clearly do not account for the contrast in the vegetation between the two zones.

Nor are there great differences in the concentrations of the bases calcium, sodium, potassium and magnesium in the two zones (Table 4.6). It has been suggested by Smith and Bradshaw (1970) that phosphorus deficiency is important on spoil heaps. On the basis of two samples, one from 14m showing a phosphorous concentration of 980 ppm, the other from 36m with 920 ppm, the phosphorous concentrations in the two zones do not appear to differ markedly.
Table 4.6  The means of the concentrations of calcium, sodium, potassium and magnesium in Zones 1 and 2 on Plombieres Tr. 2 (based on the analyses of samples at 4m intervals)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Calcium (ppm)</th>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-22m</td>
<td>4,683</td>
<td>103</td>
<td>1,085</td>
<td>950</td>
</tr>
<tr>
<td>24-40m</td>
<td>3,738</td>
<td>100</td>
<td>818</td>
<td>1,135</td>
</tr>
</tbody>
</table>

The pH values in the two zones however are quite different (Table 4.7). It appears probable that the lower pH of Zone 1 results in greater availability of the heavy metals and greater toxicity, thus retarding the process of vegetation development.

Table 4.7  pH Values in Zones 1 and 2 on Plombieres Tr.2.

<table>
<thead>
<tr>
<th>Zone</th>
<th>0m</th>
<th>6m</th>
<th>12m</th>
<th>18m</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.2</td>
<td>5.6</td>
<td>5.8</td>
<td>5.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Zone</th>
<th>24m</th>
<th>30m</th>
<th>36m</th>
<th>40m</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.5</td>
<td>6.4</td>
<td>6.2</td>
<td>6.2</td>
</tr>
</tbody>
</table>

Transect 3 investigated the vegetation of a spoil heap slope at Plombieres. As Fig. 4.4 shows the transect is short, this reflects the nature of the site. It is evident from Fig. 4.4 that heavy metal concentrations in the spoil here are lower than on Tr. 2 and that more species are present. *Thlaspi alpestre*, absent on Tr. 2, occurred here. Table 4.8 shows that the calcium concentration in the spoil on Tr. 3 is considerably higher than on Tr. 2 (Table 4.6) and it appears probable that the lower heavy metal levels of the spoil combined with a higher calcium concentration result in less toxicity on Tr. 3 than on Tr. 2 and the consequent presence of more species.
PLOMBIERES
TRANSECT 3.

GEOBOTANY

Rumex acetosa
Ranunculus acris
Helichotrichon pubescens
Agrostis tenuis
Festuca ovina
Silene cucubalus
Campanula rotundifolia
Viola calaminaria
Thlaspi alpestre
Armeria maritima
Bare Ground

GEOCHEMISTRY

Pb
Zn
Cu

RELIEF

Figure 4.4
Table 4.8  Calcium, sodium, potassium, magnesium and pH determinations from 4m on Plombieres Tr. 3.

<table>
<thead>
<tr>
<th>Calcium (ppm)</th>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>6700</td>
<td>105</td>
<td>1055</td>
<td>980</td>
<td>5.8</td>
</tr>
</tbody>
</table>

Table 4.8 shows, however, that the pH of the spoil on Tr. 3 is lower than that in Zone 2 on Tr. 2 (Table 4.7), in fact being as low as in one sample from Zone 1 on Tr. 2. It is important on spoil heap soils to distinguish between a low pH which is the result of the primary characteristics of the spoil and a low pH which is essentially secondary, the latter accompanying the accumulation of organic matter in the upper horizons of the spoil. It is suggested that the low pH on Tr. 3 is secondary, the organic carbon analysis of 12.2% at 4m suggests organic matter accumulation in the surface horizons of the spoil at this site. Under conditions of organic matter accumulation it appears that any tendency for the heavy metals to become more mobile due to lower pH is offset by the formation of stable complexes of heavy metal and organic matter. This development of a secondary low pH is also seen at La Calamine and on many other spoil heaps and will be discussed further.

La Calamine

On the outskirts of La Calamine large, flat topped spoil heaps provide a habitat for a variety of metal tolerant species. The species Armeria maritima, Minuartia verna, Thlaspi alpestre and Viola calaminaria occur on these heaps. Two areas were investigated using short transects and spot samples were taken in other localities. Fig. 4.5 shows the details of vegetation cover and heavy metal concentrations on La Calamine Tr. 1. The figure demonstrates considerable variability in heavy metal levels over short distances and this is typical of spoil heaps in many areas. Samples in the
GEOBOTANY

- Eremohexa edithica
- Enoloxys hypoxys
- Rumex acetosa
- Linaria vulgaris
- Linum catharticum
- Pimpinella saxifraga
- Plantago lanceolata
- Ranunculus acris
- Thymus pulegiodes
- Achillea millefolium
- Aster cordifolius
- Scleranthus pubescens
- Helianthus annuus
- Agrostis tenuis
- Festuca ovina
- Campanula rotundifolia
- Silene cucubalus
- Galea calaminaria
- Thlaspi alpestre
- Minuartia verme
- Bare Ground

GEOCHEMISTRY

- Cu
- Pb
- Zn

RELIEF

LA CALAMINE:
TRANSECT 1.

Figure 4.5
first six metres show lead and zinc in variable but, especially in the case of zinc, high concentrations. Beyond 7m lead decreases to consistently low levels while zinc remains at concentrations in the region of 100,000 ppm.

A large number of species, for a spoil area, is present in the short distance of the transect line. It is interesting to notice that even in conditions of high heavy metal concentration many species may be found associated with the indicator plants. *Armeria maritima* was absent from the area of the transect and *Thlaspi alpestre* occurred only occasionally. *Minuartia verna*, however, was present over much of the transect and an interesting facet of its distribution was its occurrence at cover values of 15-20% in the 7-10m region. Inspection of Fig. 4.5 suggests that this is not a straightforward effect of heavy metal concentration, although zinc levels are consistently high beyond 7m it may be argued that this is probably, to a certain extent, offset by the drop in lead concentration beyond this point.

Other analyses shown in Table 4.9 do not suggest any reason for the peculiar distribution of *M. verna* in the area of the transect line. As the table shows the pH does not change very much along the line, potassium is a little lower at 8m and 10m but, especially at 8m, not markedly so. Calcium at 8m is much lower than at 0m and 2m but is greater than at 4m where *M. verna* is only present at a low cover value. The Ca/HM ratio (discussed in Chapter 3) is believed, in most cases, to provide a better guide to the toxicity of calcareous spoil than heavy metal concentrations alone but as Table 4.9 shows the Ca/HM ratio is greater at 6, 8 and 10m, implying less toxicity, than at 4 and 12m where *M. verna* is not present at high cover values.
<table>
<thead>
<tr>
<th>pH</th>
<th>Ca/HM Ratio</th>
<th>Phosphorus (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Sodium (ppm)</th>
<th>Calcium (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.3</td>
<td>0.14</td>
<td>0.20</td>
<td>0.21</td>
<td>0.26</td>
<td>0.63</td>
<td>0.67</td>
</tr>
<tr>
<td>7.4</td>
<td>7.4</td>
<td>0.12</td>
<td>0.75</td>
<td>1.2</td>
<td>1.75</td>
<td>2.75</td>
</tr>
<tr>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>8.9</td>
<td>9.50</td>
<td>9.50</td>
<td>9.50</td>
<td>9.50</td>
<td>9.50</td>
<td>9.50</td>
</tr>
<tr>
<td>7.7</td>
<td>7.7</td>
<td>7.7</td>
<td>7.7</td>
<td>7.7</td>
<td>7.7</td>
<td>7.7</td>
</tr>
<tr>
<td>8.1</td>
<td>8.1</td>
<td>8.1</td>
<td>8.1</td>
<td>8.1</td>
<td>8.1</td>
<td>8.1</td>
</tr>
</tbody>
</table>

Table 4.9: Base concentrations, phosphorous status, pH and the Ca/HM ratio on La Calamine Tr. 1.
As Fig. 4.5 shows between 6m and 7m there was a slope on the transect line. This was of the order of 25° and some movement of spoil was taking place. The 6-7m region however is not that occupied by M. verna at high cover values and it seems unlikely that spoil would be moving from the 6-7m area to the region beyond in sufficient amounts to depress competition to the advantage of M. verna.

The textural analyses of spoil from 2m and 7m however are very different (Table 4.10). This textural distinction between the two samples is in accordance with the difference in the proportions of lead and zinc in the two places (Fig. 4.5) and it is probable that the spoil is heterogenous in origin.

Table 4.10. Particle size analyses of spoil from La Calamine Tr.1.

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>2m</td>
<td>22.9%</td>
<td>15.1%</td>
<td>18.8%</td>
<td>31.8%</td>
<td>10.1%</td>
<td>5.2%</td>
</tr>
<tr>
<td>7m</td>
<td>39.1%</td>
<td>13.9%</td>
<td>15.9%</td>
<td>24.5%</td>
<td>7.5%</td>
<td>3.1%</td>
</tr>
</tbody>
</table>

Lambinon and Auquier (1964) suggested, without presenting much evidence, that M. verna on the Aachen-Liege spoil heaps tended to occur on the drier sites. Particle size analysis can only be an indirect guide to soil moisture status but in a situation such as the one on this transect line where other environmental factors are unlikely to affect soil moisture status it seems reasonable to infer that the 7m site will be the drier one.

There are two possible explanations for the occurrence and abundance of M. verna on drier sites, one physiological and the other related to competition. As is shown in Chapter 9 M. verna is known from certain sites which are extremely, and more or less perennially,

* Diameter ranges for these separates shown in Chapter 3.
wet and the plant therefore does not appear to have a physiological requirement for a dry substrate. It appears that on La Calamine Tr. 1 M. verna is present at the highest cover values in an area which has a textural predisposition to edaphic dryness and it seems probable that this dryness results in the suppression of competition from potential competitors thus allowing the species to occur abundantly.

In view of this suggestion it may be considered surprising that M. verna shows a marked decrease in cover values beyond 10 m where toxicity levels remain high and the spoil appears, in terms of the relative proportions of lead and zinc, unchanged. It is believed that this reflects the proximity to the end of the transect line of a small river, the River Gheul mentioned previously in this chapter. Just beyond the end of the transect line the vegetation changed markedly and Molinia caerulea and a Carex sp. were present amongst others. Lambinon and Auquier (1964) have noted species of wetter habitats in the damper places on the spoil heaps of the Aachen-Liege area. It seems reasonable to suppose that the area beyond 10m on this transect line has a higher moisture status than the remainder and that this accounts for the decrease of M. verna.

On La Calamine Tr. 4 (Fig. 4.6) Armeria maritima was present at moderate cover values in certain quadrats while M. verna was absent. Thlaspi alpestre which occurred in several quadrats on Tr. 1 was only present in one quadrat on Tr. 4. Many of the accompanying species were common to both transects. The general area of Tr. 4 was more disturbed than that of Tr. 1, there was evidence of recent excavation and because of this bare ground amounts and the cover values of individual species cannot be compared directly with Tr. 1. Even though disturbed this was one of the few areas at La Calamine where Armeria maritima occurred in relative abundance and was therefore investigated. The area of the transect line was more or less flat and for this reason a plot of the relief has been omitted from Fig. 4.6.
GEOBOTANY

Linum catharticum
Lotus corniculatus
Rumex acetosa
Cerastium vulgatum
Pimpinella saxifraga
Achillea millefolium
Euphrasia officinalis
Plantago lanceolata
Thymus pulegioides
Agrostis tenuis
Festuca ovina
Campanula rotundifolia
Silene cucubalus
Viola calaminaria
Thlaspi alpestre
Armeria maritima
Bare Ground

GEOCHEMISTRY

LA CALAMINE:
TRANSECT 4.

Figure 4.6
Zinc concentrations as shown in Fig. 4.6 are lower on this transect line than on La Calamine Tr. 1 (Fig. 4.5) while lead concentrations are somewhat higher. It is clear from Table 4.11 that calcium levels in the spoil from this transect are generally, and are often considerably, higher than on Tr. 1 (Table 4.9). This has an effect on the Ca/HM ratio and as the table shows every sample on Tr. 4 has a ratio which is higher than any of those on Tr. 1 (Table 4.9). It appears that, as measured by the Ca/HM ratio, the spoil of this transect is less toxic than that of Tr. 1. With the exception of sodium which is probably not important the other chemical analyses from this transect line are similar to those from Tr. 1.

Table 4.11. Base concentrations, phosphorous status, pH and the Ca/HM ratio on La Calamine Tr. 4.

<table>
<thead>
<tr>
<th></th>
<th>0m</th>
<th>2m</th>
<th>4m</th>
<th>6m</th>
<th>8m</th>
<th>10m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (ppm)</td>
<td>35,500</td>
<td>65,000</td>
<td>62,500</td>
<td>101,500</td>
<td>62,500</td>
<td>48,500</td>
</tr>
<tr>
<td>Sodium (ppm)</td>
<td>210</td>
<td>575</td>
<td>575</td>
<td>780</td>
<td>598</td>
<td>700</td>
</tr>
<tr>
<td>Potassium (ppm)</td>
<td>1,100</td>
<td>1,810</td>
<td>1,400</td>
<td>1,140</td>
<td>1,255</td>
<td>2,250</td>
</tr>
<tr>
<td>Magnesium(ppm)</td>
<td>4,800</td>
<td>nd</td>
<td>3,070</td>
<td>nd</td>
<td>2,320</td>
<td>nd</td>
</tr>
<tr>
<td>Phosphorous(ppm)</td>
<td>nd</td>
<td>nd</td>
<td>1,660</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>Ca/HM ratio</td>
<td>0.95</td>
<td>1.36</td>
<td>1.20</td>
<td>2.77</td>
<td>1.32</td>
<td>0.77</td>
</tr>
<tr>
<td>pH</td>
<td>7.5</td>
<td>nd</td>
<td>7.7</td>
<td>nd</td>
<td>7.6</td>
<td>nd</td>
</tr>
</tbody>
</table>

As Table 4.12 shows the spoil at 6m on Tr. 4 contains a large amount of clay. The percentage of clay is three to four times that of the spoil of Tr. 1 (Table 4.10). The geological account of La Calamine in the introduction to this chapter contains a reference to the ore bodies consisting of masses of calamine with red clay, perhaps the clay in the spoil on Tr. 4 is from such a source.
Table 4.12  Particle size analysis of spoil from 6m on La Calamine Tr. 4.

<table>
<thead>
<tr>
<th></th>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>21.1%</td>
<td>6.5%</td>
<td>8.9%</td>
<td>14.8%</td>
<td>32.4%</td>
<td>8.1%</td>
</tr>
</tbody>
</table>

Armeria maritima is absent from La Calamine Tr. 1 but present on Tr. 4. It does not seem probable that this is due to the greater toxicity of the spoil on Tr. 1. The species was present in the quadrats in Zone 1 on Plombieres Tr. 2 (Fig. 4,3) and even though heavy metal concentrations in that zone are lower than at La Calamine this is probably offset by the much lower pH in Zone 1 at Plombieres. It is very probable that the spoil in Zone 1 at Plombieres is more toxic than that at La Calamine, bare ground amounts are higher than on both of the La Calamine transects and the species complement is lower. Only 4 species occur in Zone 1 at Plombieres compared with 20 on La Calamine Tr. 1.

More likely than exclusion by toxicity is that the spoil of La Calamine Tr. 1 is too dry for A. maritima. Lambinon and Auquier (1964) suggest that A. maritima in the Aachen-Liege orefield tends to occur on the more moist sites and the high clay content of the spoil of La Calamine Tr. 4 implies that the material will be less susceptible to drought than the spoil of Tr. 1.

It is believed that M. verna is absent from Tr. 4 due to the occurrence there of greater competition from other species than on Tr. 1. This suggestion of an increase in competition on Tr. 4 is based upon the lower toxicity of the spoil and the reduced likelihood of it being affected by drought.
In the course of a short visit to La Calamine in July 1972 a small number of samples were taken from other places on the spoil heaps. Samples 2, 3, 4, 5 and 6 (Table 4.13) were obtained at 4m intervals along a short transect line on the top of the spoil heap. *Minuartia verna* was generally present while *Armeria maritima* was absent. The accompanying species were similar to those of Transects 1 and 4 although slightly fewer were present. For this reason the transect has not been plotted.

**Table 4.13.** Calcium, pH and organic carbon determinations and the Ca/HM ratio of spot samples 2, 3, 4, 5 and 6 from La Calamine.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Calcium (ppm)</th>
<th>Ca/HM</th>
<th>pH</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2</td>
<td>2,200</td>
<td>0.04</td>
<td>6.9</td>
<td>4.2%</td>
</tr>
<tr>
<td>S3</td>
<td>13,150</td>
<td>0.22</td>
<td>7.4</td>
<td>5.1%</td>
</tr>
<tr>
<td>S4</td>
<td>3,330</td>
<td>0.14</td>
<td>7.2</td>
<td>3.8%</td>
</tr>
<tr>
<td>S5</td>
<td>3,050</td>
<td>0.09</td>
<td>7.1</td>
<td>2.1%</td>
</tr>
<tr>
<td>S6</td>
<td>4,900</td>
<td>0.06</td>
<td>7.1</td>
<td>3.5%</td>
</tr>
</tbody>
</table>

As Table 4.13 shows calcium concentrations and Ca/HM ratios are generally slightly lower than on La Calamine Tr. 1 (Table 4.9). Inspection of Fig. 4.2 shows that the tendency observed on Tr. 1 for lead concentrations to be variable over short distances is also evident in these samples.

On the transects of the spoil heap tops *Viola calaminaria* was not an important component of the vegetation communities. The species occurred at low cover levels in only one or two quadrats on Transects 1 and 4. *Viola calaminaria*, grew abundantly on the slopes of the heaps at La Calamine, occurring with *Armeria maritima*, *Minuartia verna* and other species. No quantitative survey was made of the vegetation of these slopes but Plates 1 and 2 show the contrast between the vegetation of the flat tops of the heaps and that of the slopes.
Plate 1.

The vegetation of a spoil heap slope at La Calamine.

Plate 2. The vegetation of the flat top of the spoil heap at La Calamine.
Table 4.14  Heavy metal, calcium, pH and organic carbon determinations and the Ca/HM ratio of Sample 1 from La Calamine.

<table>
<thead>
<tr>
<th>Copper (ppm)</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>Ca/HM</th>
<th>pH</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>167</td>
<td>42,900</td>
<td>65,000</td>
<td>4,900</td>
<td>0.06</td>
<td>6.7</td>
<td>14.2%</td>
</tr>
</tbody>
</table>

Sample 1 (Table 4.14) was taken at the site shown in Plate 1. It is evident that the organic carbon level in this spoil is greater than that of the spoil of the transects and spot samples of the spoil heap tops (Tables 4.10, 4.12 and 4.13) in which organic carbon was generally less than 5%, only reaching 8% in the less toxic material from Tr. 4. The Ca/HM ratio of Sample 1 is quite low implying considerable toxicity. It seems probable, however, that with the accumulation of organic matter on the spoil some loss of calcium relative to heavy metal has occurred through leaching and it is unlikely that the Ca/HM ratio of 0.06 reflects the original Ca/HM ratio of the spoil at this site. As a general principle the Ca/HM ratio becomes less useful as a guide to toxicity with increasing organic matter accumulation. Even on the assumption, however, that heavy metal levels in the developing soil have remained constant while calcium concentrations have dropped from a value three times their present amount the Ca/HM ratio of the original spoil would not be above 0.2. This is about the general ratio of the spoil of the area occupied by Minuartia verna on Tr. 1 (Table 4.9). It thus appears that on this particular site at least a more or less closed community of metal tolerant species, as seen on Plate 1, has developed on the spoil heap slope at a Ca/HM ratio which on Tr. 1 is associated with a community with 50% bare ground.

The general impression at La Calamine is of relatively bare spoil heap tops and well colonized spoil heap slopes; the slopes showing an organic surface horizon development. The spot sample suggests that toxicities on the slopes and on the heap tops may be similar.
any case if this is a widespread phenomenon spoil variability cannot be invoked to explain it. Perhaps the explanation is one related to physical conditions. It is possible that the tops of the spoil heaps are more compacted or more probably that there is greater availability of water on the spoil heap slopes. The subject requires further investigation, initially to check the general validity of the impression derived from the one spot sample and secondly, if validity is shown, to account for the phenomenon.

4.5 Observations in the metalliferous vegetation of the Aachen-Liege orefield

The general impression given by the continental workers about the Aachen-Liege orefield is of the importance of zinc toxicity. Schwickerath (1931) wrote of the "Zinkboden on der Umgebung Aachens" (the zinc ground in the neighbourhood of Aachen) and Lambinon and Auquier (1964) refer to the "terrains calaminares" (calamine ground) of the region. It is true that the region was an important zinc mining area but the importance of lead in many spoils in the orefield should not be overlooked.

At Theux lead exceeded zinc in concentration in every sample taken and also at Plombieres lead was in greater concentration than zinc in many samples. Plombieres was in fact predominantly a lead mining centre as the name suggests. Even at La Calamine where zinc normally shows higher concentrations than lead in the spoil, lead amounts are by no means negligible. Inspection of Fig. 4.2 will demonstrate the importance of lead in many spoils in the orefield.
Given that lead is generally considered to be more toxic than zinc then it is clear that in many places in the orefield lead must be acting as a more or less equal partner with zinc in controlling the nature of the metalliferous vegetation, the Ca/HM ratio in combining the effects of the two metals recognises this fact. To suggest that the metalliferous flora is a zinc flora is something of a misnomer. Brooks (1972) wrote "The true zinc florae are found in Western Germany and Belgium where the soils are rich in zinc and do not contain inordinate amounts of copper and lead". This statement is true as far as copper is concerned but inaccurate in respect of lead. The heavy metal vegetation of the Aachen-Liege orefield may probably be more accurately referred to as a zinc and lead flora.

It does not appear to be the case that any one of the indicator species in the orefield is tolerant of just one heavy metal alone. *Minuartia verna* and *Viola calaminaria* occur at Theux where lead is the predominant heavy metal and at La Calamine where zinc is very important. *Armeria maritima* and *Thlaspi alpestre* were seen at Plombieres associated with high lead levels and on the zinc rich heaps at La Calamine.

*Armeria maritima*, *Minuartia verna*, *Thlaspi alpestre* and *Viola calaminaria*, together with species such as *Silene cucubalus* and *Campanula rotundifolia* are the species of the "zinc flora" of the continental writers. It is easy to form an impression from the literature that this flora is generally present in association on the spoil heaps of the Aachen-Liege orefield. Fig. 4.1 which maps the distribution of the indicator species in the region, as far as it can be ascertained from the literature and the fieldwork done here, suggests that it is normal for one or more of the indicator species to be absent at any metalliferous site. It appears that only at La Calamine are all the indicator species present together. *Viola calaminaria* is found at the most sites (8) in the orefield followed by *Armeria maritima* (7), *Thlaspi alpestre* (6) and *Minuartia verna* (3).
Some conclusions about the distributions in the orefield of certain of the indicators species appear possible. The distribution of *M. verna*, it is suggested, is controlled, in different places, by insufficient or excessive toxicity. At La Calamine *M. verna* was only present at two sites where the pH was below 7. One was at the site of Sample 2 where the pH was 6.7 but the organic carbon level was 14.2% and it is suggested that the low pH here is a secondary condition associated with the accumulation of organic matter, as was explained for Plombieres Tr. 3, and does not reflect potential toxicity. The other was the site of Sample 1 where the pH was 6.9, only just below 7.

At Breinigeberg and Theux *M. verna* occurred associated with substrates with a pH above 7. At Prayon, Stolberg and Plombieres on the other hand where the species was not present all pH values were below 6.7 and some were below 6.

It has been suggested previously in the discussion of the distribution of *Armeria maritima* at La Calamine that the spoil at Plombieres is more toxic, due to greater mobility of the heavy metals at the lower pH prevailing there, than that at La Calamine. It is believed that this also applies to the substrates at Stolberg and Prayon. It is suggested therefore that *M. verna* may well be absent from these three places due to the excessive toxicity of the substrates.

There are, however, a number of sites where *M. verna* is absent and the pH in at least one sample is around 7, Angleur, Lontzen and the alluvium of the River Gheul. It was suggested that at La Calamine *M. verna* was absent from Tr. 4 due to greater competition than on Tr. 1 where the species occurred. This increased competition was due to the relatively lower toxicity and inferred relatively better soil moisture status on Tr. 4. *M. verna* was not found at La Calamine associated with spoil with a Ca/HM ratio greater than 0.67 and the majority of sites at which the species occurred showed Ca/HM ratios less than 0.25. At Theux the site on which the species occurred had a Ca/HM ratio of 0.23.
Table 4.15 The Ca/HM ratios and pH values of the substrates at Lontzen and the River Gheul.

<table>
<thead>
<tr>
<th></th>
<th>Ca/HM</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lontzen SI</td>
<td>5.14</td>
<td>7.0</td>
</tr>
<tr>
<td>River Gheul SI</td>
<td>1.39</td>
<td>7.2</td>
</tr>
</tbody>
</table>

As Table 4.15 shows although the pH at Lontzen in and the alluvium of the River Gheul is 7.0 or above the Ca/HM ratios at these sites are higher than the highest ratio at which *M. verna* occurred at La Calamine.

It is believed that *M. verna* is absent from these two sites due to their relatively low toxicity and the consequent severity of competition. Indeed at Lontzen, as mentioned previously, *V. calaminaria, A. maritima* and *T. alpestre* were absent and this was also the case at the River Gheul site. Although the alluvium from the River Gheul locality has a Ca/HM ratio which falls within the range of those of some of the spoils occupied by *Armeria maritima* at La Calamine the two sites are not comparable, it may be supposed that the physical conditions of the soil environment on the floodplain of the River Gheul are far less severe than on the spoil heaps at La Calamine and thus the absence of indicator species at this particular site is not surprising.

Angleur presents more difficulty, the Sample Tr. 1/2m showed a Ca/HM ratio of 0.27 and a pH of 7.0 and the reason for the absence of *M. verna* from this locality is not apparent.

The final anomaly in the distribution of *M. verna* in the orefield is presented by the site at Breinigeberg. Here *M. verna* occurred in the vicinity of Tr. 1/2m in soil with a calcium concentration of 295,000 ppm and a Ca/HM ratio of 15.95. This site was on the arid, steeply sloping side of an excavated vein and is believed not to
be comparable with spoil heaps elsewhere in the orefield. Indeed it is possible that in soil with such a high calcium concentration calcium toxicity replaces heavy metal toxicity as a controlling factor on the vegetation.

In contrast to *Minuartia verna*, *Viola calaminaria*, *Thlaspi alpestre* and *Armeria maritima* do not appear to be affected, in terms of their gross distribution in the orefield, by excessive toxicity. They all occur on sites which it has been suggested are too toxic for *M. verna* and correspondingly have a wider distribution in the Aachen-Liege region. *A. maritima* appears from the information available from La Calamine to be more competitive than *M. verna* and this will be a factor leading to a more widespread distribution. Insufficient information is available from the orefield about *V. calaminaria* and *T. alpestre* to elaborate further on their distribution.
CHAPTER 5

THE MENDIPS

5.1 Introduction

Lying about 20km to the south west of Bristol the Mendips stretch from just south of Weston-super-Mare in the west to Frome in the east. The geological structure of the area consists of four en echelon periclines, offset southwards from west to east. These folds dip more steeply to the north than to the south and in structure become more complicated eastwards. The folds are of Armorican age and characteristically show a core of Old Red Sandstone flanked by massive limestones of the Lower Carboniferous.

Subsequent to the Armorican folding erosion occurred in the Triassic period and at this stage the Triassic Dolomitic Conglomerate was deposited. The Dolomitic Conglomerate is a rather variable deposit consisting most often of angular Carboniferous Limestone fragments, sometimes quite large, embedded in a cement of carbonates, frequently of dolomitic type. The Dolomitic Conglomerate is variable also in thickness, it appears to have been laid down under arid conditions as a scree or alluvial fan deposit associated with the steep slopes and valleys of the Armorican massif.

Following the deposition of the Dolomitic Conglomerate rocks of Rhaetic and Jurassic age were deposited in the Mendip area but appear to have been removed by later erosion from the western part under consideration here. The Mendips were finally affected to a small degree by folding associated with the Alpine orogeny.

The dominant geomorphological feature of the Mendips is the Mendip plateau, a relatively flat erosion surface at 230 - 260m above which the rounded Old Red Sandstone hills such as Black Down rise to heights just in excess of 300m. Basically there are
two schools of thought about the origin of this erosion surface. Workers such as Donovan (1969) and Kendall (1955) have suggested different pre-Miocene ages while Trueman (1939) and Wooldridge (1961) have suggested that the surface has its origin in a subaerial peneplain of Miocene-Pliocene age. Ford and Stanton (1968) considered the matter in some detail and, taking into account the folding of the Mid-Tertiary which the surface is cut across in places, suggest a Miocene-Pliocene age but do not discount the possibility of the incorporation into the feature of exhumed earlier surfaces.

Into the flanks of this erosion surface, probably in periglacial conditions in Pleistocene times, the large limestone gorges of the area such as Burrington Combe and Cheddar Gorge have been cut. Additionally under periglacial conditions considerable mass movement of material occurred and areas of the limestone adjoining the Old Red Sandstone hills are mantled by Old Red Sandstone head. Some deposition of aeolian loess-like material appears to have occurred during the Pleistocene and in consequence many of the soils of the Mendips are somewhat heterogenous in origin (Findlay, 1965).

The Mendips rise to a general height of around 250m and the climate is therefore upland in nature. Low cloud on the high ground is not unusual and the Mendips probably receive appreciably less sunshine than surrounding areas. The January mean temperature at Weston-super-Mare is 5.2°C and the July mean is 17°C and it appears probable that mean temperatures at 250m on the Mendips are about 1.5°C lower than these. Findlay (1965) suggests that the growing season on the Mendips extends from mid March to the end of the first week in November. Precipitation in the area steadily increases with altitude and it is suggested by Findlay (1965) that the highest parts receive in excess of 1300mm each year.
The soils of the Mendip area, even those developed over Carboniferous Limestone, are often quite leached. This is due to the admixture of foreign material which many of them contain and also the relatively heavy rainfall of the region. The pH of the surface horizons of the Nordrach series, the most abundant soil series on Mendip, is generally between 5.6 and 6.5 (Findlay, 1965). Because surface horizons are somewhat leached, only where soils are very shallow is a well developed association of calcicole plants present and on the soils of most of the limestone plateau more or less calcifuge species such as Agrostis tenuis are present in the grassland associations. Only on the tops of the sandstone hills, however, is heather moorland developed.

Apart from the recently planted Forestry Commission woodlands, mainly of coniferous species, there is relatively little woodland present on the Mendip plateau today and this seems also to have been the case in Medieval times (Findlay, 1965). The abundance of prehistoric earthworks in the area suggests a high density of occupation in Neolithic and Bronze age times and it seems probable that much deforestation occurred in these periods. It is likely that any remaining woodlands were cleared in Roman times and in the Middle Ages to provide wood for the smelting of lead.

Mineralisation in the Mendips appears to be, as in other areas, the result of segregation from ascending hydrothermal solutions. There is some uncertainty about the age of the mineralisations. The youngest rocks affected by large scale mineralisation are those of the Dolomitic Conglomerate and the consensus of opinion is that mineralisation more or less immediately postdates the deposition of this rock. Green (1938) however points out that there is some evidence which might support the suggestion of a later date for the mineralisation.
Figure 5.1
Based on Geological Survey map 1:63,360 "The Bristol District" (parts of Sheets 250, 251, 264, 265, 280, 281).
As mentioned in Chapter 2 lead artefacts unearthed at Glastonbury Lake Village suggest that the mines of Mendip may have been worked prior to the period of Roman occupation; what is certain is that the Romans worked and smelted lead on a large scale in the area and were established and producing by A.D. 49 (Gough, 1930). Working continued through the Middle Ages but the available evidence suggests that mining was on a relatively small scale before the latter part of the Sixteenth Century (Green, 1958). By the middle of the Nineteenth Century the extractive phase of mining was over in the Mendips but the industry supported itself by the reworking of waste materials until 1908 when the low price of lead brought activity in the orefield to a close. Zinc mining in the Shipham area was always on a fairly small scale and was important around the beginning of the Nineteenth Century. Much of the ore was transported to Bristol for use in the manufacture of brass.

5.2 The distribution of the indicator species in the Mendips

Fig. 5.1 outlines the areas of mineralisation within the Mendips and the distribution of the indicator species. Three indicator species occur in the Mendips, Minuartia verna, Thlaspi alpestre and Silene maritima. Records of distribution derived from Kew Herbarium and the B.S.B.I. survey indicate long standing presence at Shipham, Stock Hill and Charterhouse. There are no records, new or old, of any of the species occurring on the mineralised areas to the east of Nordrach or to the north of Priddy. The mining area at Fernhill Farm to the east of Nordrach was visited in May 1972; the areas of disturbed ground were very overgrown and parts of them were being reclaimed. The workings to the southeast of Nordrach shown on Fig. 5.1 were similarly covered by a closed vegetation community and no further attention was given to these areas.
At Stock Hill, east of Priddy, the area of outcropping veins is within a coniferous plantation and workings are visible amidst the trees. Only in the small area to the south of the small lake are M. verna and S. maritima present. At Charterhouse a large area to the west of Ubley Warren Farm has been disturbed by mining operations but is generally covered by a closed herbaceous community and the indicator species occur only locally. To the north of Shipham the veins intersect the unclassified road near the cemetery and here again S. maritima and T. alpestre are very localized within the disturbed area. The general situation in the Mendips appears to be one of almost completely colonized spoil areas with the indicator species surviving in small and isolated localities.

5.3 Investigations in the indicator plant localities

Shipham

The veins at Shipham contained zinc carbonate, were very thin and were worked by rather primitive means. Thlaspi alpestre and Silene maritima grow in the area on heaps of reddish coloured Dolomite Conglomerate spoil.

A short transect on a spoil heap slope of 22°, rendered unstable by the trampling of cattle, showed lead concentrations varying from 2,400 to 8,500 ppm. and zinc levels from 10,000 to 38,000 ppm. Very little bare spoil was exposed on the transect line and T. alpestre grew in a disturbed humus rich layer overlying spoil. The organic carbon content of the surface soil varied from 12-29%. Calcium concentrations in the surface soil on the transect lines were between 7,560 and 28,800 ppm and the pH of the spoil was from 6.6 to 7.0.

In a few places elsewhere small areas of relatively bare spoil possibly excavated by rabbits, supported individuals of T. alpestre and S. maritima. Zinc in such sites varied between 20,000 and 41,000 ppm, one sample showed calcium at 32,000 ppm, a pH of
116

7.1 and an organic carbon content of 2.3%. It is evident that this spoil with a low organic carbon content shows a pH above 7 while the spoil of the transect line with higher organic carbon levels shows pH values generally below 7. This again is the phenomenon of the secondary development of a lower pH related to organic matter accumulation as discussed for the Aachen-Liege orefield.

The Ca/HM ratio of the samples from Shipham ranged between 0.4 and 2.49 and 8 out of the 12 fell within the range 0.5 to 1.10. The maximum Ca/HM ratio at which Thlaspi alpestre was found was 1.01 and this was in spoil disturbed by rabbits.

Table 5.1 shows the result of a particle size analysis of the spoil from the transect at Shipham and demonstrates that although it does not show a high clay content it is not particularly coarse by spoil heap standards.

<table>
<thead>
<tr>
<th>Table 5.1</th>
<th>Particle size analysis of spoil from 4m on Shipham Tr.1.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sand</td>
<td>Medium sand</td>
</tr>
<tr>
<td>19.3%</td>
<td>12.6%</td>
</tr>
</tbody>
</table>

It was clear that at Shipham colonization of the spoil heaps was well developed. Thlaspi alpestre and Silene maritima were only found where the ground was disturbed by either rabbits or cattle and the spoil heaps were for the most part covered by a closed vegetation community involving species such as Festuca ovina, Holcus lanatus L., Plantago lanceolata L., Hieracium pilosella and Thymus drucei Ronn.

**Charterhouse**

Minuartia verna, Thlaspi alpestre and Silene maritima are present at Charterhouse although not in association. T. alpestre and S. maritima grow on the slag materials produced by Nineteenth Century spoil smelting operations while a limestone outcrop supports small populations of M. verna and S. maritima.
The slags still contain lead and zinc in appreciable quantities. A sample showed lead at 45,200 ppm and zinc at 15,900 ppm. The pH was 5.2, the organic carbon content 7%, and the calcium concentration 16,250 ppm. It is the case in certain spoil materials, as it is in this slag from Charterhouse, that pH may be quite low when calcium concentrations are by no means negligible. Acidity in such situations probably reflects the presence of sulphur in the material in a state which can be oxidised or hydrolysed to form sulphuric acid. The sulphur is derived from the sulphide ores such as galena and zinc blende.

Slag, even when derived from the smelting of calcareous materials, seems to be somewhat more acidic than ordinary metalliferous spoil. This was also the case at Plombières and at Stolberg in the Aachen-Liege area. The low pH and high heavy metal concentrations of the slag at Charterhouse imply that it will have a high toxicity.

Although not found on the slag dumps _M._ _verna_ occurred at Charterhouse on an area of outcropping limestone. It is difficult to assess the extent to which this outcrop may have been affected by mining activity. There is some evidence in places of small scale workings and the whole area may have been disturbed, even if only indirectly, in the course of mineral exploitation in the past. The general angle of slope of the limestone outcrop was of the order of 10° although certain parts were steeper.

Lead concentrations on a transect line on the outcrop varied from 53,000 ppm to the very high level of 162,000 ppm. Zinc was low at around 2,000 ppm and calcium ranged from 8,500 to 79,500 ppm. The Ca/HM ratios for all samples were below 0.39 and the pH varied between 7.0 and 7.4. _M._ _verna_ occurred at cover values of 2% in the first two metre square quadrats of the transect line and was not present anywhere else on the transect. Lead concentrations in the area occupied by _M._ _verna_ were between 50,000 and 80,000 ppm. Table 5.2 shows the results of analyses for sodium, potassium, magnesium and phosphorous at 1m, within the _M._ _verna_ area. The bases and phosphorous show concentrations similar to those of calcareous spoil heaps.
Table 5.2: Sodium, potassium, magnesium and phosphorous determinations from 1m on Charterhouse Tr. 1.

<table>
<thead>
<tr>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>195</td>
<td>1,540</td>
<td>1,120</td>
<td>1,260</td>
</tr>
</tbody>
</table>

Table 5.3 demonstrates that the soil in the area occupied by *M. verna* on the limestone outcrop is relatively fine in texture and it seems probable that a soil of this texture, even on one of outcropping limestone, presents less difficulty for colonizing species than the coarse textured substrates of spoil heaps.

Table 5.3: Particle size analysis of soil from 2m on Charterhouse Tr. 1.

<table>
<thead>
<tr>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1%</td>
<td>2.3%</td>
<td>6%</td>
<td>46.3%</td>
<td>22.6%</td>
<td>15%</td>
</tr>
</tbody>
</table>

It is clear from the analyses that *M. verna* did not occur on the Charterhouse transect in the region of the maximum lead concentrations. The Ca/HM ratios in the *M. verna* area were between 0.2 and 0.39 while the remainder of the ratios on the transect were below 0.2 and it is apparent that *M. verna* did not occupy the area of maximum toxicity. It is unlikely that *M. verna* is excluded from the areas of maximum toxicity by excessive toxicity, the pH of these areas was above 7 and the species has been shown to grow in the Aachen-Liege orefield on substrates of similar pH but with Ca/HM ratios less than 0.2. The one distinguishing feature of the part of the transect line occupied by *M. verna* was that it was also the area of a footpath and was therefore disturbed. It appears that on this transect even though high heavy metal concentrations are present *M. verna* is only able to compete successfully in a place where competition from other species is reduced due to disturbance by trampling. It was observed that in the only other place where *M. verna* occurred in any relative abundance on the limestone scarp there was also a footpath.
The apparent success of the competitors of *M. verna*, *Festuca ovina*, *Plantago lanceolata*, *Thymus drucei* and *Campanula rotundifolia* amongst others, on the toxic soils of the limestone scarp does not seem to be related to the soil having a better nutrient status than spoil heaps, phosphorous and potassium are present in the soil in amounts similar to those of calcareous spoil. The major difference between the spoil of spoil heaps and the soil of this scarp is one of texture, the scarp soil contains much silt and clay, and it may be that edaphic conditions are not as severe as on spoil heaps with corresponding benefit to the competitors of *M. verna*.

**Stock Hill**

As at Shipham the spoil here is derived from the Dolomitic Conglomerate. To the south of the small lake at Stock Hill *Minuartia verna* and *Silene maritima* occur in a few places in the disturbed area. In this region there appears to have been considerable disturbance in the course of mining but the spoil heaps are for the most part completely vegetated by a community involving *Molinia caerulea*, *Calluna vulgaris* (L.) Hull, *Festuca ovina*, *Holcus lanatus* and other species.

One isolated site was found where *M. verna* occurred with *S. maritima* on unstable spoil sloping at 29°. The lead level in this material was 68,500 ppm. The major occurrence, however, was on a spoil heap about 23m in diameter, asymmetrical in cross section, with a slope up from the south of 4.5° and a slope down to the north of 11°.

*M. verna* was restricted to a small area between 18m and 22m on the more steeply sloping north side while *S. maritima* was generally present. As Table 5.4 shows lead concentrations were high across most of the spoil heap while zinc levels are low. The calcium concentration at 1m is anomalous, a level of around 35,000 ppm is normal.
Table 5.4  Heavy metal and calcium concentrations, Ca/HM ratios, organic carbon contents and pH values at intervals along Stock Hill Tr. 1.

<table>
<thead>
<tr>
<th>Sample distance</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>Ca/HM</th>
<th>Organic carbon</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1m</td>
<td>80,800</td>
<td>8,800</td>
<td>65,370</td>
<td>0.76</td>
<td>10.3%</td>
<td>7.1</td>
</tr>
<tr>
<td>7m</td>
<td>62,900</td>
<td>8,000</td>
<td>35,000</td>
<td>0.52</td>
<td>7.0%</td>
<td>7.2</td>
</tr>
<tr>
<td>13m</td>
<td>58,500</td>
<td>7,700</td>
<td>37,400</td>
<td>0.56</td>
<td>4.1%</td>
<td>6.9</td>
</tr>
<tr>
<td>19m</td>
<td>95,000</td>
<td>10,300</td>
<td>35,000</td>
<td>0.35</td>
<td>3.3%</td>
<td>7.3</td>
</tr>
<tr>
<td>23m</td>
<td>85,200</td>
<td>9,400</td>
<td>36,850</td>
<td>0.41</td>
<td>4.5%</td>
<td>7.3</td>
</tr>
</tbody>
</table>

The sample from 19m (Table 5.4) is within the M. verna area and appears from the Ca/HM ratio to be the most toxic. Lead, zinc and calcium determinations were made at 2m intervals along the transect line and therefore 12 Ca/HM values are available for the transect line. Of these 10 were within the range 0.4 to 0.8 and were from spoil outside the area occupied by M. verna. The other two Ca/HM values from within the M. verna area both showed a ratio of 0.38. It is clear that the distribution of M. verna on this transect line corresponds to the areas of highest toxicity as determined by the Ca/HM ratio.

Table 5.5  Sodium, potassium, magnesium and phosphorous determinations from Stock Hill Tr. 1.

<table>
<thead>
<tr>
<th>Sample distance</th>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7m</td>
<td>480</td>
<td>1,705</td>
<td>1,190</td>
<td>920</td>
</tr>
<tr>
<td>19m</td>
<td>325</td>
<td>1,400</td>
<td>1,800</td>
<td>900</td>
</tr>
</tbody>
</table>

The further analyses for the transect line shown on Table 5.5, suggest that there are no major differences in the important nutrients potassium and phosphorous between the 19m area where M. verna occurs and the 7m region where it does not and it seems to be the case on the basis of the analysis available that M. verna occurs in the area between 18m and 22m due to the high toxicity of the spoil and the consequent suppression of competition from other species.
The only parameter analysed for which appears to vary considerably along the transect line is organic carbon. As Table 5.4 shows organic carbon, with the exception of the sample from 13m, increases with an increase in the Ca/HM ratio, that is it increases with decreasing toxicity. Organic carbon and the Ca/HM ratio show a correlation in these five samples of 0.89, significant at the 5% level. This correlation suggests that with decreasing toxicity there is an increase in the rate of accumulation of organic matter in the spoil, assuming, and it seems reasonable to do so, that all the spoil on the heap is of approximately the same age. Odum (1975) has indicated that in the process of succession the amount of nonliving organic matter in an ecosystem increases and it would seem to follow from this, assuming that the spoil of this heap is of uniform age, that the lower the toxicity the greater the rate of succession.

Table 5.5 shows that the spoil at Stock Hill is very coarse in texture. Of all the spoil heap samples analysed for particle size in the course of this study this particular one has the coarsest texture.

Table 5.5  Particle size analysis of spoil from 20m on Stock Hill Tr. 1.

<table>
<thead>
<tr>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>sand</td>
<td>sand</td>
<td>sand</td>
<td>sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>42.1%</td>
<td>14.9%</td>
<td>8.1%</td>
<td>18.7%</td>
<td>7.6%</td>
<td>2.9%</td>
</tr>
</tbody>
</table>

5.4 The metalliferous areas and the indicator species in the Mendips

The areas occupied by the indicator species in the Mendips are very restricted in extent. The spoil heaps at Shipham are almost completely vegetated and the indicators only survive in disturbed habitats. Disturbance also appeared to be important in relation to the occurrence of M. verna on Charterhouse Tr. 1. At both Charterhouse and Stock Hill lead concentrations were generally very high and Ca/HM ratios were low. Although Ca/HM ratios were higher in the spoil on which the indicator plants grew at Shipham they were not much higher.
a national basis lead concentrations in the substrates at Charterhouse and Stock Hill are high and Ca/HM ratios are low and it seems probable that much of the spoil in the orefield cannot have been so toxic. A few samples from Shipham from parts of the transect where the indicator species did not occur provide evidence of the existence of spoil of lower toxicity.

It appears from the correlation between the organic carbon content and the Ca/HM ratio of the spoil at Stock Hill that the rate of succession is related to the toxicity of the spoil and although the hypothesis has not been tested it seems probable that heavy metal concentrations and toxicity are lower in the spoil beneath the widespread areas of completely vegetated waste heaps in the Mendips. Thus it seems likely that in the period of at least 150 years since the end of mining in the area heavy metal toxicity has failed to prevent extensive succession on most of the spoil heaps in the Mendips.

In the Mendip orefield Minuartia verna is absent from Shipham and from the areas of Nineteenth Century slag at Charterhouse. This slag has a low pH and it appears probable that, as in the Aachen-Liege orefield, M. verna is absent from it due to excessive toxicity. The absence of M. verna from Shipham, however, is the major anomaly of the distribution of the species in the Mendips. The calcium levels and pH of the sample of unvegetated spoil from Shipham are about the same as those in spoil on which the species occurs at Stock Hill and although the Shipham spoil is of finer texture than that at Stock Hill, this, in itself, is unlikely to be a factor preventing the growth of M. verna there. The major differences between the two localities are of heavy metal concentration and type, the predominant heavy metal at Shipham is zinc, less toxic and present in lower concentrations than the lead at Stock Hill. The Ca/HM ratios at Shipham were all above 0.4 and most were above 0.5 while at Stock Hill and Charterhouse M. verna was only found associated with substrates
with Ca/HM ratios below 0.4. The evidence suggests that _M. verna_ is absent from Shipham due to excessive competition from other species related to insufficient toxicity in the spoil. The relatively finer texture of the spoil at Shipham will probably be a further factor operating in favour of the competitors of _M. verna._

_Silene maritima_ and _Thlaspi alpestre_ were both present on the slag at Charterhouse and seem to be tolerant of the high toxicity associated with the low pH of this material. _S. maritima_ is present at all sites in the Mendips and is normally the most abundant indicator plant in the metalliferous localities. This species in the Mendips appears to possess a broad ecological tolerance and an ability to be more competitive at lower toxicities than _M. verna_. _T. alpestre_ was absent from the limestone outcrop at Charterhouse and from the spoil at Stock Hill. On the basis of the analysis available here the reasons for this are not apparent.
CHAPTER 6

THE SOUTHERN PENNINES

6.1 Introduction

The mineralisations of the Southern Pennines are confined to the region of the Carboniferous Limestone outcrop. The Carboniferous Limestone in the area is composed of crinoidal and shelly limestone with occasional reefs. Igneous rocks occur locally and are believed to be the result of volcanic activity on the floor of the Carboniferous sea. The igneous rocks are mainly vesicular lavas and are known locally as toadstones.

The Carboniferous Limestone in the Southern Pennines was folded, along with overlying Carboniferous rocks, during the period of the Armorican orogeny. The Derbyshire area was to the north of the Armorican foreland, roughly the region of the Mendips, and the folding was in consequence not particularly intense. The general structure of the Armorican folding in the southern Pennines takes the form of a broad, asymmetrical fold known as the Derbyshire Dome which is elongated from north to south. The eastern limb of the fold dips more gently than that in the west, the latter dips steeply below the rocks of the Millstone Grit and Coal Measures. Numerous small folds, generally aligned from east to west are superimposed upon this major north to south trending structure (Wray et al, 1954).

The Derbyshire Dome was subsequently covered by sediments of Jurassic and Cretaceous age and it appears probable that the drainage system of the area has been superimposed from a Cretaceous surface.

The limestone plateau of Derbyshire and a small area of north eastern Staffordshire varies in altitude between 300m in the south and 360m in the north and is deeply dissected by a number of river
valleys, the dales. It appears probable that the limestone plateau
represents an erosion surface developed in Pliocene times and since
uplifted (Edwards, 1962). The deeply incised river valleys which
traverse the plateau and the heads of which are now often dry probably
developed during the Pleistocene period when subterranean drainage
in the limestone was impossible due to periglacial conditions. The
region, however, never appears to have been glaciated to any
appreciable extent although it is believed that ice from the Irish Sea
pushed through the Dove Holes area to enter the tributary valleys of
the Derwent (Edwards, 1962). Small pockets of till are found in
places on the plateau surface (Clapham, 1969).

The climate of the limestone region is an upland one and relatively
severe. Buxton at an altitude of 307m has a January mean of 2.2°C
and a July mean of 14.2°C. The mean annual precipitation for Buxton
from 1881 to 1915 was 1229 mm and this figure seems to be of
general applicability for much of the limestone plateau. Snow falls
in the area are often quite heavy. Low cloud over the plateau is
frequent and sunshine amounts are generally low, Buxton with an
average of 3.3 hours each day over the year receives only 27% of
the total possible. Hot spells however do occur at times and the
means of the monthly maxima at Buxton exceed 21°C from May to
September (Clapham, 1969).

Brown earth appears to be the most important soil of the plateau and
Bridges (1966) has mapped the Nordrach series in the Wirksworth
area and suggests that it may be more extensive to the north and
west. This soil series is formed in a silty drift of composite
origin. Pigott (1962) has demonstrated that much of the soil material
is not derived from the underlying limestone and an aeolian origin
is suggested. This loessial material has been shown by Pigott (1962)
to be intimately mixed by cryoturbation with solution products of the
limestone. The soils are freely drained and generally acid throughout
the profile and are mainly under permanent or temporary grassland.
In the Wirksworth area, according to Bridges (1966), the Nordrach
series merges into the Lulsgate series, a more calcareous soil, on
steeper slopes.
As pointed out above large areas of the limestone are under some form of grassland. Where soils are thin, calciole species are present but over most areas of the limestone where the soils are somewhat deeper and more leached an association of calciole and calcifuge species is more normal. In places the soils over the limestone are sufficiently leached to support a limestone heath community involving most definitely calcifuge species such as *Calluna vulgaris* (Edwards, 1962).

Forest in the area is mainly confined to the dales where ash, *Fraxinus excelsior* L., is the important tree. The woodlands of the dales appear to be the remnants of a once more widespread forest which covered much of the limestone plateau. The clearance of this forest began in Neolithic times and was at its most rapid in the Saxon period (Edwards, 1962).

The most important mineral in the Derbyshire orefield was lead ore in the form of galena. In the south west however copper was worked in large quantity at the mine at Ecton Hill and for a period this mine was the largest producer of copper in the country. The lead occurred in vertical fissures in the limestone, known locally as rakes, and these normally have a more or less east west trend. In places lead was also found deposited in pipes or flats, the latter being essentially a lateral extension of a vein along a bedding plane in the limestone. Zinc blende accompanied the galena in varying proportions and fluorspar, calcite and barytes were important gangue minerals. Lead was worked in the Derbyshire area from Roman times and production reached its peak between 1750 and 1800, declining steadily thereafter. A few mines worked on into this century.

In contrast to the mineral fields of the Northern Pennines the Derbyshire mines were never worked by large mining companies (Raistrick and Jennings, 1965). The normal mode of operation was mining by individuals or small groups. The only matter of large scale co-operation appears to have been in the digging of soughs, long underground drainage channels to a convenient dale, which were needed to drain the workings.
A feature of the orefield at the present day is the extensive working of the waste materials left by the old miners. Fluorspar and barites are in demand industrially and it appears to be commercially viable to transport away spoil and to excavate the worked out rakes. This is occurring at Magpie Mine, at Long Rake and in the Castleton area and while land is being reclaimed by such means the removal of the metalliferous spoil necessarily involves a loss of habitat for the indicator species.

6.2 Investigations at indicator plant localities in the Southern Pennines

The mineralised areas in Derbyshire and Staffordshire have been explored thoroughly by generations of miners and no undisturbed mineralisations with indicator plants were located in the course of the study. Three areas were investigated by transect lines and spot samples were taken of spoil material from heaps elsewhere. The transects will be described first. Fig. 6.1 shows the location of the various sites mentioned in the text.

The River Bradford

The transect here (Tr. 1) was situated in the valley of the River Bradford just to the east of Alport. The valley here is quite deep, has a flat floor and steep sides and is relatively sheltered, the climatic conditions are not as severe as on the more exposed plateau surface. The area covered by spoil was close to the river and may be susceptible to flooding at times of very high water level. The spoil surface was generally flat and the spoil was spread over a wide area of the valley floor rather than being piled up in heaps and was of a rather more reddish colour than many spoils in the Derbyshire orefield. The vegetation on the spoil was grazed by cattle and in places the spoil had been excavated by rabbits and therefore, although the site was generally stable, there were areas of local disturbance.
Transects, sample sites and locations in the Southern Pennine orefield

- Transects
- Sample sites
- Boundary of Carboniferous Limestone

Figure 6.1
The mining waste here is probably derived from the working of veins in the Alport mining field, excavations were visible amidst the trees on the hillside to the south of the river. Carruthers and Strahan (1923) state that the last of the workings in the Alport area became idle about 1890 so it may be that the spoil here is not as old as that of the Mendips.

Minuartia verna was the only indicator species present at the site, Thlaspi alpestre, although occurring two kilometres away at Youlgreave, was not seen at this locality. Festuca rubra L. and Holcus lanatus were the most abundant species accompanying M. verna together with an assemblage of forbs such as Rumex acetosa, Plantago lanceolata and Cerastium vulgatum L. Verbascum nigrum L. was an unusual species present in places.

Lead concentrations on the transect line varied from 1,970 to 53,000 ppm with a general level of 20,000 to 40,000 ppm. Zinc concentrations were mostly within the range 10,000 to 15,000 ppm and copper was present in insignificant amounts. Calcium was generally around 100,000 ppm and the pH ranged from 7.0 to 7.4. Organic carbon levels in the spoil were between 6% and 13.5%.

<table>
<thead>
<tr>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,560</td>
<td>4,700</td>
<td>1,920</td>
<td>1,100</td>
</tr>
</tbody>
</table>

As Table 6.1 shows phosphorous in the spoil from this transect is at a similar concentration to that found in spoil in the Mendips and at La Calamine in the Aachen-Liege area. Potassium, however, occurs at a higher concentration than is normal for spoil materials. It is evident from Table 6.2 that in its textural characteristics the spoil from this site is similar to others elsewhere.
Table 6.2  Particle size analysis of a sample from 22m on the River Bradford Tr. 1.

<table>
<thead>
<tr>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Site</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.5%</td>
<td>15.1%</td>
<td>13.2%</td>
<td>37.9%</td>
<td>7.6%</td>
<td>6.3%</td>
</tr>
</tbody>
</table>

The Ca/HM ratios of samples from the River Bradford Tr. 1 fell within the range Ca/HM 1.0 to Ca/HM 9.58. Table 6.3 demonstrates that M. verna was present in all quadrats on the River Bradford Tr. 1 with Ca/HM ratios less than 1.99. On Stock Hill Tr. 1 in the Mendips M. verna showed a clear cut association with the quadrats of highest toxicity, this is not the case on the River Bradford Tr. 1 but it is clear that as the Ca/HM ratio of the spoil rises above 2.0 M. verna shows an increasing tendency to be absent. It is suggested that this is due to increasingly effective competition from other species as the toxicity decreases.

That the relationship between M. verna and toxicity is not as clear cut on this transect line as on Stock Hill Tr. 1 in the Mendips is probably explicable in terms of the pronounced stability of the Stock Hill spoil heap. Much more normal on spoil heaps is a situation of marked instability. This may be due to the way in which the material was dumped originally, the normal spoil heap is most definitely a heap, rather than a low mound or spread of material, or the spoil may be unstable due to disturbance by animals as is the case on the River Bradford Tr. 1. It was shown that at Shipham in the Mendips Thlaspi alpestre and Silene maritima were found in places disturbed by cattle or rabbits and it is probable that on the River Bradford Tr. 1 these agencies also have an effect. Due to disturbance by biotic agencies succession will be put back, competitors will be suppressed and plants such as M. verna may reoccupy or continue to occupy areas from which they might otherwise have disappeared. Such biotic effects may be difficult to identify. The scrapings of rabbits or the hoofmarks of cattle are reasonably obvious as to
### Table 6.3: The Incidence of Minuartia verana on the River Brathay FR. in Relation to the Ca/HM Ratio

<table>
<thead>
<tr>
<th>Ca/HM Category</th>
<th>1.0-1.49</th>
<th>1.5-1.99</th>
<th>2.0-2.49</th>
<th>2.5-2.99</th>
<th>3.0-3.49</th>
<th>3.5-3.99</th>
<th>4.0-4.49</th>
</tr>
</thead>
<tbody>
<tr>
<td>In the category with</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>In the category without</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>The number of quadrats</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**M. Verana**
their cause at and shortly after the moment of their creation but with time a patch of bare spoil produced by such means will come to look no different from any other bare area. Thus it will occur that species such as *M. verna* will be recorded from areas on spoil heaps which, in terms of their successional history, are not comparable with other areas of spoil on the same heap. Difficulties of this sort are believed to be implicated in the occurrence of a diffuse toxicity threshold for *M. verna* on the River Bradford Tr. 1. As description of the sites studied in Derbyshire proceeds the effect of various types of disturbance on the occurrence of *M. verna* in relation to toxicity will become clear.

**Youlgreave**

Youlgreave Tr. 1 crossed the face of a small spoil heap which abutted against the steep valley side of the River Bradford to the south of Youlgreave. The site is at an altitude of about 150m and will therefore be somewhat warmer than many places on the Derbyshire plateau.

The spoil heap was rather more vegetated than many but in the bare areas *M. verna* occurred together with *Thlaspi alpestre*. On the transect generally *Festuca rubra* and *Holcus lanatus* were the important grasses together with species such as *Anthoxanthum odoratum* L., *Plantago lanceolata*, *Ranunculus acris* L., *Campanula rotundifolia*, *Rumex acetosa*, *Cerastium vulgatum* and *Lotus corniculatus* L. *Dianthus deltoides* L. was an unusual component of the flora. The slope of the spoil on which this community grew was between 28° and 41° and the transect was at right angles to the maximum slope.

Lead concentrations along the transect line were between 20,000 and 70,000 ppm while zinc was normally present at around 10,000 ppm. The copper level was 200 ppm and calcium varied between 31,500 and 35,000 ppm. Table 6.4 shows that the amount of
phosphorous in the spoil from this site is the same as on the River Bradford Tr. 1 but that magnesium and potassium were present at lower concentrations than in that material. The pH of the spoil was between 7.2 and 7.5.

Table 6.4 Sodium, potassium, magnesium and phosphorous concentrations in spoil from 3m on Youlgreave Tr. 1.

<table>
<thead>
<tr>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>2,575</td>
<td>1,570</td>
<td>1,100</td>
</tr>
</tbody>
</table>

Particle size analysis of the spoil from this transect line (Table 6.5) demonstrates that the spoil is relatively fine in texture and has a higher clay content than is normal for spoil, clay at 19.2% is more than twice that in the sample from the River Bradford Tr. 1 (Table 6.2).

Table 6.5 Particle size analysis of spoil from 5m on Youlgreave Tr. 1

<table>
<thead>
<tr>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.3%</td>
<td>10.8%</td>
<td>17.2%</td>
<td>34.6%</td>
<td>19.2%</td>
<td>4.1%</td>
</tr>
</tbody>
</table>

The Ca/HM ratios for the transect line are shown in Table 6.6. M. verna and T. alpestre only occurred in the area between 2m and 7m and it appears that this is the area with the lowest Ca/HM ratios and consequently the highest toxicities. There is however a difficulty in that the area between 2m and 7m was also that of a rather ill defined footpath which ascended the spoil heap at this point and the associated disturbance will certainly be having some influence on the occurrence of the two indicator species in this area.
Table 6.6 The Ca/HM ratios at 3m intervals along Youlgreave Tr.1

<table>
<thead>
<tr>
<th>Ca/HM</th>
<th>0m</th>
<th>3m</th>
<th>6m</th>
<th>9m</th>
<th>12m</th>
<th>15m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.73</td>
<td>0.48</td>
<td>0.62</td>
<td>1.02</td>
<td>1.10</td>
<td>1.36</td>
</tr>
</tbody>
</table>

It will be noticed that while *M. verna* occurred on the River Bradford Tr. 1 in spoil with Ca/HM ratios above 2 it is not present on this transect associated with spoil with a Ca/HM ratio above 0.7. There seem to be two possible explanations for this and they may be acting in combination. As Table 6.5 shows the material of this spoil heap is of finer texture than that of many spoil heaps and a better moisture regime probably prevails. This will mean that the competitors of *M. verna* will be more successful and a relatively higher toxicity will be necessary to provide a habitat in which *M. verna* may exist. The second possibility is that the spoil heap is older than that of the River Bradford Tr. 1. Assuming that succession is an ongoing process, slower at higher toxicities than lower toxicities, but nonetheless occurring, then an old spoil heap will have a more closed vegetation community than a younger one and *M. verna* will be excluded by competition. The matter of succession on spoil heaps will be returned to subsequently when it will be possible to draw on evidence from a wider range of sites.

**High Rake**

High Rake is a vein running roughly from east to west in the northern part of the Derbyshire orefield. The site is at an altitude of about 300m and climatic conditions will be more severe than those of the transects at Youlgreave and the River Bradford. High Rake was one of the strongest veins in Derbyshire and was discovered some time in the Seventeenth Century. The last record for working on the vein is from 1887 (Carruthers and Straham, 1923) and the site investigated has probably been undisturbed for about 100 years.
The transect line crossed the trench of the excavated vein. The southern side of the vein was very unstable and mantled by spoil and sloped at about 35° while the northern side showed a much more gentle slope of around 15°, the substrate was stable and a more or less closed vegetation community was present. _Minuartia verna_ occurred with _Festuca rubra_ and _F. ovina_ in the unstable area while a community of _F. ovina, F. rubra, Cynosurus cristatus L., Thymus drucei, Hieracium pilosella, Plantago lanceolata, Rumex acetosa, Lotus corniculatus_ and other herbs occupied the stable region.

Lead concentrations along the transect line were between 21,000 and 55,000 ppm while zinc levels were relatively low, never exceeding 6,000 ppm. Copper was below 100 ppm in every sample. The pH was between 6.9 and 7.4 and the organic carbon content between 3.3% and 9.8%. Calcium ranged from 83,200 to 178,000 ppm.

Table 6.7 shows that while potassium was present in an amount similar to that in the spoil from Youlgreave (Table 6.4) phosphorous, at only 300 ppm, was in much lower concentration.

<table>
<thead>
<tr>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1535</td>
<td>2750</td>
<td>980</td>
<td>300</td>
</tr>
</tbody>
</table>

Table 6.8 demonstrates that the spoil from the High Rake transect line is very coarse in texture. In the coarseness of its texture it is second only to the spoil from Stock Hill Tr. 1 in the Mendips.
Table 6.8  Particle size analysis of spoil from 6m on High Rake Tr. 1

<table>
<thead>
<tr>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.0%</td>
<td>27.6%</td>
<td>15.5%</td>
<td>16.1%</td>
<td>8.2%</td>
<td>3.3%</td>
</tr>
</tbody>
</table>

Table 6.9 shows the Ca/HM ratios at 2m intervals along the transect line and it is evident that *M. verna* shows in its occurrence no well defined relationship to toxicity as measured by the Ca/HM ratio. This appears to be due to the instability of the early parts of the transect line. The 10m to 16m area was in the base of the trench of the excavated vein and on the gently sloping north side and in this region under conditions of stability, even though the spoil is very coarse and low in phosphorous, a more or less closed vegetation community of the species previously mentioned has developed to exclude *M. verna*. The only place on this northern side of the vein where *M. verna* occurred was in the last quadrate of the transect line and here, as Table 6.9 shows, the Ca/HM ratio is lower and the toxicity therefore greater. Thus in the relatively stable conditions of this part of the transect line a Ca/HM ratio of around 2.0 seems necessary to prevent *M. verna* being excluded by competition from other species. This is roughly the same ratio as that at which *M. verna* began to be absent from some quadrats on the River Bradford Tr. 1.
In the 0m to 8m part of the transect M. verna is present at Ca/IM ratios in excess of 3.0 and in two samples above 6.0. This was the area of great instability, in places individuals of M. verna and Festuca ovina were being buried by moving spoil, and it appears that under such conditions of instability succession is retarded, competition is less severe and M. verna is able to maintain itself against competitors even at relatively low toxicities.

Other sites occupied by Minuartia verna and Thlaspi alpestre in the Southern Pennines

In addition to the areas investigated by transects a number of spot samples were taken from spoil heaps where M. verna or T. alpestre or both species occurred. Analyses from these sites are shown in Tables 6.10 and 6.11. The tables are arranged in a north to south progression, the Odin Mine near Castleton being the northernmost site.

As Table 6.10 shows calcium levels in the spoil from much of the Southern Pennine orefield are high and there is a tendency for the highest concentrations to occur in the spoils in the norther part of the orefield, Odin Mine to Moss Rake in Table 6.10. High Rake Tr.1 was in this area and showed similar calcium concentrations in many samples. In most samples lead is present in high concentrations, also but these are samples from the areas occupied by the indicator species and thus might be expected to show high levels of heavy metal, there are large areas of spoil covered by more or less closed vegetation communities in Derbyshire and these, presumably, are the spoils with lower heavy metal levels (an alternative explanation might be that they have much higher calcium levels and thus less toxicity but in view of the high calcium levels in many of the samples in Table 6.10 this seems less likely). Zinc in many spoils from the orefield is present in only moderate amounts and copper is insignificant.
Table 6.10 Calcium and heavy metal determinations from sites with one or more indicator species in the Southern Pennine orefield

<table>
<thead>
<tr>
<th></th>
<th>Calcium (ppm)</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Copper (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odin Mine</td>
<td>165,000</td>
<td>36,000</td>
<td>15,000</td>
<td>105</td>
</tr>
<tr>
<td>S. E. Castleton</td>
<td>146,000</td>
<td>54,900</td>
<td>7,400</td>
<td>50</td>
</tr>
<tr>
<td>Dirtlow Rake</td>
<td>250,000</td>
<td>32,500</td>
<td>13,000</td>
<td>62</td>
</tr>
<tr>
<td>Moss Rake</td>
<td>150,000</td>
<td>48,700</td>
<td>22,000</td>
<td>50</td>
</tr>
<tr>
<td>White Rake</td>
<td>65,000</td>
<td>45,500</td>
<td>6,250</td>
<td>75</td>
</tr>
<tr>
<td>High Low</td>
<td>50,000</td>
<td>27,000</td>
<td>14,500</td>
<td>125</td>
</tr>
<tr>
<td>S. E. High Low</td>
<td>132,000</td>
<td>57,000</td>
<td>27,500</td>
<td>50</td>
</tr>
<tr>
<td>Alport Sl</td>
<td>202,000</td>
<td>23,000</td>
<td>7,700</td>
<td>57</td>
</tr>
<tr>
<td>Lomberdale Hall</td>
<td>95,000</td>
<td>30,000</td>
<td>19,000</td>
<td>150</td>
</tr>
<tr>
<td>Youlgreave S8</td>
<td>27,900</td>
<td>16,200</td>
<td>33,000</td>
<td>117</td>
</tr>
<tr>
<td>Youlgreave S9</td>
<td>32,000</td>
<td>9,500</td>
<td>16,000</td>
<td>147</td>
</tr>
<tr>
<td>Youlgreave S11</td>
<td>49,000</td>
<td>2,180</td>
<td>50,000</td>
<td>157</td>
</tr>
<tr>
<td>Upper Town</td>
<td>108,000</td>
<td>74,800</td>
<td>19,250</td>
<td>150</td>
</tr>
<tr>
<td>Bonsall Moor S1</td>
<td>137,000</td>
<td>66,200</td>
<td>16,100</td>
<td>87</td>
</tr>
<tr>
<td>Bonsall Moor S2</td>
<td>119,000</td>
<td>51,800</td>
<td>14,000</td>
<td>87</td>
</tr>
<tr>
<td>Bonsall Moor S3</td>
<td>19,500</td>
<td>16,200</td>
<td>5,000</td>
<td>77</td>
</tr>
<tr>
<td>Brassington S1</td>
<td>70,500</td>
<td>37,300</td>
<td>1,900</td>
<td>87</td>
</tr>
<tr>
<td>Brassington S2</td>
<td>44,300</td>
<td>33,000</td>
<td>3,600</td>
<td>98</td>
</tr>
<tr>
<td>Brassington S3</td>
<td>32,800</td>
<td>17,300</td>
<td>10,900</td>
<td>218</td>
</tr>
<tr>
<td>Site</td>
<td>pH</td>
<td>Organic carbon</td>
<td>Ca/HM</td>
<td>Minuartia verna</td>
</tr>
<tr>
<td>---------------------</td>
<td>----</td>
<td>----------------</td>
<td>------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Odin Mine</td>
<td>7.2</td>
<td>nd</td>
<td>3.8</td>
<td>+</td>
</tr>
<tr>
<td>S. E. Castleton</td>
<td>nd</td>
<td>nd</td>
<td>2.49</td>
<td>+</td>
</tr>
<tr>
<td>Dirtlow Rake</td>
<td>7.6</td>
<td>4.6%</td>
<td>6.4</td>
<td>+</td>
</tr>
<tr>
<td>Moss Rake</td>
<td>nd</td>
<td>nd</td>
<td>2.5</td>
<td>+</td>
</tr>
<tr>
<td>White Rake</td>
<td>nd</td>
<td>nd</td>
<td>1.34</td>
<td>+</td>
</tr>
<tr>
<td>High Low</td>
<td>7.4</td>
<td>nd</td>
<td>1.46</td>
<td>+</td>
</tr>
<tr>
<td>S. E. High Low</td>
<td>nd</td>
<td>nd</td>
<td>1.87</td>
<td>+</td>
</tr>
<tr>
<td>Alport Sl</td>
<td>7.6</td>
<td>nd</td>
<td>7.52</td>
<td>+</td>
</tr>
<tr>
<td>Lomberdale Hall</td>
<td>nd</td>
<td>nd</td>
<td>2.41</td>
<td>+</td>
</tr>
<tr>
<td>Youlgreave S8</td>
<td>7.2</td>
<td>2.2%</td>
<td>0.86</td>
<td>-</td>
</tr>
<tr>
<td>Youlgreave S9</td>
<td>7.4</td>
<td>nd</td>
<td>1.83</td>
<td>+</td>
</tr>
<tr>
<td>Youlgreave S11</td>
<td>7.2</td>
<td>6.3%</td>
<td>1.81</td>
<td>+</td>
</tr>
<tr>
<td>Upper Town</td>
<td>nd</td>
<td>nd</td>
<td>1.28</td>
<td>+</td>
</tr>
<tr>
<td>Bonsall Moor S1</td>
<td>7.2</td>
<td>nd</td>
<td>1.85</td>
<td>+</td>
</tr>
<tr>
<td>Bonsall Moor S2</td>
<td>7.0</td>
<td>3.3%</td>
<td>2.27</td>
<td>+</td>
</tr>
<tr>
<td>Bonsall Moor S3</td>
<td>6.4</td>
<td>26.9%</td>
<td>1.05</td>
<td>-</td>
</tr>
<tr>
<td>Brassington S1</td>
<td>7.4</td>
<td>nd</td>
<td>1.85</td>
<td>+</td>
</tr>
<tr>
<td>Brassington S2</td>
<td>6.9</td>
<td>1.8%</td>
<td>1.28</td>
<td>+</td>
</tr>
<tr>
<td>Brassington S3</td>
<td>6.7</td>
<td>22.9%</td>
<td>1.44</td>
<td>-</td>
</tr>
</tbody>
</table>

+ Named indicator species present
- Named indicator species absent
Inspection of Table 6.11 shows that most samples have a pH above 7.0, this was also the case for the spoils of the transect lines. Where the pH drops markedly below 7.0 as in Bonsall Moor S3 and Brassington S3 organic carbon levels are high implying the secondary development of a lower pH.

Table 6.11 shows that most of the spot samples taken from sites where M. verna occurred showed Ca/HM ratios less than 2.5. There are three exceptions and all appear to be explicable. At Alport S1 M. verna was found in spoil with a Ca/HM ratio of 7.52. The spoil had been excavated from a large rabbit warren in an otherwise completely vegetated spoil heap. The effect of rabbits in setting back the process of succession has been considered in relation to the discussion of the distribution of M. verna on the River Bradford Tr. 1, this appears to be another example. At Dirtlow Rake M. verna was found growing in spoil with a Ca/HM ratio of 6.4 and here habitat conditions were the same as those prevailing in the early quadrats of High Rake Tr. 1, the site was very unstable and much movement of spoil was occurring and such processes have the effect of retarding succession and inhibiting completion to the advantage of M. verna. The Odin Mine where M. verna grew in spoil with a Ca/HM ratio of 3.8 adjoins a layby on the A625, is regularly trampled by tourists, and much of the spoil is relatively bare.

This is not to imply that all the remaining sites where M. verna occurred were entirely stable, some were not but many were. The sites at Lomberdale Hall, High Low, South East High Low and Moss Rake were remote from major roads and human activity, showed no evidence of excavation by rabbits and no clear signs of disturbance by cattle although they were all in areas in which cattle grazing occurs.
The evidence from the spot samples and from the transects suggests that on spoil areas in Derbyshire which are reasonably stable and not greatly affected by various biotic agencies *M. verna* is rarely found at Ca/HM ratios above 3. This figure may be thought of as a toxicity threshold for the species in the Southern Pennines.

6.3 The distribution of the indicator species in the Southern Pennines

The relationship of *M. verna* to spoil toxicity has just been discussed. The overall distribution of the species in the Southern Pennines is also of interest and will be considered shortly. No attempt has been made so far to consider the ecological situation in relation to *Thlaspi alpestre* in the Southern Pennines, this will be dealt with following discussion of the general distribution of *M. verna* in the area. *Cochlearia officinalis* which occurs on a few spoil heaps in Derbyshire will also be considered.

Figs. 6.2, 6.4 and 6.5 show respectively the distribution of *M. verna*, *T. alpestre* and *Cochlearia officinalis* in the Southern Pennines. The distribution maps of the first two species have been compiled from a variety of sources. Specimens in the Herbarium at Kew provided place of collection information and sites are listed in Linton's Flora of Derbyshire (1903) and Clapham's Flora of 1969. Miss K.M. Hollick of Ashbourne provided records, with habitat comments, for the two species in Derbyshire and these were complemented by the B.S.B.I. records. Personal observations have supplemented the data from all these sources and the two distribution maps represent the aggregate of all the information.

The older records of Linton (1903) and Kew are generally less precise in location than more modern ones, the latter often providing a detailed grid reference. Many of the older records refer to a dale or the nearest town or village. The map symbols have been located centrally when the record was a vague one involving a large area;
when a town or village peripheral to the Carboniferous Limestone boundary was cited the symbol has been located nearby, within the area of the limestone outcrop.

The distribution map for *C. officinalis* in Derbyshire is based entirely upon the records in Clapham (1969). While a more rigorous search would undoubtedly reveal further records it is unlikely that the range of the species in Derbyshire would be increased.

**Minuartia verna**

Clapham (1969) states that the species is a native of lead mine spoil heaps and limestone rock ledges, locally abundant on old lead workings and rare elsewhere. Linton (1903) mentions a habitat of rocks and broken ground, mostly among lead mines. Certain records unequivocally mention the occurrence of the species unassociated with lead mine spoil. In Clapham (1969), Habitat Study 49 records *M. verna* growing on a slope of 37° in Cressbrookdale. Here, at an altitude of 275m the species grew associated with *Festuca ovina*, *Helichotrichon pratense* (L.), Pilger, *Hieracium pilosella*, *Thymus drucei* and other species. A record from the Winnats near Castleton, by F.T. and R.H. Hall and supplied by Miss Hollick states "not associated with lead mine workings but on rocky outcrops".

Comparison of Fig. 6.2 showing the range of *M. verna* in Derbyshire, with Fig. 6.3 of the distribution of mineral veins in the Southern Pennines, shows a general coincidence between the two. The area in the south and west of the Carboniferous Limestone outcrop without mineralisation is unoccupied by *M. verna*. The isolated record at Ecton refers to toxic soil associated with the Ecton Hill mines.

Certain *M. verna* records fall outside the mineralised area. Two of these appear to be from the Buxton area and both are old records. One record is labelled Buxton, the other Fairfield. It is probable that the Buxton record is a location of convenience and that the plant
Recorded sites of *Minuartia verna* in the Southern Pennines

- Recorded sites, *Minuartia verna*
- Boundary of Carboniferous Limestone

Figure 6.2
Distribution of mineral veins in the Southern Pennines

- Mineral veins, Pb, Zn, and Cu
- Boundary of Carboniferous Limestone

Figure 6.3
could have been collected from anywhere in Northern Derbyshire. The Fairfield record is problematical in that it is specific. The suburb of Buxton named Fairfield seems to be the only place of this name in Derbyshire. However *M. verna* is found to the south of Helvellyn in the Lake District in a montane area generally known as Fairfield; there seems to be the possibility of a mislocated record here. No modern records exist for the Buxton area and for this reason and the reasons stated above there are grounds for scepticism about both the above Buxton specimens.

The Eyam Moor and Froggatt records are from Linton's Flora of 1903. Froggatt is close to the limestone boundary and the record probably refers to an occurrence on mine spoil on the limestone. The Eyam Moor record presents difficulty, this area lies well within the Millstone Grit outcrop. The general situation in Derbyshire therefore is one of the recent and precisely locatable records for *M. verna* grouping within the mineralised areas while certain older records fall outside.

An exception is the record for *M. verna* from Slagmill Plantation. The B.S.B.I. information shows the species to have been known here from 1960-1969, growing "on acid bank of brook, ? waste from road works". The site was visited in 1972 and the waste heaps were found to contain, in addition to limestone fragments, slag like, apparently smelted material. Analysis of samples from this locality showed one lead concentration of 107,000 ppm and several above 25,000 ppm. Zinc was generally low at around 4,500 ppm. One sample had a pH of 7.0, a total calcium level of 7,850 ppm and an organic carbon content of 3%. The locality appears to have been an old smelter site; the name, of course, suggests this. Ore must have been transported to the site from the Bakewell area or from the Ashover field, in either case a distance of several kilometres is involved. Further information about the site has not been obtained. In view of the demonstrated transport of ore onto the
eastern grits for smelting purposes it seems possible that the old Eyam Moor record was from such a site, perhaps now disappeared. It is interesting to note that a locality just to the north of Eyam Moor is known as Bole Hill, Bole Hill being faced by Smelting Hill across the valley of Highlow Brook.

As will be shown in the following chapters at Malham, at Eller Beck and at Dolfrwynog in Wales heavy metal habitats unassociated with mining activity have been located. Some of these are difficult to identify in the field; metal concentrations are often lower and physical conditions less severe than on spoil heaps and the effects on the vegetation are correspondingly less manifest. Often these habitats are identifiable solely by the presence of an indicator species, the metal concentrations becoming evident from subsequent analysis. That such habitats are mineralised may not be realised by a person collecting distribution records and it is important to take account of this when considering the distribution of species such as _M. verna_.

Sometimes metalliferous habitats created by man may also go unrecognised by botanical recorders. A case in point is that of the Slagmill Plantation site for _M. verna_ just discussed. Here a heap of slag and spoil was thought to be waste from road works. This is not to imply any criticism of the recorder's powers of observation, misidentification arises from the difficulty of identification. It is reasonably easy to identify spoil when it is in the normal place - on a spoil heap. When it has been used to fill in holes in a track, to bolster up a stone wall or especially when it is mixed up with scree material on a steep slope its origin may be obscure and be unrecognised and if indicator plants grow on the site then it may also not be realised that they are present due to toxicity.
The complete absence of *M. verna* from most areas of the Carboniferous Limestone beyond the periphery of the orefield and the possibility that certain metalliferous sites may not have been recognised suggests that a detailed investigation of the apparently non-metalliferous habitats of the species in the Southern Pennines would be valuable.

*M. verna* is not found in certain areas of mineralisation in Derbyshire, in particular the mines at Carder Low north of Hartington and the Wetton Mines. Two samples from the small and rather overgrown heaps at Carder Low showed Ca/HM ratios of 3.9 and 5.63, the spoil here does not seem sufficiently toxic in relation to the toxicity threshold proposed for *M. verna* in Derbyshire. Three samples of relatively bare spoil from the mines at Wetton showed Ca/HM ratios of 1.58, 2.14 and 4.18. At least some of the spoil here seems sufficiently toxic and sufficiently uncolonized to support *M. verna* and the reasons for its absence from the site are not apparent.

**Thlaspi alpestre**

Fig. 6.4 shows the range of this species in Derbyshire. The plant is confined to the area of mineralisation in the south east of the limestone outcrop and occurs also on the Crich inlier but not at Ashover. The absence from Northern Derbyshire represents a break in the range of a species which occurs on mining spoil from Belgium and the Mendips to the Northern Pennines; a climatic explanation of the range of the species in Derbyshire seems, on this basis, untenable.

The records were assembled from the same sources as used for *M. verna*. Linton (1903) mentions a record of the species from Castleton, no later records exist. Linton's record appears to be derived from a Botanical description of the Midland Counties by Purton (1817, 1821); in the discussion which follows no importance has been attached to this record.
Recorded sites for *Thlaspi alpestre* in the Southern Pennines

- Recorded sites, *Thlaspi alpestre*
- Boundary of Carboniferous Limestone

Figure 6.4
Clapham (1969) describes *T. alpestre* as a species of spoil heaps on old lead workings, less common on rocks and walls and in woods on the Carboniferous Limestone. Linton (1903) states the habitat to be limestone rocks and walls. He cites a record of the species from a wood between Matlock Bridge and Brightgate; this appears to be Jughole Wood. Miss Hollick in her records indicated the localities for the species known to be from lead workings, one of these was from Clough Wood, Wensley. She has observed the species at the old High Peak railway cutting at Longcliff where the plant grew on rabbit diggings.

In view of the fairly large number of sites, the imprecise nature of many of them and the consequent impossibility of checking them it is impossible to be firm on the point but it is believed that the situation in Derbyshire is one of lead spoil heaps in woods, heavy metal contaminated walls and rabbit burrows in spoil. In this respect it is interesting to note that the soil in the interstices of a dry stone wall near a mine to the south of Upper Town (Upper Town, Table 6.10), soil in which *T. alpestre* and *M. verna* grew, contained 74,800 ppm lead. As has been pointed out previously that sites such as this have not been recognised as mineralised is not a reflection upon the observers but rather upon the widespread dissemination of toxicity in the mine areas and the difficulty of recognising toxic soil, even if that soil be spoil derived, under certain conditions.

This does not of course explain the absence of the species from the mineralised areas of north Derbyshire. In Clapham (1969) it is stated that "the species composition of the spoil heaps depends primarily on the abundance of rock containing lead ore. Where amounts are high *Festuca ovina* and *Minuartia verna* are the only species, where there is a greater admixture of limestone a more species rich vegetation, containing *Cochlearia officinalis* in the Castleton area and *Thlaspi alpestre* in the Matlock area, develops". The implication of this statement seems to be that *Thlaspi alpestre* is present in those
spoil areas with lower heavy metal concentrations, lead being singled out. This does not seem to be true. T. alpestre was found at Upper Town in spoil with a lead concentration of 74,800 ppm and on the Youlgrave Tr. 1 in spoil with lead concentrations in the region of 60,000 ppm. Inspection of Table 6.10 shows that these lead concentrations are among the highest found in spoil in the Southern Pennine orefield. It does not appear to be the case either that the spoils with T. alpestre, even though containing large quantities of lead, are less toxic due to high calcium concentrations. Table 6.11 shows that the Ca/HM ratios in spoil from sites with T. alpestre are comparable with those in some of the spoils from places where the plant does not occur. In the Mendips and in the Aachen-Liege orefield T. alpestre occurred on slags with low pH which, it was suggested, were quite toxic, so toxic that M. verna did not grow on them. An explanation which suggests that T. alpestre is absent from certain spoils in Derbyshire due to excessive toxicity is not supported by the analyses presented here and in view of the presence of the species on quite toxic substrates elsewhere seems unlikely.

T. alpestre is often found where there is considerable organic matter accumulation in the spoil. At Brassington S3 and Bonsall Moor S3 (Table 6.11) the species occurred in spoil with an organic carbon content greater than 20%. The species was present in the Mendips at Shipham in spoil containing organic carbon levels between 12% and 29%. In these sites with high organic carbon contents M. verna is often absent, the vegetation is often more or less closed and it appears that T. alpestre may be a little more tolerant of competition than M. verna. The presence of T. alpestre in spoil with much organic matter when it is frequently not present in spoil nearby which is bare and unstable suggests that the plant may be more sensitive than M. verna to edaphic conditions such as drought.
The spoil from High Rake Tr. 1 was much more coarse grained than that from Youlgreave Tr. 1 where T. alpestre occurred and if it is generally the case that the spoils of the northern part of the orefield are more coarse than those in the south then this may be having some influence on the distribution of the species in the orefield.

Work done by Riley (1956) suggests an interesting possibility in relation to the peculiar distribution of T. alpestre in Derbyshire. He mentioned the poor dispersal capabilities of the species and suggested that much of the migration of the plant has been achieved with human assistance, transport in ore for example. In Derbyshire the western edge of the range of the species coincides with the western border of the orefield, the northern with the deep valley of the River Bradford and the westerly extension of the Millstone Grit. In extending to Youlgreave the species occupies a narrow corridor between the Millstone Grit and the western edge of the orefield.

To migrate northwards from Youlgreave the species would have to ascend the northern slope of the Bradford valley and reach the mines on the plateau surface. The nearest metalliferous site northwards from Youlgreave is the very small spoil heap to the west of Lomberdale Hall which supported a small M. verna population. A short distance north again are the Long Rake workings but there are few spoil heaps associated with the rake. To the north of Long Rake is a further gap of over one kilometre to the mines of Lathkilldale and not until the mines in the Monyash, Flagg and Sheldon area are reached is there a region of concentration of mineral veins with many mines and spoil heaps.

If, as Riley (1956) suggests, migration of T. alpestre within the orefields has been achieved by means of the agencies of man then the deep valley of the River Bradford at Youlgreave, the northern boundary for T. alpestre, would probably be an obstacle across which
there would be relatively little mining traffic, especially transport of ore. There would therefore be relatively little dispersal of *T. alpestr*$ across the River Bradford. There are also relatively few spoil dumps in the immediate area north of the river for the species to occupy and because of this the chance of successful dispersal will be further reduced. It seems possible that the northern boundary of *T. alpestr*$ in Derbyshire is a function of the poor dispersal capa-

abilities of the species.

**Cochlearia officinalis**

This species, according to Clapham (1969) is one of north facing cliffs on the Carboniferous Limestone and a colonist of recently reworked spoil on the limestone plateau. *C. officinalis* (Fig. 6.5) shows a bipolar distribution in Derbyshire, occurring around Castleton and Matlock. Habitat Study 69 already quoted from Clapham (1969) states the species to occur on calcareous heaps in the two areas. *C. officinalis* has been encountered in this study only at Dirtlow Rake and the Odin Mine where it grew on spoil with high calcium levels. The species does not occur on the more southerly of the calcareous northern rakes. This is interesting as habitat conditions in the initial quadrats of High Rake appeared to be very similar to those at Dirtlow Rake. The range of this species in Derbyshire requires further study.

### 6.4 Historical aspects of the distributions of the indicator species in the Southern Pennine orefield

It appears that in the Southern Pennines, as in other mining areas, spoil from mining operations, even spoil containing fairly high concentrations of heavy metal is, in time, occupied by closed vegetation communities to the exclusion of the indicator species. Historical evidence from the British Isles generally, as pointed out in Chapter 1, does not seem to suggest that the indicator species
Recorded sites of *Cochlearia officinalis* in the Southern Pennines

- Recorded sites, *Cochlearia officinalis*
- Boundary of Carboniferous Limestone

Figure 6.5
were important to the old miners for prospecting purposes and the historical record further suggests that the veins were often not evident at the surface.

In the Southern Pennines at the present time trees, especially *Acer pseudoplatanus* L., are often present on the workings. Even if not present in the most toxic areas they sometimes shade the spoil heaps and must supply organic matter in litter fall to the more toxic sites. In an area of narrow zones of mineralisation such as the Southern Pennines covered with soils in part derived from material of aeolian origin (Pigott, 1962) and trees, perhaps, closely bordering the metal rich areas it seems unlikely, due to the action of succession, that for much of the Post Glacial period toxic open habitats, occupied by *Minuartia verna* and *Thlaspi alpestre*, existed on the limestone plateau. Only where mineral veins remained exposed is it likely that conditions were suitable for the survival of the two species from the end of the last glaciation, when they were presumably more widespread, to the onset of mining activity. Maintenance of an open habitat combined with high toxicity is only likely to have occurred where the processes of succession were prevented, probably where mineral veins outcropped on steep limestone cliffs or scree and instability combined with toxicity in maintaining the open condition. This is of course comparable with the ideas of Pigott and Walters (1954) concerning other species of discontinuous distribution in open habitats. Indeed these postulated survival sites may be considered to be "heavy metal refugia". This survival site hypothesis supposes movement by the metal tolerant species out of the refugia in response to habitats made available by mining operations.

It has been suggested that *T. alpestre* in Derbyshire is entirely associated with mineralisation and that *M. verna* appears to be very strongly associated with the same. *C. officinalis* has not been
considered in any detail but many of the observations made in respect of *T. alpestris* and *M. verna*, particularly the possibility of undisturbed mineralised habitats being unrecognised by field observers, seem likely to apply. A combination of the ranges of the three species seems to suggest refuge areas in the regions of Castleton and Matlock. The cliffs of the Winnats, for which there is a record for *M. verna* from a site not associated with mining, would appear to be a suitable area, for there steep north facing limestone cliffs coincide with zones of mineralisation. The steep cliffs in the Matlock area may also have offered similar conditions.
CHAPTER 7.
ELLER BECK: WENSLEYDALE

7.1 Introduction

Wensleydale is one of the main areas of exposure of the Yoredale series in the Pennines and the distinctive physiographical features of the Eller Beck region have their origins in the particular characteristics of this Carboniferous facies.

The Yoredale series are in excess of 300m thick in the area and are composed of a rhythmic succession of shale, sandstone and limestone repeated many times. The series was deposited in a Carboniferous sea of everchanging depth, the limestones represent deeper water conditions well offshore and the shales and sandstones relatively shallow, at times deltaic, conditions nearer to the margin of the Carboniferous continent which lay to the north.

Subsequent to the deposition of the Yoredale rocks and the overlying beds of the Millstone Grist and Coal Measures the area was affected by the Armorican earth movements. Folding did not occur to any extent in the region but there was considerable movement along the large faults of the northern and central Pennines, the Craven faults in the south and the Dent and Pennine faults in the west. Greater uplift occurred in the west and as a result the strata show a general regional dip towards the east at the present day. Some slight folding took place later in the orogenic episode and this has produced a slight doming centred on Ingleborough and superimposed upon the general regional structure (Raistrick, 1968). Even though there are these regional patterns of dip, angles of dip in most places are slight and the general impression in a small area is one of more or less horizontal bedding.
Although the area was glaciated during the Pleistocene period there appear to be no large depositional features resulting from glaciation in the Eller Beck area. It is possible that in places the ground surface is mantled by a thin layer of till, this is certainly the case around Malham to the south.

A singular feature of Wensleydale and of the immediate region of Eller Beck is the alternation on the valley sides of limestone scarps and flat benches. This particular morphology is a reflection of the cyclical nature of the Yoredale deposits. The limestone bands, 20m or so thick, weather to form a long scar on the valley side while the shales are easily removed. This process, in the words of Raistrick (1968), "leaves the top of the limestone like the tread of a stair". The pronounced limestone cliffs of Ivy Scar and Haw Bank at Eller Beck are thus separated by a low lying bench of Yoredale shales and sandstones and these may be seen exposed in the stream valley above the waterfall of Disher Force (Fig. 7.3).

The indicator plant communities studied at Eller Beck range in altitude from around 215m on the flood plain to about 340m at Thackthwaite Beck. Some climatic differences are to be expected over an altitude difference of this magnitude. By adjustment of the temperature data for Malham supplied by Manley (1957) using the environmental lapse rate for the Pennines suggested by Manley (1957) the January mean of the Eller Beck flood plain appears to be of the order of 2.6°C and the July mean 14.6°C. The spoil heaps at Thackthwaite Beck will probably experience mean temperatures about 1°C lower. Microclimatic effects in the region are probably quite pronounced, the steep south facing scarps of Haw Bank and Ivy Scar will receive maximum insolation but on the other hand are quite exposed to strong winds. Even in summer the exposure of Ivy Scar to winds from the south west was noticeable. Rainfall at Leyburn, farther east in Wensleydale and at an altitude of 128m, averaged nearly 890mm annually from 1901 to 1930. The flood plain
at Eller Beck at 215m is farther west and at a higher altitude and it is probable that the annual precipitation total is around 1000 mm.

The soils and vegetation of the immediate area of Eller Beck are controlled to a large extent by parent material and morphological position in the landscape. The bench to the south of Haw Bank is covered by permanent grassland which has been improved to a certain extent to the north of Ballowfield. The lower slopes of Haw Bank are wooded while the upper slopes are occupied by an association of calcicole species. The crest of Haw Bank is an area of thin calcareous soil rapidly changing on the bench feature between Haw Bank and Ivy Scar to a thin peat covered by Nardus stricta L. grassland. Ivy Scar is not wooded and the flatter surface to the north is again peat covered. The various transects presented later provide more detailed information on the floristic composition of many of these areas.

The major faulting of Armorican times was accompanied by many minor dislocations of the strata and mineralising hydrothermal solutions appear to have risen along these lines of weakness. Galena and blende are the major ore minerals at Eller Beck accompanied by barytes, calcite and fluor spar. Earp (in Dunham, 1952) describes three main ore bearing locations in the vicinity of Eller Beck. These are at Thackthwaite Beck, Wet Grooves and Disher Force (Fig. 7.3). An east west trending vein along Thackwaite Beck is intersected in the region of the old mine by a fault trending north west south east which appears to extend southwards to the Wet Grooves area. At Wet Grooves there is a triangular area of ground in which the strata are highly disturbed, the area of the Knot. According to Earp (in Dunham, 1952) the Knot contained an anastomosis of veins and strings which were worked from shafts and levels.
ELLER BECK: The distribution of the indicator species

Figure 7.1
ELLER BECK: Areas of mine spoil

Figure 7.2
ELLER BECK: Locations

Figure 7.3
Two levels penetrate the foot of the limestone scar of Haw Bank, one in the region of The Straits and the other to the south south east of Disher Force. The purpose of these adits is unclear, they may have been driven to work the lower parts of the mines at Disher Force or at Wet Grooves (Earp, in Dunham, 1952).

The age of the mining at Eller Beck is also uncertain. The mines were not mentioned by Carruthers and Strahan (1923) in their Special Report on Mineral Resources and Dunham (1952) merely records them as abandoned. They probably date from the early Nineteenth Century and have the appearance of not having been worked for a long time. In 1975 the spoil heaps at Wet Grooves were being reworked for fluorspar.

7.2 The heavy metal communities adjoining Eller Beck

From its source at Eller Springs the water flows first of all southwards and then from east to west along Thackthwaite Beck (Fig. 7.3). The stream sinks and reappears as Eller Beck in the valley occupied by the Disher Force mines. The beck falls about 8m at Disher Force and flows in a relatively narrow valley as far as the Old Lead Mines before wandering through the fields to the River Ure. The parts of the flood plain adjoining the stream are contaminated in many places by lead and zinc. Communities involving the indicator species occur along the stream for much of its length (Fig. 7.1). Transects and spot samples have been employed to investigate the plant communities associated with the contamination by heavy metals of the flood plain and Fig. 7.3 shows the locations of the various sites from which samples were taken. Table 7.1 shows the results of various analyses of these samples.

The Straits (Fig. 7.3) appears to be the lowest possible input site for heavy metal along Eller Beck and it is apparent from Table 7.1 that lead decreases in concentration in the sites occupied by the indicator species on the alluvium of the flood plain downstream.
<table>
<thead>
<tr>
<th>Type of Soil</th>
<th>Thaspis</th>
<th>Verena</th>
<th>Maritima</th>
<th>Amsitea</th>
<th>Ph</th>
<th>Ca/HM</th>
<th>Pb/Zn</th>
<th>Zn</th>
<th>Pb</th>
<th>Cd</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.9</td>
<td>0.24</td>
<td>18.95</td>
<td>0.6</td>
<td>1.6</td>
<td>1070</td>
<td>2.0</td>
<td>16.650</td>
<td>1.4</td>
<td>14.000</td>
</tr>
<tr>
<td>2</td>
<td>1.4</td>
<td>0.60</td>
<td>9.750</td>
<td>0.50</td>
<td>0.56</td>
<td>9.4</td>
<td>1.4</td>
<td>10.300</td>
<td>1.3</td>
<td>12.000</td>
</tr>
<tr>
<td>3</td>
<td>1.4</td>
<td>0.60</td>
<td>9.750</td>
<td>0.50</td>
<td>0.56</td>
<td>9.4</td>
<td>1.4</td>
<td>10.300</td>
<td>1.3</td>
<td>12.000</td>
</tr>
<tr>
<td>4</td>
<td>1.4</td>
<td>0.60</td>
<td>9.750</td>
<td>0.50</td>
<td>0.56</td>
<td>9.4</td>
<td>1.4</td>
<td>10.300</td>
<td>1.3</td>
<td>12.000</td>
</tr>
<tr>
<td>5</td>
<td>1.4</td>
<td>0.60</td>
<td>9.750</td>
<td>0.50</td>
<td>0.56</td>
<td>9.4</td>
<td>1.4</td>
<td>10.300</td>
<td>1.3</td>
<td>12.000</td>
</tr>
<tr>
<td>6</td>
<td>1.4</td>
<td>0.60</td>
<td>9.750</td>
<td>0.50</td>
<td>0.56</td>
<td>9.4</td>
<td>1.4</td>
<td>10.300</td>
<td>1.3</td>
<td>12.000</td>
</tr>
<tr>
<td>7</td>
<td>1.4</td>
<td>0.60</td>
<td>9.750</td>
<td>0.50</td>
<td>0.56</td>
<td>9.4</td>
<td>1.4</td>
<td>10.300</td>
<td>1.3</td>
<td>12.000</td>
</tr>
<tr>
<td>8</td>
<td>1.4</td>
<td>0.60</td>
<td>9.750</td>
<td>0.50</td>
<td>0.56</td>
<td>9.4</td>
<td>1.4</td>
<td>10.300</td>
<td>1.3</td>
<td>12.000</td>
</tr>
</tbody>
</table>

*Table 7.1: Heavy metal, calcium, and pH determinations and the Pb/Zn and Ca/HM ratios of flood plain sediments from different plots.*
from this point. Zinc on the other hand remains at more or less the same concentration downstream from Site 2 and may even increase slightly. Hawkes and Webb (1962) point out that it is normal for there to be a progressive decay in the amount of heavy metal in the active material of a stream bed downstream from the lowest input site and this will presumably tend to be the case also in flood plain alluvium. It appears from the analyses of Table 7.1 that the lead anomaly decays more rapidly than the zinc anomaly in the alluvium on the Eller Beck flood plain. The Pb/Zn ratio in Table 7.1 makes this even more clear.

Table 7.2 shows the results of further analyses from the spot sites along Eller Beck. It is apparent from these analyses that the bases sodium, potassium and magnesium are present in amounts similar to those found in many spoils but that organic carbon in the surface soils are quite high.

**Table 7.2** Sodium, potassium, magnesium and organic carbon determinations at certain sites along Eller Beck.

<table>
<thead>
<tr>
<th>Site number</th>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>195</td>
<td>2,750</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>3</td>
<td>105</td>
<td>2,050</td>
<td>1,080</td>
<td>nd</td>
</tr>
<tr>
<td>6</td>
<td>150</td>
<td>1,650</td>
<td>1,080</td>
<td>20.1%</td>
</tr>
<tr>
<td>9</td>
<td>105</td>
<td>1,650</td>
<td>nd</td>
<td>25.5%</td>
</tr>
<tr>
<td>10</td>
<td>125</td>
<td>2,300</td>
<td>1,260</td>
<td>nd</td>
</tr>
<tr>
<td>12</td>
<td>175</td>
<td>1,905</td>
<td>nd</td>
<td>18.0%</td>
</tr>
<tr>
<td>13</td>
<td>175</td>
<td>1,540</td>
<td>950</td>
<td>nd</td>
</tr>
</tbody>
</table>

Analyses of alluvium from sites on the vertical bank of the stream where the indicator species grew are shown in Table 7.3. The pH of these samples is above 7.0 and this indicates the pH of alluvial material without substantial organic carbon accumulations. It appears therefore that the pH values below 7.0 of many of the samples
<table>
<thead>
<tr>
<th>Site</th>
<th>Name indicator species present</th>
<th>Name indicator species absent</th>
<th>+</th>
<th>8' 300</th>
<th>11' 200</th>
<th>12' 950</th>
<th>0' 93</th>
<th>7' 2</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>+</td>
<td>11' 750</td>
<td>8' 500</td>
<td>11' 300</td>
<td>7' 1</td>
<td>55</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>-</td>
<td>1' 45</td>
<td>10' 000</td>
<td>16' 800</td>
<td>7' 1</td>
<td>7</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Site</th>
<th>Name indicator species present</th>
<th>Name indicator species absent</th>
<th>+</th>
<th>8' 300</th>
<th>11' 200</th>
<th>12' 950</th>
<th>0' 93</th>
<th>7' 2</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>+</td>
<td>11' 750</td>
<td>8' 500</td>
<td>11' 300</td>
<td>7' 1</td>
<td>55</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>-</td>
<td>1' 45</td>
<td>10' 000</td>
<td>16' 800</td>
<td>7' 1</td>
<td>7</td>
<td>4</td>
</tr>
</tbody>
</table>

**Table 7.3** Heavy metal levels, calcium concentrations and the pH of stream bank alluvium from Elver Beck.
of flood plain alluvium (Table 7.1) represent the secondary development of a lower pH associated with organic matter build up in the soil.

Table 7.1 also shows the incidence of the indicator species at the various sites. It is clear from this that *Armeria maritima* is the most widespread species, being present in all sites except Site 10. Fig. 7.3 shows that Site 10 was in the region just after Eller Beck turns to flow southwards. Fig. 7.1 demonstrates that this was an area where the indicator species were not present and Table 7.1 shows that the soil at this site was not as toxic as that from the other sites along Eller Beck. It appears that relatively less deposition of lead and especially of zinc has occurred in this particular section of the flood plain. In comparison with *A. maritima* *Minuartia verna* and *Thlaspi alpestre* were infrequent in the area of the flood plain from which the spot samples were taken.

Table 7.1 shows the Ca/HM ratios of alluvial material from the spot sites. It is probable that these Ca/HM ratios are not entirely comparable with those from spoil heaps, it may be that the substantial accumulations of organic matter in the surface horizons are having some effect on the relative amounts of calcium and heavy metal but probably more important are the differences between the physical conditions of the environment on the flood plain of Eller Beck as opposed to those of spoil heaps. Table 7.4 shows the results of particle size analyses of alluvium from the flood plain and it is clear that in comparison with some samples from spoil heaps there is not much coarse sand in the alluvium. The high levels of organic matter will promote the retention of soil moisture and the proximity of the stream itself will presumably mean that drought conditions on the flood plain will be of lower incidence than on spoil heaps. For reasons such as these the Ca/HM ratios of the soils of the flood plain may not be directly comparable with ratios from spoil heaps but nonetheless they appear to be useful in terms of internal comparisons.
Table 7.4  Particle size analyses of alluvium from the Eller Beck flood plain

<table>
<thead>
<tr>
<th>Site number</th>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.5%</td>
<td>2.5%</td>
<td>20.3%</td>
<td>35.1%</td>
<td>16.7%</td>
<td>20.1%</td>
</tr>
<tr>
<td>12</td>
<td>8.0%</td>
<td>16.7%</td>
<td>22.2%</td>
<td>20.3%</td>
<td>13.1%</td>
<td>18.0%</td>
</tr>
</tbody>
</table>

It is evident from Table 7.1 that *M. verna* and *T. alpestre* are found only in those sites with Ca/HM ratios less than 1 while *A. maritima* extends to sites with Ca/HM ratios in excess of 1. This suggests that *A. maritima* under these habitat conditions is more competitive than *M. verna* and *T. alpestre*. This is interesting for *A. maritima* also appeared to be the most competitive of these three indicator species on the spoil heaps at La Calamine in Belgium.

A feature of the Ca/HM ratio on the flood plain at Eller Beck is that in the sites just below the Straits it is predominantly a Ca/Pb ratio while in samples such as those of sites 11 and 12 zinc is a more important part of the calculation. In Chapter 3 it was pointed out that the basis of the assumption that zinc is for a given amount half as toxic as lead is to a certain extent an empirical one, Ca/HM ratios calculated on this basis appear to explain plant distributions. Eller Beck is an instructive site in this respect for here, without much change in other environmental factors, lead and zinc change in relative proportions along the stream. This means that it is possible to consider the Ca/HM ratio as employed in this study under conditions where the major variables are lead and zinc concentrations.

Table 7.5 shows ratios between calcium and either lead or lead and zinc worked out using different assumptions. Column 1 shows a Ca/Pb ratio, zinc as a toxic agent is ignored. This method shows *M. verna* to occur at ratios below 1 while *A. maritima* extends to ratios in excess of 1. A difficulty is site 10 which appears on this basis to be more toxic than sites 11, 12 and 13 and yet has no indicator species.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Zn (ppm)</th>
<th>Ca/HM</th>
<th></th>
<th>Ca/HM</th>
<th></th>
<th>Zn (ppm)</th>
<th>Ca/HM</th>
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<tbody>
<tr>
<td>+</td>
<td>+</td>
<td>8.68</td>
<td>0.75</td>
<td></td>
<td>0.85</td>
<td></td>
<td>2.4</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>0.56</td>
<td>0.58</td>
<td></td>
<td>0.40</td>
<td></td>
<td>6.9</td>
<td>0.66</td>
<td>3</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>0.60</td>
<td>0.55</td>
<td></td>
<td>0.45</td>
<td></td>
<td>1.5</td>
<td>0.44</td>
<td>6</td>
</tr>
<tr>
<td>-</td>
<td>+</td>
<td>0.51</td>
<td>0.60</td>
<td></td>
<td>0.35</td>
<td></td>
<td>1.2</td>
<td>0.31</td>
<td>8</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>0.88</td>
<td>0.52</td>
<td></td>
<td>0.43</td>
<td></td>
<td>1.9</td>
<td>0.25</td>
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**Named Indicator Species Present**

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<td>0.31</td>
<td>12</td>
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<td></td>
<td>0.43</td>
<td></td>
<td>1.9</td>
<td>0.31</td>
<td>12</td>
</tr>
</tbody>
</table>

**Named Indicator Species Absent**

Different assumptions. Table 7.5

**Table 7.5** Ratios between calcium and heavy metal for the top sample soils at desktop calculation using...
Column 2 shows a Ca/HM ratio calculated on the basis that lead and zinc are equally toxic. This method accounts for the distribution of *M. verna* and *A. maritima* and also accounts for the absence of indicator species from Site 10. It does not however agree with the results of Jeffrey et al (1975) discussed in Chapter 3 which suggested zinc to be less toxic than lead.

Column 3 shows a Ca/HM ratio calculated using the assumption that zinc, for a given amount, has a quarter of the toxicity of lead. Site 10 without indicator species appears by this method to be more toxic than Sites 12 and 13 where *A. maritima* grew.

Column 4 shows a Ca/HM ratio calculated on the assumption used in the study that zinc is about half as toxic as lead. Comparison of the ratios in this column with the incidence of the indicator species shows that *M. verna* tends to occur at the higher toxicities and that *A. maritima* is present at all sites except Site 10, the one which appears in terms of this method of calculating the Ca/HM ratio the least toxic.

It appears from the basis of these calculations that assigning relatively little importance to zinc toxicity is erroneous. On the other hand the assumption that zinc is equally as toxic as lead is not in accordance with the findings of Jeffrey et al (1975). The application of the assumption that zinc has half the toxicity of lead appears to account for the distribution of the indicator species at the spot sampling sites at Eller Beck and has also provided explanations for the distributions of the indicator species in the other areas considered so far. Thus while no claim is made for the absolute accuracy of the assumption its justification is the empirical one that it appears to account for plant distributions in calcareous metalliferous environments.
In addition to the sites at which spot samples were taken several transects were employed to investigate the indicator plant communities adjoining Eller Beck. Eller Beck Tr. 7 (Fig. 7.4) crossed an area of the flood plain close to Site 2 just discussed. The location of the transect line is shown in Fig. 7.3.

Fig. 7.4 demonstrates that the concentration of zinc in the flood plain soil decreases rapidly and progressively away from the stream, the stream bank was at 8m, while lead shows the same general tendency but has a peak concentration at 5m. The rapid reduction in the concentrations of the heavy metals away from the stream on this transect line is probably normal in this section of Eller Beck. As Fig. 7.1 shows the indicator plant communities are very closely associated with the stream bank and will be reflecting the high concentrations of lead and zinc found there.

It is apparent from Fig. 7.4 that the indicator species *M. verna*, *T. alpestris* and *A. maritima* are associated with the area with the highest lead concentration at 5m. The Ca/HM ratio of alluvium from this point was 0.61, about the same ratio as those in the spot samples from this area (Table 7.1). Sodium, potassium, and magnesium were present in the sample from 5m in about the same concentrations as in the spot samples from elsewhere on Eller Beck (Table 7.2) while phosphorous analysis showed a result of 640 ppm.

A feature of interest on this transect line is the considerable number of forbs occupying the area from 6m to the stream bank, an area in which heavy metal levels are moderately high. Some of these such as *Helianthemum chamaecistus* Mill., *Succisa pratensis* Moench and *Parnassia palustris* L. are absent or relatively unusual on spoil heaps.
GEOBOTANY

Trifolium pratense
Linum catharticum
Pimpinella saxifraga
Campanula rotundifolia
Euphrasia officinalis
Filipendula ulmaria
Ranunculus acris
Leontodon hispidus
Potentilla recta
Parnassia palustris
Lotus corniculatus
Helianthemum chamaecistus
Succisa pratensis
Rumex acetosa
Plantago lanceolata
Molinia caerulea
Holcus lanatus
Antirrhinum odoratum
Dactylis glomerata
Agrostis tenius
Festuca rubra
Festuca ovina
Thlaspi alpestre
Minuartia verna
Armeria maritima
Bare Ground

GEOCHEMISTRY

RELIEF

ELLER BECK: TRANSECT 7.

Figure 7.4
Eller Beck Tr. 9 (Fig. 7.5) crossed Eller Beck in an approximately
est west direction just to the north of the point where the stream joins
the River Ure (Fig. 7.3). It is clear from Fig. 7.5 that zinc is
present in higher concentrations than lead in the alluvium in this area,
a continuation of the tendency observed in the spot samples (Table 7.1)
for zinc to increase in importance relative to lead downstream.
Table 7.6 shows that Ca/HM ratios in the alluvium along the transect
line are higher than those in samples from nearer to The Straits,
reflecting the same decrease in the toxicity of the alluvium downstream
which was noticed for the spot samples. A phosphorous determination
for alluvium from 12m on this transect line showed a concentration of
400 ppm, slightly lower than that from 5m on Eller Beck Tr. 7 and
a low concentration compared to some spoils.

Table 7.6  Heavy metal and calcium determinations and the Ca/HM
ratio of samples from Eller Beck Tr. 9.

<table>
<thead>
<tr>
<th>Sample distance</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>Ca/HM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2m</td>
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<td>5,900</td>
<td>10,150</td>
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<td>7m</td>
<td>5,850</td>
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<td>16,900</td>
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<td>3,070</td>
<td>8,200</td>
<td>11,750</td>
<td>1.64</td>
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<tr>
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<td>4,290</td>
<td>5,900</td>
<td>14,650</td>
<td>2.48</td>
</tr>
</tbody>
</table>

Both M. verna and A. maritima occurred in the area but as Fig. 7.5
shows M. verna was restricted to the eastern bank of the stream. In
this region around 2m the Ca/HM ratio (Table 7.6) was just above 1.
This is a higher Ca/HM ratio than those found in other sites along
Eller Beck where M. verna occurred and it seems probable that the
occurrence of the species at this relatively low toxicity on this
transect line is related to the fact that the stream bank where the
species occurred was quite steep and somewhat unsteady, thus
GEOBOTANY

*Equisetum sp.*

*Chelidonia millefolium*

*Parassia pakastris*

*Filipendula ulmeria*

*Euphorbia officinalis*

*Holanthemum chamaccistus*

*Hieracium sp.*

*Ranunculus acris*

*Succisa pratensis*

*Linnum cathericum*

*Cerastium vulgatum*

*Campanula rotundifolia*

*Tribulus spp.*

*Rumex acetosa*

*Plantago lanceolata*

*Carex bisnervis*

*Anthosanthes odoratum*

*Molinia caerulea*

*Koeleria cristata*

*Deschampsia caespitosa*

*Holcus lanatus*

*Agrostis tenua*

*Festuca ovina*

*Menispermum cernuum*

*Armeria maritima*

*Bare Ground*

GEOCHEMISTRY

GEOCHEMISTRY

RELIEF

ELLER BECK:
TRANSECT 9.

Figure 7.5
reducing competition from other species to the advantage of *M. verna*. On the west bank of the stream the main occurrence of *A. maritima* was in the region of 12 and 13m. The Ca/HM ratio (Table 7.6) in the soil here is just under 1.3. Comparison of Fig. 7.4, Eller Beck Tr. 7, and Fig. 7.5 for this transect line shows the marked contrast in the cover values of *A. maritima* between the two transect lines. It appears that *A. maritima* is less competitive on this transect line than on Eller Beck Tr. 7 and this is probably related to the lower toxicity of the soil. *A. maritima* is apparently approaching at a Ca/HM ratio of around 1.3 its toxicity threshold on the flood plain of Eller Beck and this figure accords well with the limit of the species suggested by the spot samples (Table 7.1).

A feature of this transect line in comparison to Eller Beck Tr. 7 (Fig. 7.4) is that lead and zinc concentrations in the soil do not decrease as rapidly with distance away from the stream. Hawkes and Webb (1962) point out that anomalous values of heavy metals normally decay on flood plains with distance away from the active channel, this appears to be the case, especially for zinc, on both transects but clearly on Eller Beck Tr. 9 decay occurs much more slowly. A possible explanation for this is that when Eller Beck and the River Ure are in flood, and this site is very near the confluence, backing up of the water coming down Eller Beck occurs in the region of Tr. 9 and sediment containing lead and zinc is spread over a much wider zone than is normal in the area upstream nearer to The Straits.

Eller Beck Tr. 6 was located in the region to the north west of The Straits where Eller Beck runs close to the Carperby to Woodhall secondary road (Fig. 7.3). It is apparent from Fig. 7.6 that the indicator species *M. verna* and, especially, *A. maritima* occur over a much wider area of the flood plain that was the case on Eller Beck Transects 7 and 9 below The Straits. The relief profile
## GEOBOTANY

<table>
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<th>Species</th>
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<td>Cochloaria officinalis</td>
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<tr>
<td>Carastium vulgatum</td>
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<td>Campanula rotundifolia</td>
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<td><em>cotentHia erecta</em></td>
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<tr>
<td>Laontodon hispidus</td>
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<td>Pentagia iarkeolata</td>
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<td>Rumex acetosa</td>
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<tr>
<td>Euphrasia officinalis</td>
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<td>Juncus effusus</td>
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<td>Koeleria cristata</td>
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<tr>
<td>Deschampsia caespitosa</td>
</tr>
<tr>
<td>Armeria maritima</td>
</tr>
</tbody>
</table>

## GEOCHEMISTRY

![Graph](image)

**Figure 7.6**

## RELIEF

![Graph](image)

**ELLER BECK: TRANSECT 6.**
demonstrates that the bed of Eller Beck at 10m is at about the same altitude as the end of the transect line at 45m. At a position equivalent to about 60m on an extension of the transect line a subsidiary stream, apparently developing to cut off the curve of Eller Beck in this region, was present. It seems very probable that in times of flood much of the area beyond 10m on the transect line will be submerged, resulting in the deposition of toxic alluvium over a wide zone.

In several samples from the transect line lead and zinc are present in concentrations above 20,000 ppm, higher concentrations than those encountered in most of the spot samples, and on the transects, from below The Straits. In the account of the spot samples it was pointed out that the area of The Straits with its spoil heaps appeared to be the lowest possible input site for heavy metal into the stream system. While this is true it is probable that most of the metalliferous alluvium on the Eller Beck flood plain is derived from the mines near to Disher Force. It is certainly the case at the present day that the spoil heaps at the side of the beck at the Old Lead Mines about 200m to the south of Disher Force are being actively eroded by the action of the stream. It appears therefore that the area of Eller Beck Tr. 6 is nearer to the source of origin of much of the metalliferous alluvium which pollutes the flood plain of Eller Beck and the high concentrations of heavy metal on the transect line, for example 94,200 ppm lead at 14m, may be understood in terms of this proximity to source.

It is evident from Fig. 7.6 that M. verna and T. alpestre are found in the areas of the higher heavy metal concentrations and that A. maritima reaches its highest cover value in a quadrat adjoining the point where the greatest concentration of lead occurred. A. maritima indeed is widespread on the transect line, being absent only in the quadrats of the lowest heavy metal concentrations, 22, 24, 36 and 44m for example.
Table 7.7 indicates that the pH values of the surface soils are, with the exception of the sample from 42m, very similar to those encountered in the spot samples from below The Straits (Table 7.1). The Ca/HM ratios at 6m, 14m and 28m were 0.29, 0.16 and 0.33 respectively, a little lower than those found in alluvium below The Straits, this due to the higher concentrations of heavy metals in the soils on Eller Beck Tr. 6. This greater toxicity is reflected of course in the more widespread occurrence of the indicator species on the transect.

Table 7.7 pH values at 6m intervals along Eller Beck Tr. 6.

<table>
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<th></th>
<th>0m</th>
<th>6m</th>
<th>12m</th>
<th>18m</th>
<th>24m</th>
<th>30m</th>
<th>36m</th>
<th>42m</th>
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</thead>
<tbody>
<tr>
<td>pH</td>
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<td>6.7</td>
<td>7.0</td>
<td>6.6</td>
<td>6.4</td>
<td>6.4</td>
<td>6.5</td>
<td>5.7</td>
</tr>
</tbody>
</table>

A large number of other species is associated with the indicator species on this transect line. Of particular interest are species such as Molinia caerulea, Filipendula ulmaria (L.) Maxim., Parnassia palustris and Succisa pratensis. These are species of relatively moist environments and reflect the habitat conditions on the metalliferous riparian sites of Eller Beck.

Cochlearia officinalis was present in one quadrat virtually in the stream bed. This species was noticed occasionally at Eller Beck, generally occurring in a stream side situation. It was suggested in Chapter 1 that this species might be considered to be an indicator in certain parts of the British Isles, it occurs on spoil in parts of Derbyshire (Chapter 6) and also in the Alston area (Chapter 10).

Eller Beck Tr. 1 (Fig. 7.7) will be considered in this section on the metalliferous communities adjoining Eller Beck but it is essentially a composite transect, it runs from an area covered by spoil to a region of alluvium adjoining Eller Beck. The transect may be divided into two parts, the area from Om to the wall just beyond
ELLER BECK: TRANSECT 1.
40m, the northern area as the transect ran roughly from north to south, and the region beyond the wall. Fig. 7.7 shows that the area to the south of the wall was floristically relatively diverse while few species were associated with the indicator plants and *Festuca ovina* to the north of the wall. This is especially the case in the region between the base of the spoil heap and the wall. The two zones are also reasonably distinct in terms of the relative proportions of lead and zinc found in their substrates. In many samples from the area to the north of the wall zinc occurs at a higher concentration than lead while the reverse is true to the south of the wall. It is probable that this dichotomy in the relative proportions of lead and zinc is related to the source of the metalliferous material. The area adjoining Eller Beck appears to be covered by metalliferous alluvium deposited by the stream and Eller Beck Tr. 6 above The Straits and the spot samples from immediately below demonstrate that it is normal for lead to be the heavy metal in highest concentration in the alluvium in this area. In contrast the substrate to the north of the wall is spoil, probably derived from the adit which enters Haw Bank at The Straits.

The first 15m of the transect line crosses a ridge of mine spoil, this ridge ran like a railway embankment along the foot of Haw Bank. The heavy metal levels in many samples from this material, especially in the case of lead, are not high and if much of the spoil of this ridge is of similar heavy metal content then it is difficult to appreciate why it was mined. It seems probable that in the area to the north of the wall on this transect line there are spoils from two discrete stages of mining. The spoil from about 15m to the wall is believed to represent the waste from the productive mining of a vein in the foot of Haw Bank while the ridge of spoil probably represents the material excavated from more or less barren rock in the course of driving an access level, probably to the Wet Grooves mines to the north (Fig. 7.3).
Table 7.8 shows that Ca/HM ratios along the transect line are generally below 1 and that the pH values of the substrates are normally below 7.0. Where the pH is above 7.0, in the first 20m, bare ground in many quadrats is above 75% (Fig. 7.7), while in the samples where the pH is below 6 Festuca ovina and other grasses, mainly Agrostis tenuis, generally approach cover values of nearly 100% and organic carbon levels are high, in excess of 25%. This appears again to be a situation where with increasing cover and the attendant increased organic matter levels in the soil pH values are tending to fall. It is noticeable from the calcium concentrations in Table 7.8 that where pH values are below 6.0 calcium levels are lower than in adjacent samples and in consequence the Ca/HM ratios are lower also. The places with the lowest Ca/HM ratios also appear to be those with high cover values of grasses such as F. ovina. This is probably not a case of the grasses being very successful in colonizing the most highly toxic areas but one of the developments of illusory high toxicity due to calcium leaching from the organic surface soil while heavy metals remain more or less unaffected. It is probable that for various reasons of which substrate toxicity is only one different areas of this transect line are at different stages in succession and the Ca/HM ratio is not very useful in a comparative sense.

Table 7.9 shows the concentrations of the bases and phosphorous at intervals along the transect line. It is evident that phosphorous concentrations are little different in the areas north and south of the wall and also that phosphorous is present in low amounts as compared to spoils from Derbyshire and the Mendips where 1,000 ppm appeared general. Potassium concentrations however are quite different in the areas north and south of the wall. The samples from 50, 60 and 70m contain potassium at about 2,000 ppm, the normal concentration for Eller Beck alluvium while the samples from the 0 to 40m region show potassium concentrations at quite high levels for spoil.
<table>
<thead>
<tr>
<th>Sample distance</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>Ca/HM</th>
<th>pH</th>
<th>Organic carbon</th>
</tr>
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<td>750</td>
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<td>5,500</td>
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<td>nd</td>
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</tr>
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<td>44,000</td>
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<td>nd</td>
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<td>nd</td>
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<tr>
<td>30m</td>
<td>31,900</td>
<td>27,000</td>
<td>7,250</td>
<td>0.16</td>
<td>5.2</td>
<td>30.5%</td>
</tr>
<tr>
<td>35m</td>
<td>58,500</td>
<td>85,000</td>
<td>40,250</td>
<td>0.40</td>
<td>6.7</td>
<td>nd</td>
</tr>
<tr>
<td>40m</td>
<td>44,000</td>
<td>22,900</td>
<td>42,500</td>
<td>0.97</td>
<td>6.7</td>
<td>nd</td>
</tr>
<tr>
<td>45m</td>
<td>33,000</td>
<td>14,900</td>
<td>8,250</td>
<td>0.20</td>
<td>5.8</td>
<td>28.6%</td>
</tr>
<tr>
<td>50m</td>
<td>13,500</td>
<td>6,200</td>
<td>12,500</td>
<td>0.71</td>
<td>6.2</td>
<td>nd</td>
</tr>
<tr>
<td>60m</td>
<td>27,200</td>
<td>14,300</td>
<td>12,500</td>
<td>0.46</td>
<td>6.4</td>
<td>23.3%</td>
</tr>
<tr>
<td>65m</td>
<td>30,700</td>
<td>5,900</td>
<td>6,500</td>
<td>0.19</td>
<td>5.3</td>
<td>nd</td>
</tr>
<tr>
<td>70m</td>
<td>28,700</td>
<td>9,700</td>
<td>9,950</td>
<td>0.34</td>
<td>6.5</td>
<td>nd</td>
</tr>
<tr>
<td>75m</td>
<td>14,200</td>
<td>1,000</td>
<td>10,150</td>
<td>0.69</td>
<td>6.6</td>
<td>nd</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample distance</th>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0m</td>
<td>195</td>
<td>3,010</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>10m</td>
<td>150</td>
<td>4,650</td>
<td>1,330</td>
<td>240</td>
</tr>
<tr>
<td>20m</td>
<td>225</td>
<td>7,900</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>30m</td>
<td>500</td>
<td>4,750</td>
<td>1,820</td>
<td>400</td>
</tr>
<tr>
<td>40m</td>
<td>225</td>
<td>4,750</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>50m</td>
<td>150</td>
<td>2,000</td>
<td>980</td>
<td>nd</td>
</tr>
<tr>
<td>60m</td>
<td>210</td>
<td>2,050</td>
<td>nd</td>
<td>380</td>
</tr>
<tr>
<td>70m</td>
<td>150</td>
<td>2,300</td>
<td>1,400</td>
<td>nd</td>
</tr>
</tbody>
</table>
The data from particle size analysis for two samples from this transect line in Table 7.10 suggests that the texture of the substrates in the areas north and south of the wall is not very different.

**Table 7.10**  Particle size analyses of soil from two sites on Eller Beck Tr. 1

<table>
<thead>
<tr>
<th>Sample distance</th>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>20m</td>
<td>12.9%</td>
<td>5.6%</td>
<td>23.6%</td>
<td>49.3%</td>
<td>10.3%</td>
<td>3.0%</td>
</tr>
<tr>
<td>60m</td>
<td>4.1%</td>
<td>6.3%</td>
<td>20.7%</td>
<td>34.3%</td>
<td>17.1%</td>
<td>23.3%</td>
</tr>
</tbody>
</table>

The analyses do not seem to suggest any obvious reason which accounts for the floristic differences between the areas to the north and south of the wall on this transect line. Substrate texture is not radically different and the nutrient status of the spoil is not lower than that of the alluvium. Heavy metal levels are somewhat higher to the north of the wall but so are calcium concentrations. Organic carbon levels are very similar in certain samples. Nevertheless the greater floristic diversity of the alluvium suggests that this substrate is in some way less inimical to plant growth. This matter requires further investigation.

**7.3**  The heavy metal communities of the spoil heaps and limestone scarps

In addition to their occurrence on the metalliferous alluvium at Eller Beck the indicator plants are found on the spoil heaps at several mines in the area and in places with above normal concentrations of heavy metal on the limestone scarps of Ivy Scar and Haw Bank.

Disher Force Tr. 5 (Fig. 7.8) crossed a spoil covered area a short distance to the north of the waterfall of Disher Force (Fig. 7.3). The transect line sampled the most northerly major site for *A. maritima* in the Eller Beck region.
GEOBOTANY

Cochlearia officinalis
Campanula rotundifolia
Anthoxanthum odoratum
Deschampsia caespitosa
Holcus lanatus
Festuca ovina
Agrostis tenuis
Armeria maritima
Minuartia verna

Bare Ground

GEOCHEMISTRY

120,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Pb
Zn
Cu

RELIEF

Debris Covered Slope
Limestone Cliff

DISHER FORCE: TRANSECT 5. Figure 7.8
In the first few metres of the transect line *Festuca ovina* and *Agrostis tenuis* were present at high cover values but beyond both species were infrequent and an area with much bare ground, occupied in places by *M. verna* and *A. maritima*, was encountered. The concentrations of both lead and zinc on this transect line are high and calcium is present in low amounts, the result is spoil of relatively high toxicity (Table 7.11). It is evident from Table 7.11 that the pH of the spoil is below 7.0 and also that organic carbon levels in the spoil, at around 7.5%, are higher than might be expected in spoil with very little plant cover, bare ground values in many quadrats approach 100%.

Although the apparent slope of the transect line on Fig. 7.8 is of the order of 10° the true slope of the ground surface was slightly oblique to the transect line, about north east to north west across the north to south trending transect. Drainage water from the spoil heaps to the north east (Fig. 7.2) appeared to flow across the transect line at times, a shallow channel crossed the line at 25m and a deeper one was present at 29m. The area between these two channels preserved in its surface the general slope of the transect line and sections through the spoil were exposed on the channel sides. These sections showed an upper layer, about 15cms in depth, stained by organic matter with lighter coloured spoil below. In places on the transect line tussocks of *A. maritima* stood 10cm
above the general surface of the spoil and sometimes up to 3m of
the top roots of individual plants were exposed.

pH values lower than 7.0 in an area with bare spoil, highish organic
carbon levels in bare spoil and the tussocks of _A. maritima_ standing
above the soil surface when considered in combination suggest that
considerable erosion of surface material has taken place on this
transect line. It appears possible that a fairly complete vegetation
cover of species such as _Festuca ovina, Agrostis tenuis, M. verna_
and _A. maritima_, and there is evidence of this sort of community in
the first few metres, has been almost completely removed, only
_A. maritima_ with its firm and deep tap roots resisting the process to
any extent. _M. verna_ has probably recolonized the bare spoil
subsequent to this episode of erosion.

Where, as apparently happened in this case, a closed vegetation
community develops over toxic material some of that development
almost certainly occurs within the less toxic upper horizon produced
by accumulation of organic matter. It seems probable that this
organic and less toxic upper horizon will not be firmly bound by the
roots of plants to the more toxic material at depth. Such an organic
horizon is probably susceptible to erosion. At the Hafna lead mine
near Betws-y-Coed the sloughing off of an organic mat on a
steeply sloping heap was very noticeable. On a spoil heap there can
be little incorporation of the organic matter into the deeper soil
layers by faunal action and organic mats developed on spoil
materials may be especially susceptible to erosion. Although water
is probably the responsible erosive factor on this particular
transect line it may be that accumulations of organic matter on
spoil heap slopes develop an inherent instability in the way that
peats on slopes are believed to do. This may be a significant
factor in the colonization of sloping debris materials even when
the spoil itself is not necessarily unstable.
Table 7.12  Particle size analysis of spoil from 18m on Disher Force Tr. 5

<table>
<thead>
<tr>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.9%</td>
<td>10.4%</td>
<td>14.3%</td>
<td>24.8%</td>
<td>12.5%</td>
<td>8.2%</td>
</tr>
</tbody>
</table>

It appears from Table 7.12 that the spoil from Disher Force Tr. 5 is more coarse grained than the alluvium of the Eller Beck flood plain (Table 7.4). The spoil areas to the north of Disher Force are probably a major source area for the metalliferous alluvium of Eller Beck and have, from the evidence from this transect, been subject to erosion subsequent to their deposition. The finer texture of the alluvium of the flood plain suggests that the coarse particles in the spoil are not transported in large quantities for any distance downstream. It may also be supposed that the coarse grained spoils of the spoil heaps are, on the basis of their texture, more susceptible to drought than the finer grained alluvium of the flood plain.

Table 7.13  Sodium, potassium, magnesium and phosphorous concentrations in spoil from 18m on Disher Force Tr. 5

<table>
<thead>
<tr>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>105</td>
<td>2,150</td>
<td>1,000</td>
<td>420</td>
</tr>
</tbody>
</table>

It is evident from Table 7.13 that the levels of nutrients such as potassium and phosphorous in the spoil from Disher Force Tr. 5 are very similar to those found in the alluvium of the flood plain of Eller Beck.

Thackthwaite Beck Tr. 2 (location on Fig. 7.3) was a short transect which crossed a small spoil heap with Festuca ovina, M. verna and T. alpestre. A.maritima was not present at this site. As Table 7.14 shows the spoil here is fairly toxic but not to the extent of that on Disher Force Tr. 5. The heavy metal concentrations in this spoil
Table 7.14  Heavy metal, calcium, Ca/HM ratio and pH determinations from Thackthwaite Beck Tr. 2

<table>
<thead>
<tr>
<th>Sample distance</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>Ca/HM</th>
<th>pH</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>0m</td>
<td>8,640</td>
<td>3,300</td>
<td>6,500</td>
<td>0.63</td>
<td>5.7</td>
<td>nd</td>
</tr>
<tr>
<td>5m</td>
<td>9,400</td>
<td>6,200</td>
<td>7,400</td>
<td>0.95</td>
<td>7.0</td>
<td>3.1%</td>
</tr>
<tr>
<td>10m</td>
<td>14,200</td>
<td>8,500</td>
<td>7,150</td>
<td>0.39</td>
<td>6.9</td>
<td>nd</td>
</tr>
</tbody>
</table>

are considerably lower than on Disher Force Tr. 5 but the calcium values are very similar. The low pH of the sample from 0m was associated with almost complete cover of *F. ovina*. The pH at 5m emphasises a point that was made for the Disher Force transect. In this sample which has a very similar calcium concentration to many from Disher Force Tr. 5 but has a lower organic carbon content the pH is 7.0; this supports the suggestion that was made for the Disher Force transect that the pH values between 6.0 and 7.0 there were related to the levels of organic carbon in the spoil.

Table 7.15  Sodium, potassium, magnesium and phosphorous concentrations in spoil from 5m on Thackthwaite Beck Tr. 2

<table>
<thead>
<tr>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>195</td>
<td>1,140</td>
<td>3,240</td>
<td>400</td>
</tr>
</tbody>
</table>

Magnesium (Table 7.15) is present in higher concentration in this sample than on Disher Force Tr. 5 but the potassium concentration is a little lower. The amount of phosphorous is virtually the same.

A textural analysis of the spoil from 5m (Table 7.16) shows that it is again coarse grained like that of Disher Force and it appears that much of the spoil in the Disher Force region may be relatively coarse in texture.
Table 7.16 Particle size analysis of spoil from 5m on Thackthwaite Beck Tr. 2

<table>
<thead>
<tr>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.8%</td>
<td>13.2%</td>
<td>16.8%</td>
<td>30.1%</td>
<td>12.0%</td>
<td>3.1%</td>
</tr>
</tbody>
</table>

On the scarp of Haw Bank above The Straits (Fig. 7.3) a small community of *M. verna* occurred near to the top of the slope. Haw Bank Tr. 8 (Fig. 7.9) ran horizontally along the limestone scarp and for this reason there is no plot of the relief on the transect diagram. The scarp at this point was relatively unstable and covered in places by blocky limestone debris. The strata of the Carboniferous Limestone here are more or less horizontal and successive beds outcrop on the face of the scarp, resulting in ledges up to 30cms wide. The slope across the transect line varied from 34° to 39°, generally being between 37° and 39°.

Above the area occupied by *M. verna* a trench appears to have been cut through the crest of the scarp. No spoil heaps were present near to this trench and it appears probable that the excavated rock was dumped onto the scarp slope although it was impossible to identify any such material amidst the mantle of slope deposits. There is a possibility therefore that the toxic area occupied by *M. verna* on Haw Bank is not a naturally outcropping mineralisation but due to metaliferous spoil dumped onto the slope. The very fact of the excavation on the crest of the scarp however suggests that a mineral vein occurs at this point and it is probable that the metalliferous area on the slope is the result of a naturally outcropping mineralisation augmented by spoil containing heavy metal.

Fig. 7.9 shows that *M. verna* is clearly associated with the zone of high lead concentrations. It is evident that lead is the major agent of toxicity, concentrations of zinc appear to increase only slightly on the anomalous area. Although cover values of associated species such as *Sesleria albicans* Kit. ex Schult. and *Helianthemum*
GEOBOTANY

<table>
<thead>
<tr>
<th>Species</th>
<th>Percentage Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galium pumilum</td>
<td>25</td>
</tr>
<tr>
<td>Lotus corniculatus</td>
<td>25</td>
</tr>
<tr>
<td>Helianthemum chamaecistus</td>
<td>75</td>
</tr>
<tr>
<td>Thymus drucei</td>
<td>25</td>
</tr>
<tr>
<td>Linum catharticum</td>
<td>25</td>
</tr>
<tr>
<td>Koeleria cristata</td>
<td>25</td>
</tr>
<tr>
<td>Sesleria albicans</td>
<td>75</td>
</tr>
<tr>
<td>Festuca ovina</td>
<td>75</td>
</tr>
<tr>
<td>Minuartia verna</td>
<td>25</td>
</tr>
<tr>
<td>Bare Ground</td>
<td>100</td>
</tr>
</tbody>
</table>

GEOCHEMISTRY

<table>
<thead>
<tr>
<th>Metals</th>
<th>Levels</th>
<th>Metres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb</td>
<td>40,000 ppm</td>
<td>30</td>
</tr>
<tr>
<td>Zn</td>
<td>20,000 ppm</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>30,000 ppm</td>
<td></td>
</tr>
</tbody>
</table>

HAW BANK: TRANSECT 8.

Figure 7.9
chamaecistus are a little lower in the anomalous zone and they tend also
to occur in fewer quadrats it does not appear that they are completely
excluded by excessive toxicity. It is clear from Table 7.17 that
Ca/HM ratios are lower in the zone of higher lead concentrations.

Table 7.17 Heavy metal, calcium, Ca/HM ratio and pH determinations
from Haw Bank Tr. 8

<table>
<thead>
<tr>
<th>Sample distance (m)</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>Ca/HM</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3,850</td>
<td>2,700</td>
<td>13,500</td>
<td>3.50</td>
<td>7.5</td>
</tr>
<tr>
<td>10</td>
<td>35,200</td>
<td>5,600</td>
<td>31,500</td>
<td>0.89</td>
<td>7.6</td>
</tr>
<tr>
<td>20</td>
<td>33,000</td>
<td>4,400</td>
<td>57,500</td>
<td>1.74</td>
<td>7.7</td>
</tr>
<tr>
<td>30</td>
<td>5,090</td>
<td>5,600</td>
<td>20,000</td>
<td>3.93</td>
<td>7.6</td>
</tr>
</tbody>
</table>

Phosphorous concentrations in the soil from Haw Bank Tr. 8 (Table 7.18) are a little higher than those found in many other metalliferous
substrates in the Eller Beck region while potassium and magnesium
are present in quite high amounts.

Table 7.18 Sodium, potassium, magnesium and phosphorous con-
centrations in soil from 20m on Haw Bank Tr. 8

<table>
<thead>
<tr>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>480</td>
<td>4,290</td>
<td>4,430</td>
<td>600</td>
</tr>
</tbody>
</table>

To the north of Haw Bank at the western end of Ivy Scar (Fig. 7.3),
just below the outcropping limestone which marks the scarp crest,
an extensive M. verna community occurs. At Haw Bank as just
discussed there was the possibility of some disturbance due to
mining, the community of M. verna on Ivy Scar appears to be one
entirely unaffected by mineral extraction, a community occurring
on a completely natural metalliferous habitat.
Ivy Scar Tr. 3 (Fig. 7.10) ran along Ivy Scar just below the crest and for this reason relief is not plotted on the transect diagram. The angle of slope across the transect line was generally between 35° and 40°, about the same as on Haw Bank Tr. 8. Fig. 7.10 shows that M. verna occupied the area of the main heavy metal anomaly in the 5m to 40m region and occurred again at small cover values in the region of 70m. It is reasonably clear that M. verna is restricted to those areas where both lead and zinc are present at high concentrations in the soil, the species is not associated with the high zinc concentrations beyond 80m.

It is evident from Table 7.19 that the areas where M. verna occurs at the highest cover values, represented by the samples from 20m and 30m, are those with soils with the lower Ca/ HM ratios.

Table 7.20 shows that the soil of Ivy Scar is much finer in texture than the spoils of the spoil heaps or the alluvium of the flood plain of Eller Beck. Thus although Ivy Scar is rather more exposed to wind and sun than most spoil heaps the greater moisture holding capacity of the soil which may be inferred from its texture will offset this to some extent.
Table 7.19  Heavy metal, calcium, Ca/HM ratio and pH determinations from Ivy Scar Tr. 3

<table>
<thead>
<tr>
<th>Sample distance</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>Ca/HM</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>2m</td>
<td>4,290</td>
<td>10,900</td>
<td>17,000</td>
<td>2.77</td>
<td>7.5</td>
</tr>
<tr>
<td>10m</td>
<td>6,200</td>
<td>12,100</td>
<td>44,500</td>
<td>3.63</td>
<td>7.6</td>
</tr>
<tr>
<td>20m</td>
<td>27,200</td>
<td>13,800</td>
<td>40,000</td>
<td>1.17</td>
<td>7.3</td>
</tr>
<tr>
<td>30m</td>
<td>21,800</td>
<td>13,200</td>
<td>44,500</td>
<td>1.57</td>
<td>7.6</td>
</tr>
<tr>
<td>40m</td>
<td>7,070</td>
<td>10,000</td>
<td>33,000</td>
<td>2.73</td>
<td>7.5</td>
</tr>
<tr>
<td>50m</td>
<td>1,730</td>
<td>13,800</td>
<td>15,500</td>
<td>1.80</td>
<td>7.5</td>
</tr>
<tr>
<td>60m</td>
<td>1,520</td>
<td>16,100</td>
<td>37,500</td>
<td>3.92</td>
<td>7.4</td>
</tr>
<tr>
<td>70m</td>
<td>8,410</td>
<td>17,800</td>
<td>16,650</td>
<td>0.96</td>
<td>7.5</td>
</tr>
<tr>
<td>80m</td>
<td>1,730</td>
<td>30,000</td>
<td>55,000</td>
<td>3.29</td>
<td>7.6</td>
</tr>
<tr>
<td>90m</td>
<td>1,420</td>
<td>16,800</td>
<td>18,000</td>
<td>1.80</td>
<td>7.7</td>
</tr>
<tr>
<td>102m</td>
<td>1,730</td>
<td>15,200</td>
<td>35,500</td>
<td>3.80</td>
<td>7.7</td>
</tr>
<tr>
<td>110m</td>
<td>1,420</td>
<td>8,500</td>
<td>15,750</td>
<td>2.78</td>
<td>7.7</td>
</tr>
<tr>
<td>130m</td>
<td>1,520</td>
<td>27,000</td>
<td>31,500</td>
<td>2.10</td>
<td>7.7</td>
</tr>
<tr>
<td>150m</td>
<td>1,970</td>
<td>9,100</td>
<td>42,500</td>
<td>6.52</td>
<td>7.7</td>
</tr>
</tbody>
</table>

Table 7.20  Particle size analysis of soil from 14m on Ivy Scar Tr. 3

<table>
<thead>
<tr>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0%</td>
<td>3.2%</td>
<td>7.6%</td>
<td>59.2%</td>
<td>19.1%</td>
<td>11.4%</td>
</tr>
</tbody>
</table>

As Table 7.21 indicates the soil on Ivy Scar is in its phosphorous and potassium concentrations entirely the opposite of that on Haw Bank. Here phosphorous is present in high concentration and potassium occurs at only 765 ppm.
Table 7.21 Sodium, potassium, magnesium and phosphorous concentrations in soil from 30m on Ivy Scar Tr. 3

<table>
<thead>
<tr>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>370</td>
<td>765</td>
<td>2,700</td>
<td>1,920</td>
</tr>
</tbody>
</table>

Thlaspi alpestre occurred in two places on Ivy Scar, neither of which was on the transect line. These two places, farther down the slope, were at points equivalent to 30m and 90m on the transect line.

7.4 Minor occurrences of the indicator species

In addition to their sites on the limestone scarps, spoil heaps and flood plain at Eller Beck the indicator species are found in diverse habitats, often represented by only a few plants. The spot samples which follow give an indication of the nature of some of these sites.

At Disher Force waterfall and upstream where the leat joins Eller Beck on its eastern side by means of a small waterfall (Fig. 7.3) A. maritima and M. verna grew in joints and cracks on the limestone faces of the falls. Sample 17 in Table 7.22 is from such a site on the Disher Force waterfall and Sample 21 is from the leat waterfall. It is clear that both samples contain considerable amounts of both lead and zinc. About 40m to the east of Disher Force is an area from which the peat, which covers the bench feature to the north of Haw Bank, has been eroded and here M. verna and T. alpestre grew in a soil (Sample 22, Table 7.22) which was a mixture of limestone and peat fragments and contained high concentrations of lead and, especially, zinc. The toxicity at this site is probably related to water carrying heavy metal percolating through the basal layers of the peat from the workings at the Wet Grooves Lead Mine (Fig. 7.3). These waters may also be responsible for the high heavy metal concentration in Sample 17 from just east of the waterfall at Disher Force, this is probably the place at which water seeping
Table 7.22  Heavy metal concentrations in spot samples from the Eller Beck region

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Copper (ppm)</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>77</td>
<td>6,440</td>
<td>10,300</td>
</tr>
<tr>
<td>16</td>
<td>400</td>
<td>21,800</td>
<td>41,000</td>
</tr>
<tr>
<td>17</td>
<td>35</td>
<td>10,000</td>
<td>15,800</td>
</tr>
<tr>
<td>18</td>
<td>77</td>
<td>90,000</td>
<td>68,000</td>
</tr>
<tr>
<td>19</td>
<td>67</td>
<td>34,200</td>
<td>24,000</td>
</tr>
<tr>
<td>21</td>
<td>47</td>
<td>31,500</td>
<td>29,100</td>
</tr>
<tr>
<td>22</td>
<td>87</td>
<td>8,250</td>
<td>19,700</td>
</tr>
<tr>
<td>23</td>
<td>15</td>
<td>1,000</td>
<td>770</td>
</tr>
<tr>
<td>24</td>
<td>26</td>
<td>1,900</td>
<td>300</td>
</tr>
</tbody>
</table>

from this direction joins Eller Beck. Certainly the high heavy metal content of Sample 17 does not appear to be related to mineralisation of a bedding plane in the limestone, the bedding plane on which the indicator plants grew at Disher Force was traced to the east and west of the fall and no indicator species were present. Samples 23 and 24 (Table 7.22) from west and east of the fall respectively do not show high levels of heavy metal.

At The Knot near the Wet Grooves Lead Mine A. maritima, T. alpestre and M. verna grew in a few places in pockets of soil on the outcropping limestone. The name, The Knot, is presumably an allusion to the appearance of the limestone at this point, the bedding is extremely confused and disturbed and it was impossible to be certain whether the site from which Sample 15 was taken had been affected by mining activity. It is thought however that it has been. The analyses for this site in Table 7.22 show moderate levels of lead and zinc to be present.
To the north of Disher Force a leat, no longer carrying water, leaves Eller Beck and trends approximately westwards. The banks of the leat provide a habitat for the indicator species *T. alpestre*, *M. verna* and *A. maritima*. All of them grew at the site from which Sample 18 was taken while only *A. maritima* was present farther west at the site of Sample 19. Both these samples (Table 7.22) show high amounts of both lead and zinc.

Sample 16 was of material from the road connecting Disher Force with the Wet Grooves Lead Mine. *M. verna* grew at this site. The heavy metal content of this material (Table 7.22) emphasises the point that in many mining areas the tracks are constructed from spoil, this fact at Eller Beck and in other mining fields is reflected in the presence of the indicator species on mining roads and tracks.

### 7.5 Observations on the indicator species and their habitats at Eller Beck

The Eller Beck region has been thoroughly searched for occurrences of the indicator species and they have been found growing in sites as diverse as streamside alluvium and limestone scarps. The various sites differ in the texture of their substrates, their nutrient status, their degree of stability and the extent to which they are the result of the activities of man but they all have one thing in common, relatively high concentrations of heavy metals in their soils. Some of the habitats are obviously the result of mining in the past, the spoil heaps clearly fall into this category. One site at least, Ivy Scar, where *M. verna* and *T. alpestre* grew, appears to have been unaffected by heavy metal mining and is a naturally occurring metal-liferous habitat.

In the discussion of the survival of the indicator species in Derbyshire from the immediate Post Glacial period to the time of the first mining activity when spoil heaps became available for colonization the "heavy metal refugium" was postulated. This was a place where
heavy metals were in sufficiently high concentration in the soil to
depress competition sufficiently to allow species such as *M. verna*
to occur and where also succession would be prevented by instability,
for with succession comes the accumulation of organic matter which
tends to immobilize the heavy metals in the soil and also improve the
physical conditions of the substrate, and both these developments are
to the advantage of the competitors of the indicator species.

On Eller Beck Tr. 1 the effects of such succession were evident,
considerable accumulations of organic matter occurred in the soil
and species such as *Festuca ovina* and *Agrostis tenuis* occupied the
spoil at high cover values to the exclusion of the indicator species.
The process of succession on Ivy Scar, however, is prevented by the
instability of the limestone screee. It is furthermore unlikely that
woody vegetation even in the past extended to the crest of the scarp
and it is believed that Ivy Scar is an example of one type of heavy
metal refugium.

It is the case, however, that the limestone scarp of Ivy Scar looks
like many others which flank the Yorkshire Dales. On closer
inspection the situation is little different, characteristic species of
limestone scarps such as *Sesleria albicans*, *Thymus drucei*,
*Helianthemum chamaecistus* and *Galium pumilum* Murray grow with
*M. verna* and *T. alpestre*. It was suggested in the discussion of the
distribution of the indicator species in Derbyshire that certain
kinds of metalliferous habitat might easily go unrecognised by field
observers and Ivy Scar clearly falls into this category.

As has been stated previously certain sites at Eller Beck are clearly
the result of the hand of man and one site, Ivy Scar, is almost
certainly entirely natural. Many other sites at Eller Beck fall
somewhere between the two. Haw Bank Tr. 8 may have been affected
by mining operations on the scarp crest above and the waterfall
at Disher Force with its high heavy metal concentrations in the
backwall appears to have been influenced by drainage waters containing heavy metal flowing from the large area of spoil heaps at the Wet Grooves Mine but the main example of the "semi-natural" habitat is the flood plain of Eller Beck. It cannot be supposed that the flood plain has been unaffected by the mining activity in the headwaters of the stream. There is abundant evidence at the present day of erosion of spoil heaps in the Disher Force area and in the past water from the beck would have been used for washing ore with the reasonable certainty that some of the finer metalliferous material would find its way into the stream by this means. On the other hand to the north of Disher Force Eller Beck flows in a well developed valley apparently along the line of a vein. Although the valley sides have been considerably modified in this area and it is impossible to define the situation before mining it is possible that some metalliferous alluvium found its way into the flood plain of Eller Beck at this stage due to natural agencies of erosion.

The bed load of Eller Beck today seems rich in heavy metal, stream sediment analyses from three places below The Straits showed lead and zinc to be present in concentrations between 10,000 and 50,000 ppm, the equal of those in the alluvium of the flood plain, and presumably deposition of metalliferous alluvium is occurring in places on the flood plain today.

In the account of the distribution of the indicator species on the flood plain of Eller Beck it was pointed out that their distribution conformed to the areas of high toxicity in the soil and that these high toxicities depressed competition from other species sufficiently to allow the indicator plants to exist. This is essentially a spatial interpretation, the temporal dimension of succession must also be considered.
On Ivy Scar at Eller Beck _M. verna_ occurs in what may be considered to be a stable metalliferous site in terms of succession. Some succession has taken place, there is evidence of the autogenic process (Odum, 1975) of organic matter accumulation in the soil but this appears to have come to balance with the allogenic process (Odum, 1975) of slope instability. On spoil heaps, at least those which are not actively eroding, autogenic processes, such as organic matter accumulation, will be dominant although their rate and perhaps also the degree of ultimate development of the vegetation community will be controlled by the toxicity of the substrate. Succession on stable spoil heaps will be a process which in most cases will proceed without much interference from allogenic forces. This will not be the case on the alluvium of Eller Beck for clearly the process of succession will be interrupted by the deposition of fresh toxic alluvium. It may be the case that the distribution of the indicator species at Eller Beck represents a balance between the autogenic forces of modification of the alluvium by community action and the allogenic forces of alluvium deposition. This would be a situation equivalent to the balance of allogenic and autogenic forces maintaining the long term stability of the Ivy Scar indicator plant community. A balance of autogenic and allogenic forces on the flood plain would require deposition of toxic material to occur in the same places on the flood plain at each alluvium depositing flood.

On parts of Eller Beck, especially in the area below The Straits the indicator plant communities tend to occur on the slip off slopes of the meanders (Fig. 7.1) and according to Schumm (1977) placer deposits of heavy minerals are characteristically found in such places. The deposition of heavy minerals on the slip off slopes of meanders is related to the reduction in the velocity of the stream in such areas and the segregation of the heavy minerals is an effect of their density. Given then that deposition of the heavy metals on the flood plain of Eller Beck will tend to occur at each depositional
episode in more or less the same places then there is a possibility that succession, the autogenic force, and deposition of new toxic alluvium, the allogenic force, are in dynamic equilibrium at many sites and thus the riparian indicator communities may represent a relatively stable system.

It seems more probable however that, even though the bed load of the stream contains substantial quantities of heavy metal at the present day, contemporary deposition of toxic alluvium is not as great as in the period when mining operations were in progress (ore washing must have contributed a lot of toxic alluvium to the stream system and this is not a factor in operation at the present day) and it seems probable that a slow succession is occurring in the Eller Beck riparian communities at the present time. Succession will be relatively slow, of course, due to the input of fresh alluvium.

These conclusions assume relative stability in the position of the channel. As Schumm (1977) points out a flood plain is usually composed primarily of lateral accretion deposits with an overlay of fine vertical accretion deposits. It is in the overlay of fine vertical deposits that the progressive decline in heavy metal concentrations away from the active channel, stated to be general by Hawkes and Webb (1962) and observed in this study at Eller Beck, will occur. This is easy to understand for at an overbank flood when alluvium is deposited over the flood plain velocities will be least farthest from the active channel and the relatively dense particles of heavy metal will not be transported to distant parts of the flood plain. At depth, however, in the alluvium which is the result of deposition by lateral accretion the distribution of the heavy metals will be less regular for they will tend to show concentrations related to segregation in placer deposits, placer deposits which essentially become "fossilised" by channel shift. It is not known whether such deposits occur in the areas of the flood plain of Eller Beck remote from the stream. Profile sampling would be necessary to detect them.
In relation to the problem of the stability of the stream channel on the Eller Beck flood plain the evidence available, the absence of abandoned stream courses and of indicator plant communities away from the river, suggests that the stream channel has not moved much in the recent past although as was discussed in relation to Eller Beck Tr. 6 there was an indication in that region of the development of a new channel for the stream. Because there is relative stability of the channel there will not be much interference by channel shifting with the process of succession which is believed to be occurring in the riparian indicator plant communities.

In the Eller Beck region *Armeria maritima* appears to be the most competitive of the indicator species. The plant occurs on the stream-side alluvium of Eller Beck on sites which appear to be considerably less toxic than those occupied by *Minuartia verna* and *Thlaspi alpestre*. Never theless the species does not occur in many of the toxic areas occupied by *M. verna* and *T. alpestre*. Comparison of Figs. 7.1 and 7.2 shows that *A. maritima* is largely absent from the spoil areas at Disher Force and the Wet Grooves Lead Mine and the plant occurred only infrequently on the ridge of bare spoil crossed by Eller Beck Tr. 1 at The Straits. The species is also absent from the limestone scarps of Haw Bank and Ivy Scar. It appears unlikely that this absence from the spoil heaps is due to toxicity or other chemical conditions of their environments. *A. maritima* was not present on Thackthwaite Beck Tr. 1 and the spoil there was very similar in heavy metal, calcium and major nutrient concentrations to the alluvium of the Eller Beck flood plain where the species occurred. It seems probable that *A. maritima* is absent from most of the spoil heaps and from the limestone scarps due to the relative aridity of these habitats. The major difference between the Thackthwaite Beck spoil and the alluvium of the flood plain of Eller Beck was one of texture, the alluvium was much finer grained than the spoil of the spoil heap and may be presumed to be more water retentive. The presence of
species such as *Parnassia palustris*, *Lychnis flos-cuculi* L., and *Succisa pratensis* on the flood plain along with *A. maritima* is further evidence that these are damp habitats. The only spoil heap region where *A. maritima* occurred in any abundance was the area of Disher Force Tr. 5 and there there was evidence of erosion of the spoil by water and this particular location appears to be wet due to local conditions of drainage.

In contrast to *A. maritima* *T. alpestre* and *M. verna* appear to occur in a wide variety of situations where heavy metal concentrations are high enough to depress competition sufficiently. *T. alpestre* however is generally of less frequent occurrence in the Eller Beck region than *M. verna*.

It has been suggested already that the limestone scarp of Ivy Scar will have provided a heavy metal refugium for *M. verna* and *T. alpestre* prior to the availability of metalliferous sites resulting from mining activity but clearly *A. maritima* does not occupy this habitat at the present day and may be presumed not to have done so in the past. This species appears to grow only in damp situations and if the possibility of long distance dispersal of *A. maritima* into the area from elsewhere is discounted then a heavy metal refugium which was also damp must be postulated for the species. Survival on the flood plain of Eller Beck does not appear very probable. The high heavy metal concentrations in the soil are probably in considerable measure related to relatively recent mining activity and even today heavy metal levels decrease rapidly away from the stream. Just below The Straits at the present day trees closely border Eller Beck and the indicator species are absent and it seems probable that trees bordering the stream will have been a more widespread situation in the past. A more likely survival site is one such as the Disher Force waterfall where *A. maritima* grew in the limestone cliff of the fall associated with a seepage of heavy metal bearing water. This type of site combines high toxicity with the instability which is
necessary to prevent succession. It was pointed out in the
discussion of the Disher Force site that this particular locality
may well have been affected by heavy metal movement in water
from the Wet Grooves area. Thus, unlike Ivy Scar, Disher Force
waterfall cannot be proposed as a probable example of a heavy
metal refugium but as an example of the sort of site in which a
refugium suitable for the survival of A. maritima from the immediate
Post Glacial when it was more widespread (Godwin, 1956) to the
onset of mining activity might be expected to occur.

Little mention has been made of Cochlearia officinalis which it has
been suggested might be considered to be an indicator. This plant
at Eller Beck was infrequently found in habitats where A. maritima
was more widespread. It appears that the species has similar
edaphic requirements to those of A. maritima and probably survived
in the area in the same type of refugium.
CHAPTER 8

THE MALHAM DISTRICT

8.1 Introduction

The Carboniferous Great Scar Limestone dominates the scenery of the Malham district (Fig. 8.1) and outcrops at Malham Cove where 75m of limestone are exposed and in the Proctor High Mark area to the east of Malham Tarn. Rocks of the Yoredale series overlie the Great Scar Limestone and the summits of the highest hills of the area such as Fountains Fell have a capping of Millstone Grit.

A general account of the Armorican earth movements in the Pennine area has already been given in Chapter 7 and will not be repeated here. Specifically however the Malham area is that of the Craven Faults and considerable movements along these faults have resulted in great vertical displacements of the strata. Many of the major morphological features of the district, Malham Tarn, Malham Cove and Gordale Scar among them, are in part the result of such faulting.

Glaciation has had an important effect upon the region. Varied deposits of glacial and periglacial origin mantle the area but there are few erratics and the drift appears to be of very local origin (Bullock, 1971).

Manley (1957) indicates that the climate of the Malham region is prevailinglly windy, humid and cloudy with a rather high frequency of days with measurable rainfall. Precipitation at Malham Tarn House averages about 1450mm annually, occurring on 220 days of the year. Manley (1957) calculated approximate temperature averages at Malham Tarn for a 30 year period by comparing the seven available years at the House with neighbouring stations. Taking into account the fact that Manley (1957) considered that due to local conditions temperatures at the House were about 0.2°C higher than might be
expected at the altitude and using his environmental lapse rate figure of 1°C temperature reduction for a rise in height of 154m, mean temperatures at Twinbottom Scar (488m), the main study area, may be calculated. They appear to be of the order of mean July temperature, 12.7°C, mean January 0.7°C. The length of the growing season at Twinbottom Scar appears to be from late April to late October. This is similar to Nenthead in the northern Pennines, altitude 458m, where Manley (1952) suggests that the growing season extends from the 18th of April to the 23rd of October. Manley (1952) pointed out that the climate of the northern Pennines was a severe one, the climate at Twinbottom Scar appears comparable.

It was indicated earlier that glacial and periglacial materials mantle much of the Malham region. According to Bullock (1971) the main contribution of the solid geological formations to soil parent material is through drift which is present in most places. Material of aeolian origin is an important parent material over the limestone. Leaching, as might be expected in view of the climate, is the predominant soil process and soils vary from leached brown earths where limestone is near to the surface to gleyed soils where any thickness of till is present. A thin peat is a normal upper horizon in many of the soils and a peaty organic horizon may accumulate even on areas of limestone pavement where the limestone of the clints is near to the surface.

The importance of leaching in soil formation results in acid soils in all places other than where limestone outcrops. True calcicole vegetation only occurs on the soils of limestone cliffs and screes and, according to Bullock (1971), where the limestone is obscured by drift of a depth of 50cms the plant associations are calcifuge ones. The transect diagrams at Twinbottom Scar presented later clearly illustrate the transition from calcicole to calcifuge communities away from a limestone outcrop.
LOCATIONS IN THE MALHAM DISTRICT

Figure 8.2
Pigott and Pigott (1959) have investigated the vegetation history of the area and this appears to be reasonably typical for the British Isles. *Armeria maritima* was noted from Zone III and *Pinus sylvestris* L. was widespread in Zone VI. Deciduous woodland covered much of the area later but in Zone VIIa occasional grains of *Helianthemum* suggest the continued existence of open habitats. An abrupt rise in herbaceous pollen during Zone VIIb is correlated with late Neolithic forest clearance and by Medieval times forest appears to have disappeared from much of the region, presumably due to a combination of the effects of continued woodland clearance and the deterioration of climate associated with the Sub-Atlantic period.

The Malham region has been the scene of long standing but fairly small scale mining activity. In the Proctor High Mark area (Fig. 8.1) the veins occur in the D2 limestone and are here approaching the lower limit of mineralisation and were therefore not very productive (Raistrick, 1947). The Proctor High Mark veins contained calcite in quantity but those of the Grizedale area (Fig. 8.1) were rich in quartz and iron pyrites. Important ore minerals at Proctor High Mark were galena and blende but at Grizedales and in the Pikedaw region galena, calamine, malachite and azurite were important.

The copper mines of the Malham district were to the west of the calamine workings in the Twinbottom Scar area (Fig. 8.2). They appear to have been worked in the Seventeenth Century. Hartley (1786) quoted in Raistrick (1947) states that the copper mines were derelict at the time of writing and he dated them as pre-1699. The old copper mines are visible today as a number of bell pits at the summit of the bridle path from Malham to Settle.

At the beginning of the Nineteenth Century calamine, occurring as a cave filling, was discovered in quantity at the Calamine Mine. According to Raistrick (1954) there is, and presumably was, no surface indication of its presence and the discovery was made
accidentally in the course of the re-opening of the Pikedaw copper mines. A shaft was dug to facilitate the extraction of the calamine. Much of the calamine appears to have been in the form of compacted precipitate or silt and not a vein material. In the course of the working of the calamine lead ores were also obtained from the veins encountered in the cavern (Raistrick, 1954).

Following the successful exploitation of the calamine at the Calamine mine, ochre, associated with calamine, was found at Twinbottom Scar (Fig. 8.2). At Twinbottom Scar a bedding plane solution cavity containing this material has been excavated over, according to Raistrick (1954), 100m of outcrop and downdip for up to 10m. The phase of calamine and ochre working in the region continued up to 1830 when the mines were abandoned.

Towards the end of the Nineteenth Century there was some working of ore on Malham Moor and the smelt mill near Malham Tarn (Fig. 8.1) is of this period. The results were poor and Raistrick (1938) suggests that only lead was smelted at the mill. With the cessation of smelting at the smelt mill mining activity in the Malham area drew to a close.

8.2 The metalliferous communities of Twinbottom Scar

Twinbottom Scar (Figs. 8.2 and 8.3) is a small limestone scarp, about 10m from crest to foot, the top 1 or 2m being limestone cliff, the remainder limestone scree with a drift covering. The feature is about 100m long, has an approximately north to south orientation and declines progressively at each end. The Scar may well be fault controlled. A bedding plane outcropping near the top of the Scar has been secondarily enriched by mineralising solutions and perhaps in places deposition occurred within solution caverns in the limestone as at the nearby calamine workings. Raistrick (1954) stated that the deposit had been worked over 100 yards of
THE TWINBOTTOM SCAR AND CALAMINE MINE AREA.

Transect locations.

Figure 8.3
outcrop but this gives a false impression for entrance to the bedding plane appears to have been restricted to two or three places. One of these is at the northern end of the Scar in the vicinity of Tr. 1 (Fig. 8.3) where the cavelike entrance to the workings is visible. Near this point but just to the north of the drystone wall a spoil heap suggests that an entrance may have been made there also but nothing is visible today. At the southern end of the Scar in the vicinity of Tr. 4 (Fig. 8.3) spoil heaps again suggest an entrance to the workings although no sign remains of the mine itself. The intervening area appears to be undisturbed, no spoil heaps or mine entrances are visible, and the Scar therefore offers an opportunity to investigate sites of undisturbed mineralisation.

Twinbottom Scar Tr. 1 crossed the limestone scarp just to the south of the wall (Fig. 8.3). The diagram (Fig. 8.4) covers only the region from 30 to 90m. Soil samples were taken in the areas from 0 to 30m and from 90 to 120m but in both cases heavy metal concentrations were similar to the low heavy metal values of the background areas of Fig. 8.4.

The transect crossed the major spoil heap at Twinbottom. At the base of the scarp a bedding plane has been excavated to form a small cave about 1m high and material from these working mantles the slope below. Fig. 8.4 indicates the transition from a calcifuge community with Juncus squarrosus L. and Nardus stricta in the region of 30m to a calcicol community with the species Sesleria albicans and Scabiosa columbaria L. on the limestone cliff. The pH at 30m was 3.8 increasing to 5.3 and 44m and 6.4 at 48m. In this region heavy metal concentrations are low and the vegetation is apparently controlled by the increasing influence of the Carboniferous Limestone bedrock.
It is clear from Fig. 8.4 that the high heavy metal concentrations on the transect line are within the area of the excavated spoil, although the sample from 44m on the limestone cliff shows higher heavy metal values than those of background areas and provides evidence of some mineralisation within the limestone. In the Malham area copper is often present in greater concentration than the normal background amounts of 100 or 200 ppm for Carboniferous Limestone spoil. On this transect line a maximum copper concentration of 1,870 ppm occurred in the sample from 54m. In the calculations of the Ca/HM ratio shown in Table 8.1 copper, when in concentrations greater than 300 ppm, has been included in the manner described in Chapter 3. It is evident from Fig. 8.4 that zinc concentrations in this spoil are very high and as Table 8.1 shows calcium levels, as compared to spoil from Derbyshire and the Mendips, are low. The result is spoil with a low Ca/HM ratio and high toxicity. The low Ca/HM ratios in many samples are not the result of substantial organic matter accumulation in the spoil; as Table 8.1 shows the pH of the spoil at 54m was 7.2 and as Table 8.3 demonstrates the organic carbon level in that sample was only 1.5%.

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Calcium (ppm)</th>
<th>Ca/HM</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>46m</td>
<td>25,000</td>
<td>0.74</td>
<td>nd</td>
</tr>
<tr>
<td>48m</td>
<td>18,000</td>
<td>0.34</td>
<td>6.4</td>
</tr>
<tr>
<td>52m</td>
<td>13,500</td>
<td>0.15</td>
<td>nd</td>
</tr>
<tr>
<td>54m</td>
<td>9,200</td>
<td>0.09</td>
<td>7.2</td>
</tr>
<tr>
<td>56m</td>
<td>13,750</td>
<td>0.15</td>
<td>nd</td>
</tr>
<tr>
<td>58m</td>
<td>13,500</td>
<td>0.17</td>
<td>7.0</td>
</tr>
</tbody>
</table>
Table 8.2 demonstrates that spoil from this transect line is low in potassium in comparison with spoils from other orefields. The phosphorous concentration, although a little higher than in many samples from Eller Beck, is lower than that of many spoils from Derbyshire, the Mendips and the Aachen-Liege orefield. Magnesium too is low by the standards of spoil elsewhere and the overall impression is of a spoil of low nutrient status.

Table 8.2  Sodium, potassium, magnesium and phosphorous concentrations in spoil from 56m on Twinbottom Scar Tr. 1

<table>
<thead>
<tr>
<th></th>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>125</td>
<td>530</td>
<td>950</td>
<td>720</td>
</tr>
</tbody>
</table>

Particle size analysis of the spoil (Table 8.3) from this transect shows it to be relatively coarse in texture, clay, especially, is present in a low amount.

Table 8.3  Particle size analysis of spoil from 54m on Twinbottom Scar Tr. 1.

<table>
<thead>
<tr>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.4%</td>
<td>10.3%</td>
<td>19.2%</td>
<td>31.1%</td>
<td>5.2%</td>
<td>1.5%</td>
</tr>
</tbody>
</table>

On this spoil heap, as Fig. 8.4 shows, only three species are present in the most toxic regions, Minuartia verna, Thlaspi alpestre and Festuca rubra and of these only the first two are important. In the area of the highest zinc concentrations and the lowest Ca/HM ratios, around 54m, two quadrats are without plant cover and the adjoining quadrats show only small cover values of M. verna and T. alpestre. It appears that in this region even the indicator species are affected by the high toxicity. Beyond 58m zinc concentrations decrease rapidly and M. verna, especially, appears to benefit from the reduced
toxicity and reaches cover values of nearly 50%. With the continued decrease in toxicity as the border of the spoil material is reached *M. verna* is rapidly replaced by grasses such as *Festuca ovina* and *Agrostis tenuis* but *T. alpestre* persists into the base of the depression.

A noticeable feature of this transect line is that in the base of the depression both zinc and lead increase slightly in concentration before decreasing to background levels. This was also a feature of other transects at Twinbottom Scar and will be returned to.

Twinbottom Scar Tr. 4 crossed a spoil heap at the southern end of Twinbottom Scar (Fig. 8.3). As Fig. 8.5 shows debris from mining was in a very similar place to that of Tr. 1 (Fig. 8.4). Unlike Tr. 1 however the entrance to the workings is not visible but was probably in the region of 5m at the foot of the steep section of the limestone cliff. The spoil has been spread from some distance downslope.

Copper concentrations in the spoil on Tr. 4 are lower than on Tr. 1, the maximum value is 625 ppm at 12m. Zinc levels too are lower with a maximum of 77,000 ppm at 12m but lead is generally in higher concentration with a maximum of 50,900 ppm at 10m. These generally lower heavy metal concentrations appear to be offset by the lower calcium concentrations in the spoil at this site and as Table 8.4 shows the Ca/HM ratios of the spoil are very similar to those of Tr. 1 (Table 8.1). pH values in the spoil (Table 8.4) are comparable to those of Tr. 1.

The nutrient status of the spoil on this transect line (Table 8.5) is again low, potassium and magnesium are present in lower concentrations than on Tr. 1 (Table 8.2) but the phosphorous concentration is a little higher.
GEOBOTANY

Asplenium viride
Campanula rotundifolia
Cerastium vulgatum
Trifolium repens
Hesperidium sp.
Galium pumilium
Galium saxatile
Viola lutea
Thymus drucei
Numex acetosa
Carex caryophyllea
Carex binevis
Nardus stricta
Koeleria cristata
Deschampsia flexuosa
Holcus lanatus
Anthoxantium odoratum
Poa annua
Agrostis tenus
Sesleria albicans
Festuca rubra
Festuca ovina
Thlaspi alpestre
Minuartia verna

GEOCHEMISTRY

RELIEF

TWINBOTTOM SCAR.
TRANSECT 4.

Figure 8.5
Table 8.4 Calcium, Ca/HM ratio and pH determinations from the spoil area of Twinbottom Scar Tr. 4

<table>
<thead>
<tr>
<th>Sample point</th>
<th>6m</th>
<th>8m</th>
<th>10m</th>
<th>12m</th>
<th>16m</th>
<th>18m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (ppm)</td>
<td>4,250</td>
<td>5,000</td>
<td>5,500</td>
<td>4,850</td>
<td>3,550</td>
<td>2,000</td>
</tr>
<tr>
<td>Ca/HM</td>
<td>0.15</td>
<td>0.12</td>
<td>0.07</td>
<td>0.06</td>
<td>0.15</td>
<td>0.09</td>
</tr>
<tr>
<td>pH</td>
<td>nd</td>
<td>7.1</td>
<td>6.9</td>
<td>7.0</td>
<td>6.7</td>
<td>nd</td>
</tr>
</tbody>
</table>

Table 8.5 Sodium, potassium, magnesium and phosphorous levels in spoil from 12m on Twinbottom Scar Tr. 4

<table>
<thead>
<tr>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>350</td>
<td>660</td>
<td>980</td>
</tr>
</tbody>
</table>

Particle size analysis of the spoil from Tr. 4 (Table 8.6) demonstrates that it is very different in texture from the spoil on Tr. 1 (Table 8.3). It contains much more silt and clay and it is surprising that spoil from essentially the same mineralisation should be so different.

Table 8.6 Particle size analysis of spoil from 10m on Twinbottom Scar Tr. 4

<table>
<thead>
<tr>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.7%</td>
<td>4.7%</td>
<td>12.0%</td>
<td>55.4%</td>
<td>18.6%</td>
<td>5.1%</td>
</tr>
</tbody>
</table>

It is evident from Fig. 8.5 that five species occurred in the spoil area on this transect line, M. verna, T. alpestre, Poa annua L., Rumex acetosa and Festuca rubra. Although R. acetosa is present on spoil in other mining areas abundant occurrence in the most toxic region is unusual. Even though the Ca/HM ratios of the spoil on Tr. 1 and Tr. 4 are very similar more species are present on the spoil on Tr. 4 and some of these occur at greater average cover values than on Tr. 1. M. verna for example occurs on 17 quadrats on Tr. 4.
at a mean cover value of 19.4%; for the 18 quadrats occupied by the species on the spoil of Tr. 1 the average cover is 12.3%. The means of the two samples differ significantly ($P < 0.001$). Bare ground in many of the quadrats in the spoil are on Tr. 4 is less than in the equivalent region on Tr. 1. On the assumption that equal time has been available for colonization by plants, reasonably certain in this locality, some factor seems more favourable for vegetation growth on the spoil of Tr. 4.

The spoil of Tr. 1 was rather more disturbed than that of Tr. 4. The spoil heap on Tr. 1 was frequently crossed by cattle which descended Twinbottom Scar at the northern end and also there was some disturbance by sheep which used the cave on Tr. 1 for shelter. This will have the effect of retarding succession on Tr. 1 but it appears unlikely that all the vegetation differences between the two areas are due to disturbance. The only other major difference between the spoil heaps is one of substrate texture; it appears possible that a proportion of the observed differences between the vegetation of the heaps may be ascribed to the rather more favourable textural characteristics of the spoil of Tr. 4.

About 20m to the south of Tr. 1 (Fig. 8.3) Twinbottom Scar Tr. 5 (Fig. 8.6) crossed an area of mineralisation unaffected by mining activity. In the first two quadrats copper, lead and zinc levels are low and calcicole species such as Galium pumilum and Sesleria albicans occupied pockets of soil in the limestone pavement and cliff. At 3m however the zinc concentrations of the soil increases to 74,000 ppm, this coinciding with a mineralised bedding plane in the limestone. This concentration of zinc is almost equal to that of the spoil on Tr. 4 and contrasts with the undisturbed mineralisations at Eller Beck in Wensleydale where heavy metal levels in the undisturbed sites were often much lower than on adjacent areas of spoil. This site is quite significant as an example of an undisturbed mineralisation of very high heavy metal concentration. However, as Fig. 8.6 shows, in contrast to the spoil in Twinbottom, lead and copper concentrations at 3m are not high.
TWINBOTTOM SCAR. TR 5.

**GEOBOTANY**

- Astragalus melilotiformis
- Cerastium vulgatum
- Campanula rotundifolia
- Lotus corniculatus
- Potentilla erecta
- Vulpia lutea
- Thymus douciar
- Rhodiola repens
- Rumex acetosa
- Galium triflorum
- Gentian saxatilis
- Carex bifurca
- Anticyon squarrosus
- Juncus effusus
- Nemophila sericea
- Gastrodiospora campestris
- Gastrodiospora floribunda
- Briza media
- Holcus lanatus
- Anthoxanthum odoratum
- Serratula tinctoria
- Agrostis tenuis
- Festuca paniculata
- Festuca rubra
- Festuca alpina
- Thlaspi alpestre
- Minsurtia verna

**GEOCHEMISTRY**

**RELIEF**

Figure 8.6
Table 8.7 Calcium, Ca/HM ratio and pH determinations from the cliff on Twinbottom Scar Tr. 5

<table>
<thead>
<tr>
<th>Sample point</th>
<th>3m</th>
<th>4m</th>
<th>5m</th>
<th>6m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (ppm)</td>
<td>3,550</td>
<td>2,770</td>
<td>3,150</td>
<td>2,700</td>
</tr>
<tr>
<td>Ca/HM</td>
<td>0.08</td>
<td>0.15</td>
<td>0.38</td>
<td>0.76</td>
</tr>
<tr>
<td>pH</td>
<td>6.9</td>
<td>6.8</td>
<td>6.0</td>
<td>5.1</td>
</tr>
</tbody>
</table>

Table 8.7 demonstrates that calcium concentrations are relatively low in the area occupied by *M. verna* on Tr. 5 as are the Ca/HM ratios at 3 and 4m. The soil at 4m contained 12.1% organic carbon and the relatively low pH at 6m (Table 8.7) suggests even greater organic matter accumulation. Because of this organic matter accumulation and the attendant immobilisation of heavy metal the Ca/HM ratios are not comparable with those of the spoil heaps. As has been pointed out before the Ca/HM ratio becomes much less useful once there is substantial organic matter accumulation in the soil.

*M. verna* on this transect line occurred solely within the area of high zinc concentration associated with the steep limestone scarp. The quadrat with the highest cover of *M. verna* was that from 5 to 6m, not the area of maximum zinc concentration. It may be that the lower cover values for *M. verna* in the 3 to 5m region are related to the high toxicity of the soil, it appeared that on Tr. 1 the species was absent from the most toxic areas, but a very important factor affecting the distribution of the species in this area will be the difficulty of colonizing the steep limestone scarp.

Potassium and magnesium (Table 8.8) in the area on Tr. 5 occupied by *M. verna* were at lower concentrations than those of the spoil of Tr. 1 and Tr. 4 (Tables 8.2 and 8.5) but phosphorous was present in a greater amount.
Table 8.8  Sodium, potassium, magnesium and phosphorous determinations of soil from 5m on Twinbottom Scar Tr. 5

<table>
<thead>
<tr>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>275</td>
<td>320</td>
<td>1140</td>
</tr>
</tbody>
</table>

Fig. 8.6 demonstrates that both lead and zinc increase in concentration in the soil of the floor of the depression. The lead concentration in the sample from 22m is 8,080 ppm and, assuming that lead has been transported into the base of the depression, a directly lateral source does not seem probable; on Tr. 5 the anomalous area in the 3 to 6m region contains little lead. The depression of Twinbottom slopes from north to south and the spoil heaps in the Tr. 1 area (Fig. 8.3) seem a probable source. As on Tr. 1 and Tr. 4 lead exceeds zinc in concentration in the soil of the floor of the depression even though zinc is the predominant heavy metal of the mineralisation.

The heavy metal accumulation between 20 and 26m on Tr. 5 appears to be sufficient to provide a habitat for *T. alpestre*. The pH of the soil at 24m is 4.1 and even though the organic carbon content of the soil at this point was over 25% it is very probable that at the low pH the soil is quite toxic. It was suggested for the Aachen-Liege ore-field and the Mendips that *T. alpestre* was able to grow in the sites of lower pH and high heavy metal concentrations which appeared to be too toxic for *M. verna*. This particular site appears to provide another example of this.

Twinbottom Scar Tr. 3 (Fig. 8.7) was located between Tr. 1 and Tr. 4, a short distance down Twinbottom from Tr. 5 (Fig. 8.3). As on Tr. 5 the scarp on the transect line was unaffected by mining operations. The background areas of limestone pavement and acidic grassland show the low heavy metal values seen on the other transect lines. In contrast to Tr. 5 where very high zinc concentrations
GEOBOTANY

Cerasium vulgarum
Arabis hirsuta
Arabis hirsuta
Galium saxatile
Galium pyrenaicum
Potentilla erecta
Trifolium pratense
Trifolium repens
Plantago lanceolata
Thymus serpyllum
Viola kerri
Centaurea montana
Loelia campestris
Anemone nemorosa
Anemone affinis
Nelumbo nucifera
Rumex crispus
Briza media
Nelumbium fasciculatum
Anthericum liliaceum
Sesleria albicans
Nepeta stricta
Deschampsia flexuosa
Deschampsia caespitosa
Agritis tenax
Festuca rubra
Festuca ovina
Ilex aquifolium
Masarnia versicolor
Bare Ground

GEOCHEMISTRY

RELIEF

TWINBOTTOM SCAR. TRANSECT 3. Figure 8.7
occurred in the anomalous area zinc on this transect line reaches a level of only 12,000 ppm. As on Tr. 5 lead levels are low over the anomaly.

The pH of the soil at 18m, within the area occupied by _M. verna_ and _T. alpestre_ was 5.6 and the organic carbon content of the soil was 17.2%. This pH is lower than that found in spoils on which _M. verna_ occurs but this sample also contains a substantial amount of organic matter. This organic matter will have the effect of immobilising some of the zinc. On many of the spoil materials considered elsewhere the relationship between calcium and heavy metal concentrations has been shown to be a useful determinant of toxicity. In this particular site the toxicity is probably a reflection of a relationship between pH, organic matter concentration and zinc levels, quite a different situation. At Dolfrwynog bog in Wales _M. verna_ occurs on peaty soil with a pH of 5.5 and containing copper. The relationship between the occurrence of _M. verna_ and heavy metal concentrations in organic soil will be discussed in the next chapter.

It is apparent from Fig. 8.7 that on Tr. 3 lead only slightly exceeds zinc in concentration in the floor of Twinbottom. It is the case also that both lead and zinc do not substantially increase in concentration above background levels in the depression. This is in contrast to the other transects.

It seems probable that in the floor of the depression at Twinbottom there is some movement of lead and zinc in solution. Although, as Hawkes and Webb (1962) point out, zinc is generally more mobile than lead, lead appears to be present in great concentration in the floor of Twinbottom. Presumably the greater mobility of zinc is resulting in it being transported out of the depression while the less mobile lead is not migrating so far. Thus lead is accumulating in substantial amounts in the depression floor.
Tr. 3 however does not show accumulations of the heavy metals in the depression while Transects 1 and 5 do. Assuming that the spoil heap at Tr. 1 and probably also the one just to the north of the wall (Fig. 8.3) are major sources for the lead and zinc then it is apparent that the heavy metals moving southwards down the depression do not reach Tr. 3. Fig. 8.3 shows a pothole just south of the line of Tr. 5 and it seems probable that this pothole intercepts the water carrying lead and zinc down the depression and directs it into the subterranean drainage system. If this is the case then the lead anomaly in the depression floor on the line of Tr. 4 is presumably derived for the most part from the spoil heap on that transect line.

If, as seems the case, the spoil heaps are a major source of the heavy metal contamination of the depression floor then it is apparent that the T. alpestre habitat associated with this contamination on Tr. 5 (Fig. 8.6) is another example of the "semi-natural" metalliferous habitat as demonstrated in the Eller Beck region. It is clear that as far as the indicator species are concerned the legacy of mining often extends beyond the confines of the spoil heap.

The transects of Twinbottom Scar also provide some indication of variation in the location of the zone of maximum mineralisation on the cliff. The dip of the limestone in Twinbottom Scar is towards the east and the top of the cliff is more or less horizontal. In consequence the bedding planes in the limestone are parallel with the cliff top. Raistrick (1954) gave an impression of mineralisation within a bedding plane of the limestone but the transects suggest some vertical variability in the zone of maximum mineralisation. Transects 1 and 5 are quite close together but the point of maximum mineralisation on Tr. 5 (Fig. 8.6) is quite close to the top of the cliff while on Tr. 1 (Fig. 8.4) the excavated bedding plane is much lower down. On Tr. 3 (Fig. 8.7) the maximum heavy metal values again occur low down on the limestone outcrop. It may be that on Tr. 5 (Fig. 8.6) further mineralisation is concealed by drift and
scree which has been removed on Tr. 1 but it seems reasonably certain that the high heavy metal levels virtually at the cliff top on Tr. 5 represent an upward extension in this region of the zone of mineralisation.

Southwards from the region of Tr. 4 on Twinbottom Scar the prominent limestone cliff becomes subdued and the indicator communities are reduced to infrequent occurrences of isolated individuals. Tr. 6 (Fig. 8.8, location on Fig. 8.3) crossed one such area. As Fig. 8.8 shows the first 25m of the transect traversed a region of limestone pavement but there were also pockets of acidic soil. The variability in soil pH is seen in the results for 4, 12 and 20m, pH 7.1, 5.7 and 4.3 respectively. In consequence both calcicole and calcifuge species are present in this region. Within this area lead and zinc are present at background values for the Twinbottom region but at 30m zinc increases in concentration to 2,240 ppm and a few individuals of *M. verna* occurred in the associated quadrat. The pH of the soil at this site was 6.7 and as Table 8.9 shows the nutrient status was similar to that of the area occupied by *M. verna* on Tr. 5 (Table 8.8)

<table>
<thead>
<tr>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>105</td>
<td>350</td>
<td>510</td>
<td>1020</td>
</tr>
</tbody>
</table>

The *M. verna* occurrence on this transect line, as judged by the bw cover value, is a marginal one but it is apparent that a small increase in zinc concentration, where it is associated with some instability as it is here, is sufficient to swing the competitive balance in favour of *M. verna*.
GEOBOTANY

A splénium trichomanes
Urtica dioica
Viola lutea
Campanula rotundifolia
Cerastium vulgatum
Galium saxatile
Achillea millefolium
Trifolium repens
Thymus drucei
Rumex acetosa
Plantago lanceolata
Carex caryophylla
Nardus stricta
Deschampsia caespitosa
Deschampsia flexuosa
Poa annua
Cynosurus cristatus
Koeleria cristata
Briza media
Holcus lanatus
Anthosanthemum odoratum
Sesleria albicans
Agrostis tenuis
Festuca rubra
Festuca ovina
Minuartia verna
Bare Ground

GEOCHEMISTRY

RELIEF

TWINBOTTOM SCAR.
TRANSECT 6.

Figure 8.8
At 34m on this transect lead increases in concentration to 2,850 ppm and the pH was 4.9. This increase of lead in the soil of depression floor is similar to those seen further north in Twinbottom although the source of the lead at this point is uncertain. *T. alpestre*, the usual indicator species in this situation, was not present.

8.3 The metalliferous communities at the Calamine Mine

Calamine occurring as a cave filling was discovered in the Malham area at the beginning of the Nineteenth Century (Raistrick, 1954) and a shaft was dug by the side of the Settle to Malham bridle-path to facilitate its removal, this is the shaft shown adjoining Tr. 8 on Fig. 8.3. Tr. 8 (Fig. 8.9) ran northwards from the northern end of the most southerly spoil heap on Fig. 8.3. A subsidiary transect, Tr. 8b, ran southwards from the 0m point of Tr. 8. Tr. 8b has not been included on Fig. 8.9 but will be discussed in due course.

It is apparent from Fig. 8.9 that Tr. 8 crossed two pronounced heavy metal anomalies, corresponding to the spoil heaps on Fig. 8.3. The ground surface along the transect line was almost horizontal and the relief has not been included on the diagram. As Fig. 8.9 shows zinc exceeds lead in concentration in the anomalous areas, this was also the case in the Twinbottom area, and the highest heavy metal levels are attained in the spoil heap adjoining the shaft of the Calamine Mine. In the background region between the two anomalies lead slightly exceeds zinc in concentration.

The spoil on this transect line is rather variable in calcium concentrations (Table 8.10) and the sample from 140m with 71,500 ppm is unusual for the region.
Table 8.10  Calcium, sodium, potassium, magnesium and pH determinations from the Calamine Mine Tr. 8.

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Calcium (ppm)</th>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0m</td>
<td>8,450</td>
<td>175</td>
<td>990</td>
<td>750</td>
<td>6.5</td>
</tr>
<tr>
<td>10m</td>
<td>7,500</td>
<td>175</td>
<td>1,255</td>
<td>nd</td>
<td>6.8</td>
</tr>
<tr>
<td>20m</td>
<td>1,350</td>
<td>105</td>
<td>1,100</td>
<td>950</td>
<td>4.5</td>
</tr>
<tr>
<td>30m</td>
<td>22,500</td>
<td>240</td>
<td>1,100</td>
<td>nd</td>
<td>7.1</td>
</tr>
<tr>
<td>40m</td>
<td>2,500</td>
<td>195</td>
<td>1,055</td>
<td>1,120</td>
<td>7.0</td>
</tr>
<tr>
<td>50m</td>
<td>2,250</td>
<td>175</td>
<td>600</td>
<td>nd</td>
<td>3.5</td>
</tr>
<tr>
<td>60m</td>
<td>1,800</td>
<td>175</td>
<td>730</td>
<td>540</td>
<td>3.7</td>
</tr>
<tr>
<td>70m</td>
<td>1,800</td>
<td>175</td>
<td>530</td>
<td>nd</td>
<td>3.6</td>
</tr>
<tr>
<td>80m</td>
<td>3,550</td>
<td>150</td>
<td>530</td>
<td>400</td>
<td>4.0</td>
</tr>
<tr>
<td>100m</td>
<td>1,800</td>
<td>150</td>
<td>530</td>
<td>540</td>
<td>3.8</td>
</tr>
<tr>
<td>110m</td>
<td>2,350</td>
<td>105</td>
<td>400</td>
<td>nd</td>
<td>6.1</td>
</tr>
<tr>
<td>120m</td>
<td>5,500</td>
<td>150</td>
<td>850</td>
<td>660</td>
<td>5.3</td>
</tr>
<tr>
<td>130m</td>
<td>20,000</td>
<td>225</td>
<td>810</td>
<td>nd</td>
<td>6.8</td>
</tr>
<tr>
<td>140m</td>
<td>71,500</td>
<td>370</td>
<td>730</td>
<td>890</td>
<td>6.8</td>
</tr>
<tr>
<td>150m</td>
<td>8,200</td>
<td>125</td>
<td>890</td>
<td>nd</td>
<td>4.0</td>
</tr>
</tbody>
</table>

The Ca/HM ratios for the spoil areas, which again include copper in the calculation, are shown in Table 8.11. As comparison with Table 8.10 shows the samples are from areas where the pH is near to 7.0 and thus from samples where the Ca/HM ratio may be expected to provide a reasonable guide to toxicity. Certain of the samples from the spoil heaps at the Calamine Mine appears to be less toxic than those from Twinbottom Scar Tr. 1 (Table 8.1) but much of the spoil nevertheless is quite toxic by the standard of, for example, the spoil from Derbyshire with its higher calcium concentrations.
Table 8.11  Ca/HM ratios for spoil from the Calamine Mine Tr. 8

<table>
<thead>
<tr>
<th>Sample point</th>
<th>0m</th>
<th>10m</th>
<th>30m</th>
<th>40m</th>
<th>130m</th>
<th>140m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca/HM</td>
<td>0.27</td>
<td>0.98</td>
<td>0.36</td>
<td>0.13</td>
<td>0.25</td>
<td>1.38</td>
</tr>
</tbody>
</table>

This relatively high toxicity is reflected in the presence of only a few species in the spoil areas. Only *T. alpestre* and *M. verna* are regularly present in the regions of highest toxicity. It is noticeable from Fig. 8.9 that *M. verna* is present at lower cover values in the anomalous zone around 130m than in the metalliferous region in the first 40m.

Although heavy metal levels are somewhat higher in the neighbourhood of 130m it appears from the Ca/HM ratios in Table 8.11 that the toxicity is not greater. It is probable that the bare ground in this region, which in many quadrats approaches 100%, is due to trampling. As Fig. 8.3 shows the Malham to Settle bridle-path, much used by walkers, crosses the spoil heap and the shaft obviously excites considerable interest.

The Calamine Mine Tr. 8b crossed a very bare spoil heap, the base of a washing floor, to the south of the 0m point of Tr. 8. Twenty four samples from this heap showed very high zinc levels and quite high lead and copper concentrations. Calcium was present in low amounts. Table 8.12 shows the means and ranges of heavy metal and calcium concentrations on this transect and it is clear that the mean

Table 8.12  Heavy metal and calcium analyses from the Calamine Mine Tr. 8b.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc (ppm)</td>
<td>108,000</td>
<td>181,000</td>
<td>74,000</td>
</tr>
<tr>
<td>Lead (ppm)</td>
<td>24,000</td>
<td>67,500</td>
<td>13,000</td>
</tr>
<tr>
<td>Copper (ppm)</td>
<td>3,885</td>
<td>5,770</td>
<td>3,300</td>
</tr>
<tr>
<td>Calcium (ppm)</td>
<td>4,760</td>
<td>8,120</td>
<td>1,900</td>
</tr>
</tbody>
</table>
levels of lead and zinc approximate to the maxima seen on Tr. 8
(Fig. 8.9) and that in addition copper is present in substantial amounts.
The Ca/HM ratio of the mean values is 0.04 and it is apparent that
this is a very toxic spoil heap. As Table 8.13 shows the spoil in other
characteristics was similar to that elsewhere in the area.

Table 8.13  Sodium, potassium, magnesium, phosphorous and pH
determinations from 20m on the Calamine Mine Tr. 8b

<table>
<thead>
<tr>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>240</td>
<td>765</td>
<td>1,220</td>
<td>400</td>
<td>7.2</td>
</tr>
</tbody>
</table>

The high toxicity of the spoil on Tr. 8b was reflected in the virtual
absence of plant life. Fourteen of the twenty four quadrats showed no
plants whatsoever and the average cover values for all quadrats were
M. verna, 2%, T. alpestrae, 1.1% and Festuca ovina, 3.9%. The
figure of 3.9% for F. ovina is mainly attributable to a high cover value
of 64% in one quadrat of lower heavy metal levels, elsewhere the
species was virtually absent. Some disturbance of the spoil by cattle
occurred at this site but it appears that the low cover values for
vegetation may be attributed for the most part to the high toxicity
of the spoil. The spoil heap can be dated as about 150 years old and
it is clear that in that time in this particular environment little
colonization has taken place.

8.4  Other metalliferous sites to the west of the Cove Road at
Malham

The Grizedale Copper Mines are about 500m to the west of the Calamine
Mine on the bridle-path from Malham to Settle. Tr. 9 (Fig. 8.2)
was at this locality and Plate 3 shows the mineralised limestone
scarp down which the transect ran. In places the limestone scarp
has been disturbed but, as Plate 3 shows, there was no evidence of
Plate 3.

A mineralised limestone scarp at the Grizedale Copper Mines.
mining near to the transect line. Table 8.14 shows that, as compared with some of the other metalliferous sites in the Twinbottom region, lead and zinc are present in low concentrations in the spoil and copper is probably the predominant toxic heavy metal.

Table 8.14 Heavy metal, calcium, pH and organic carbon determinations from the Grizedale Copper Mine Tr. 9

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Copper (ppm)</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>pH</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>20m</td>
<td>2,090</td>
<td>1,520</td>
<td>12,900</td>
<td>20,000</td>
<td>7.3</td>
<td>12.7%</td>
</tr>
<tr>
<td>24m</td>
<td>2,500</td>
<td>1,970</td>
<td>11,800</td>
<td>6,735</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>26m</td>
<td>2,850</td>
<td>2,300</td>
<td>22,900</td>
<td>6,220</td>
<td>7.0</td>
<td>10.2%</td>
</tr>
</tbody>
</table>

_M. verna_ and _T. alpestrae_ were present in the anomalous area (Table 8.14) on and at the base of the cliff. Plate 3 emphasises a point that has been made before, this site is not obviously a metalliferous one and only the presence of the indicator species gives an indication of the toxicity of the soil. This is the sort of place which it has been suggested might go unrecognised as a toxic locality and sites such as this may be responsible for a number of records for _M. verna_ and _T. alpestrae_ from supposedly unmineralised localities.

_M. verna_ and _T. alpestrae_ were also seen in a few other places to the west of the Cove Road at Malham. Analyses from these sites are shown in Table 8.15 and their locations are on Fig. 8.2.

Table 8.15 Heavy metal, calcium and pH determinations from sites to the west of the Cove Road at Malham

<table>
<thead>
<tr>
<th>Site</th>
<th>Copper (ppm)</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2,240</td>
<td>67,500</td>
<td>27,000</td>
<td>46,500</td>
<td>7.0</td>
</tr>
<tr>
<td>2</td>
<td>652</td>
<td>8,080</td>
<td>106,000</td>
<td>nd</td>
<td>7.4</td>
</tr>
<tr>
<td>3</td>
<td>57</td>
<td>730</td>
<td>4,400</td>
<td>nd</td>
<td>6.9</td>
</tr>
<tr>
<td>4</td>
<td>717</td>
<td>8,750</td>
<td>10,000</td>
<td>nd</td>
<td>7.4</td>
</tr>
</tbody>
</table>
The samples from Sites 1 and 2 are of spoil from workings to the north of Twinbottom Scar. Both indicator species occurred at these sites and the main value of the analyses is the reaffirmation of the variability in the heavy metal concentrations in the mineralisations in this area. Site 3 was more interesting. This was on a slope of about 25° just to the west of the Cove Road (Fig. 8.2) and here just a few individuals of *M. verna* and *T. alpestre* occurred, growing with the normal calcicolous species of the district. The site was very comparable to that where *M. verna* occurred at 30m on Twinbottom Scar Tr. 6. As in the *M. verna* area on the transect zinc levels in this site are above the background level for the Twinbottom region (around 1,000 ppm) but lead concentrations are not above normal. Allied to the instability of the site, the slope was about 25°, the enhanced zinc levels at Site 3 appear to tip the competitive balance in favour of the indicator species.

Site 4 was rather different, a small disturbed area next to a layby at the roadside where *M. verna* was represented by a couple of plants. Lead and zinc concentrations (Table 8.15) are relatively high. The toxicity appears to be due to a small quantity of spoil dumped at the roadside or perhaps ore fallen from a cart. The site was no more than 50cms square and was not a spoil heap.

The two sites 3 and 4 are quite significant. The area to the west of the Cove Road at Malham has been extensively reconnoitred and *M. verna* and *T. alpestre* have only been found in places where heavy metal levels in the soil are above normal. Certain of these sites have been created by man but others appear to be entirely natural. It is apparent that the indicator species in this area are indeed acting as indicators of mineralisation.
8.5 Metalliferous localities elsewhere in the Craven District

To the east of Malham Tarn small mineralisations occur on the crest of Proctor High Mark (Fig. 8.1). The mines here according to Raistrick (1947) were never important but *T. alpestre* and *M. verna* occur associated with the spoil heaps today. The spoil heaps are not large, Table 8.16 shows the results of heavy metal and calcium analyses from one of the bigger ones. Although zinc is still the most important heavy metal in the spoil here, copper is relatively insignificant in comparison to the Twinbottom Scar area. The major difference however between the spoils of the Proctor High Mark and Twinbottom areas is in their calcium concentrations, the calcium concentrations of the spoil at Proctor High Mark are similar to those of Derbyshire.

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Copper (ppm)</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>Ca/HM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1m</td>
<td>218</td>
<td>2,850</td>
<td>33,000</td>
<td>162,000</td>
<td>8.16</td>
</tr>
<tr>
<td>3m</td>
<td>157</td>
<td>5,090</td>
<td>29,100</td>
<td>120,500</td>
<td>6.05</td>
</tr>
<tr>
<td>5m</td>
<td>230</td>
<td>8,300</td>
<td>22,000</td>
<td>158,500</td>
<td>8.0</td>
</tr>
<tr>
<td>7m</td>
<td>290</td>
<td>8,300</td>
<td>18,000</td>
<td>132,000</td>
<td>7.5</td>
</tr>
<tr>
<td>9m</td>
<td>250</td>
<td>10,700</td>
<td>10,700</td>
<td>68,000</td>
<td>3.5</td>
</tr>
</tbody>
</table>

In consequence the Ca/HM ratios of the spoil from this site are high and the toxicity is not great. Raistrick (1947) pointed out that the Proctor High Mark veins contained calcite in quantity while those of the Grizedale area were rich in quartz. The analyses clearly reflect this.
Table 8.17. Sodium, potassium, magnesium, phosphorous, pH and organic carbon determinations from 6m on Proctor High Mark Tr. 1

<table>
<thead>
<tr>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
<th>pH</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>655</td>
<td>1,540</td>
<td>1,260</td>
<td>1,000</td>
<td>7.2</td>
<td>8.2%</td>
</tr>
</tbody>
</table>

The nutrient status of the spoil at Proctor High Mark (Table 8.17) shows that again the spoil here has a greater similarity with that of Derbyshire than with the Twinbottom area.

The spoil heap at Proctor High Mark was stable and *M. verna* occurred all along the transect line. *T. alpestre* however was restricted to the 5m region. A number of other species also occurred on the spoil heap, *Festuca ovina, Thymus drucei, Saxifraga hypnoides, Galium pumilum, Euphrasia officinalis, Campanula rotundifolia* and *Geranium robertianum* L. These are the species that were present on the calcareous spoil dumps of Derbyshire. *Saxifraga hypnoides* has been suggested as an indicator in Derbyshire by Cole (1975) and *Geranium robertianum* is present on the copper rich spoil heaps at Ecton Hill in Staffordshire. It appears that rather more species are present on this spoil heap than on those of the Twinbottom area due to the less toxic nature of the substrate.

A feature of interest on this transect line is the presence of *M. verna* on stable spoil at Ca/HM ratios up to 8.16, in Derbyshire the species was rarely found on stable spoil at Ca/HM ratios in excess of 3.0.

Further east again is the mineralised area of Grassington Moor (Fig. 8.1). Here mineralisation extended into the Millstone Grit and there were rich workings in the Eighteenth and Nineteenth Centuries (Raistrick and Jennings, 1965). At the present day large spoil heaps may be seen on the moor. Table 8.18 presents the results of heavy metal and calcium analyses from a number of spoil heaps on Grassington Moor. Copper is not included, it was present in all samples at levels
Table 8.18  Heavy metal, calcium and Ca/HM ratio determinations from spoil on Grassington Moor.

<table>
<thead>
<tr>
<th>Site</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>Ca/HM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38,200</td>
<td>7,700</td>
<td>113,000</td>
<td>2.69</td>
</tr>
<tr>
<td>2</td>
<td>32,700</td>
<td>3,800</td>
<td>65,000</td>
<td>1.88</td>
</tr>
<tr>
<td>3</td>
<td>1,240</td>
<td>3,600</td>
<td>8,500</td>
<td>2.8</td>
</tr>
<tr>
<td>4</td>
<td>1,680</td>
<td>3,800</td>
<td>14,500</td>
<td>4.02</td>
</tr>
<tr>
<td>5</td>
<td>5,860</td>
<td>2,200</td>
<td>115,500</td>
<td>16.62</td>
</tr>
<tr>
<td>6</td>
<td>15,700</td>
<td>44,000</td>
<td>107,000</td>
<td>2.87</td>
</tr>
<tr>
<td>7</td>
<td>94,700</td>
<td>5,300</td>
<td>78,000</td>
<td>0.8</td>
</tr>
<tr>
<td>8</td>
<td>2,250</td>
<td>23,300</td>
<td>69,000</td>
<td>4.96</td>
</tr>
</tbody>
</table>

below 250 ppm. It is apparent that although the workings were in the Millstone Grit some of the spoil heaps contain large amounts of calcium. Pieces of crinoidal Carboniferous Limestone were visible on some of the spoil heaps and it appears that the workings penetrated to the limestone.

Table 8.19 shows that potassium was present in the spoil from Site 4 in high concentration for a spoil heap while the magnesium level is within the normal range.

Table 8.19  Sodium, potassium and magnesium determinations from Site 4 on Grassington Moor.

<table>
<thead>
<tr>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>210</td>
<td>7,280</td>
<td>2,100</td>
</tr>
</tbody>
</table>

M. verna was present at all the sites shown in Table 8.18. These sites show a broad range of Ca/HM ratios from 0.8 to 16.62. Sites 2, 3 and 5 were from unstable spoil while all the other samples were from stable sites. M. verna therefore has been found on Grassington Moor to occur in stable sites up to a Ca/HM ratio of 4.96 (Site 8) and to grow in unstable, eroding spoil at a Ca/HM ratio of 16.162 (Site 5).
To the south east of Grassington Moor at Appletreewick (Fig. 8.1) a sample was taken from a spoil heap at a small lead mine. This sample was from stable spoil where _M. verna_ occurred at a cover value of 22%, other species, mainly _F. ovina_, occupied 47% of the quadrat and the remainder was bare ground. Calcium concentrations in this spoil (Table 8.20) are high while heavy metal concentrations are relatively low. The result is the occurrence of _M. verna_ at quite a high Ca/HM ratio.

Table 8.20  Heavy metal, calcium and Ca/HM ratio determinations from Appletreewick S.1.

<table>
<thead>
<tr>
<th></th>
<th>Lead</th>
<th>Zinc</th>
<th>Calcium</th>
<th>Ca/HM</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ppm)</td>
<td>(ppm)</td>
<td>(ppm)</td>
<td></td>
<td>________</td>
</tr>
<tr>
<td>7,220</td>
<td>12,300</td>
<td>162,000</td>
<td>12.12</td>
<td></td>
</tr>
</tbody>
</table>

The analyses from Proctor High Mark, Grassington Moor and Appletreewick demonstrate that there are essentially two discrete types of metalliferous habitat in the Craven district, the toxic sites of the Twinbottom area which are low in calcium and the more calcareous sites in the east. It appears from the analyses for these eastern sites that _M. verna_ is present there on spoil with quite high Ca/HM ratios. This topic will be returned to in Chapter 11.
CHAPTER 9
THE DOLFRWYNOG AREA IN THE GOED-Y-BRENIN FOREST,
NORTH WALES

9.1 Introduction

The copper mineralisation in the Dolfrynog region lies within an area of moderate relief on the south eastern flank of the Harlech Dome about 6 km to the north of Dolgellau in Wales. The country rocks are argillites and greywackes of the Maentwrog and Ffestiniog formations of Upper Cambrian age and dip steeply towards the east (Rice and Sharp, 1976). The intrusive chalcopyrite mineralisation within an altered and fractured hornblende quartz diorite is believed to have been emplaced in Lower Ordovician times (Mehrtens et al, 1972).

The major structures of the North Wales area within which Dolfrynog lies are the result of earth movements of Caledonian age. In North Wales subsequent to the deposition of sediments of Cambrian, Ordovician and Silurian age there occurred the Caledonian period of intense orogenic activity. These earth movements were controlled by the Pre-Cambrian masses of Anglesey and the Bangor and Padern ridges in the north west and the tougher members of the Cambrian formation of the Harlech Dome in the west and south west (Smith and George, 1961). This control ultimately produced two main synclinal areas, the Snowdon syncline to the north west and the Central Wales syncline, on the margins of which Dolfrynog lies, to the south east. These major structures show a general caledonoid direction (north east to south west) which subsequent erosion has emphasised (Smith and George, 1961).
Figure 9.1
The Armorican earth movements at the close of the Carboniferous period produced some further folding and faulting but the North Wales area appears to have acted as a resistant mass and the movements tended to conform to the caledonoid grain of the country (Smith and George, 1961).

There is no evidence of Mesozoic or Tertiary rocks in the area but it has been suggested by numerous workers (Brown, 1960) that subsequent to a series of planations in the early Mesozoic Wales was completely covered by deposits of Cretaceous age. Following this Wales was uplifted in the early Tertiary and radial drainage, later to be superimposed upon the underlying Palaeozoics, developed on the Cretaceous cover. In the course of these events old peneplains were exhumed and new platforms created (Brown, 1960).

Following the Tertiary denudation Wales was subjected to several episodes of glaciation in the Pleistocene period. It appears that during the Pleistocene glaciations the isolated mountain massifs of Wales operated as local centres of ice accumulation and radial ice streams developed (Smith and George, 1961). The local Welsh ice tended to keep out the major Irish Sea ice and in consequence much moraine is of local origin. This seems generally to be the case in the Dolfrwynog district. Ice movement appears to have been from the north and according to Mehrtens et al (1972) mineralised rock from the chalcopyrite anomaly has been transported for no great distance, they suggest tens rather than hundreds of metres. The till in the Dolfrwynog area has an average thickness of 6m (Mehrtens et al, 1972) but at the copper bog (to the north of Mynydd Bach, Fig. 9.1) the till, composed of grey shale foreign to the area, is much deeper and large diorite boulders overlie the moraine (Rice and Sharp, 1976).

The till here is present at depths up to 30m and fills a buried valley which runs roughly from east to west. It is suggested by Rice and Sharp (1976) that this valley represents the pre-glacial course of the Afon Wen which formerly flowed east to west to join the Afon Mawddach rather than turning sharply south to the east of Dolfrwynog (Fig. 9.1) as it does now.
Although it lies in the lee of the Harlech Dome the Dolfrwynog region probably experiences a high rainfall. In the period from 1916 to 1950 Dolgellau recorded 1,495 mm of precipitation annually while Blaenau Ffestiniog to the north experienced an average of 2,795 mm each year. Dolfrwynog lies between the two and is more or less intermediate in altitude, around 2,000 mm of precipitation annually seems probable. Mean temperatures for July and January based on adjustment of the figures for Aberystwyth are probably of the order of 14.2°C and 3.9°C respectively.

Cazalet (in Rice and Sharp, 1976) surveyed the soils of the Dolfrwynog district and found seven soil types; brown podsolic, podsol, ranker, humic gley, placosol, peaty gley and peat. Of these the brown podsolic was by far the most important, occupying 56% of the area. The vegetation of the region has been greatly modified by the widespread planting of coniferous trees by the Forestry Commission. Sitka spruce, *Picea sitchensis* (Bong.) Carrière is the most widespread tree. Where plantations are absent an acidic *Festuca-Agrostis* grassland occurs. Much of the terrain is gently sloping and peaty soils are not general but in depressions and valley bottoms there is some peat accumulation and the development of communities of bog plants. The copper bog occupies one such site.

The occurrence of copper in considerable concentrations in peat in the Coed-y-Brenin area was observed by Henwood (1857). He mentioned a peat at Maes-y-Glwysan containing relatively little copper before proceeding to describe the extensive deposit of "copper turf" at Dolfrwynog where, he states, 70 acres (28 ha) were worked in the early Nineteenth Century. This is a much larger area than that occupied by the copper bog today (Fig. 9.2), about 10 acres (4 ha).
Henwood (1857) described a surface bed of peat, 60cm or so in thickness, below which there was a bed of stones of unexplained origin and then a further layer of peat containing little copper and left unworked. Such a configuration of beds is not apparent today. The peat was burned in kilns and the ashes were sent to Swansea for further processing. Henwood (1857) records that at the time of his visit the remaining peat would not yield more than 2½% copper and working it was not an economic proposition. This remaining peat is presumably the material investigated in the course of this study.

Within the general area of Dolfrwynog some vein mineralisations also occur and in 1847 the North Wales Silver, Lead, Copper and Gold Mining Company was created to work the lodes at Dolfrwynog and elsewhere in the Dolgellau gold belt (Andrew, 1910). The spoil of the mine dumps in the area of the bog and along the Afon Wen (S1 and S9, Fig. 9.1) probably dates from this period. The gangue material of the stronger veins according to Henwood (1857), and this is visible on the tips today, is a mixture of quartz and calcite.

It was obvious to the old miners that the copper contained in the peat of the copper bog had a local origin and much effort was expended in the search for this. They envisaged a strongly mineralised source but never located one. Recently Rio Tinto Finance and Exploration Ltd. have carried out exploration work in the area (Rice and Sharp, 1976) which has revealed that the origin of the copper is the low grade chalcopyrite mineralisation mentioned previously. Mehrmens et al (1972) have presented some of the results of this exploration and have shown a broad soil anomaly elongated from north to south surrounding the bog. The bog however is not the centre of the mineralisation, this is to the east of the bog (Rice and Sharp, 1976). The blocking of the former valley of the Afon Wen mentioned previously has resulted in a perched water table in the area (Rice and Sharp, 1976) and the anomaly has been displaced by hydromorphic means towards the west. In the case of the copper bog the channel course which underlies it
acts as a channelway for metal rich groundwaters which emerge within the bog after passing through mineralised ground some distance to the east (Mehrtens et al, 1972). Other springs and seepages occur near Maes-yr-eglwys-wen, Cae'n-y-coed and Buarthre (Fig. 9.1) and communities of the indicator species, as also is the case in the bog, are associated with them.

The bog additionally receives drainage waters from the mineralised areas on the slope to the south and from an adit driven into the southern hillside (Fig. 9.2), the latter perhaps the working which Henwood (1857) refers to as having contained "several irregular masses of copper pyrites, weighing some two tons each."

9.2 The outlying indicator plant communities

The analyses for heavy metal and calcium in this section were, with the exception of Site 2, carried out in a -80 mesh sieve fraction digested in 8N nitric acid. The soil from Site 2 was analysed by the method of ashing before sieving and digestion in 8N nitric acid. These analytical procedures were described at greater length in Chapter 3.

The difference in procedure is due to the different characteristics of the soils, all the sites other than Site 2 had soils relatively low in organic matter. The soils of the copper bog which will be considered in Section 9.3 were analysed by both procedures and it appears that the two methods do not give substantially different results for copper concentrations.

Fig. 9.1 shows the distribution of the indicator species between the Afon Wen and the Afon Mawddach in the Coed-y-Brenin forest. The indicator plants are associated with peaty soils impregnated by water transported copper and also with spoil and cupferous exposures. Inspection of Fig. 9.1 shows that Armeria maritima is the most widespread indicator species in the district, occurring at all sites except Site 3, and frequently occurs in isolation.
At Site 1 (Fig. 9.1) by the Afon Wen *A. maritima* and *Minuartia verna* grow on spoil heaps derived from the working of the Doltrwynog lodes. Farther south along the Afon Wen the same two species occurred again on mine spoil at Site 9. The copper concentrations in these spoils were between 2,000 and 8,000 ppm and Table 9.1 shows heavy metal and other analyses of a representative sample from Site 1.

**Table 9.1** Heavy metal, calcium, pH and organic carbon determinations of spoil from the spoil heap at Site 1.

<table>
<thead>
<tr>
<th>Copper (ppm)</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>pH</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>7,550</td>
<td>62</td>
<td>115</td>
<td>3,500</td>
<td>7.1</td>
<td>2.6%</td>
</tr>
</tbody>
</table>

The sites at Maes-yr-eglwys-wen (S. 2), to the south west of Buarthre (S. 3) and to the south east of Cae'n-y-coed (S. 5) show similarities, all seem to be associated with springs and water seepages carrying copper and this copper has accumulated in organic soil. *A. maritima* is present at all three sites. *Silene maritima* grew only at Maes-yr-eglwys-wen and *M. verna* was not seen at any of the sites. An interesting associate of *A. maritima* at Cae'n-y-coed is *Trollius europaeus* L. A soil sample from Maes-yr-eglwys-wen showed copper to be present at 8,250 ppm.

The sites to the west of Ty'n-y-mynydd (S. 4), to the west of Bryn Coch (S. 3) and to the south of Bwlch-rhos-wen-isaf (S. 6) are again similar. At these places moraine is exposed in roadside cuttings which appear relatively recent in origin. Copper was present in the substrate at Site 6 at a concentration of 2,200 ppm and at Site 3 at the very similar level of 2,000 ppm. All these sites appeared to be relatively unstable.
At Site 7 A. maritima grew in a small area on a stream bank. The bank at this point showed a black stratum with charcoal, about 45cm thick, overlying lighter coloured moraine. A surface sample showed a copper concentration of 5,400 ppm but a sample from near the base of the black layer contained copper at the exceptionally high concentration of 56,000 ppm. It seems possible that this site may be one of former smelting activity.

It is clear that in a number of places in this area of the Coed-y-Brenin forest the indicator species occur associated with high levels of copper in the substrate. At the present day much of the district is thickly forested, it seems reasonable to suppose that if this was not the case then there would be more communities of the indicator species along the watercourses and on small exposures of copper rich moraine.

9.3 The Dolfrwynog copper bog

In Coed-y-Brenin the best known and most extensive area occupied by the indicator species is the copper impregnated bog, the "copper turf" of the old miners. Occurring to the north of Mynydd Bach on Fig. 9.1 the area contains a complex of vegetation communities which have been affected by afforestation and mining operations.

The bog (Fig. 9.2) occupies a hollow which slopes gently from east to west. To the south of the bog and extending uphill for some distance are three parallel outcropping veins, occupied by an indicator community involving primarily Armeria maritima. The westernmost vein is penetrated at the base of the hill by a level at the mouth of which spoil dumps are present. To the west of these spoil heaps, on ground not actually within the bog area and planted with coniferous trees A. maritima occurs along small drain lines. The track which runs from the spoil heaps approximately northwards across the bog appears to be constructed from spoil material. The toxicity of the road material is responsible for the small northwards extension of the indicator plant communities (Fig. 9.2) on the north side of the bog.
DOLFRWYNOG BOG
The approximate locations
of the transects and the
extent of the major communities
of the indicator species

Figure 9.2
The road divides the bog into approximately an eastern third and a western two thirds; the eastern area is less affected by the activities of man. A drilling team have disturbed the peat in places but this is relatively insignificant. To the west of the road disturbance is more pronounced. Adjacent to the spoil heaps sawdust has been dumped and in the summer of 1973 and on subsequent visits seepage of oil from the sawdust covered area was occurring. In the region to the west of the road are the main Forestry Commission drainage works. The major stream along the northern edge of the bog has been deepened and one large channel and other subsidiary ones have been excavated to take water from south to north across the bog.

To the west of the bog the indicator species extend down the channel of the stream for some distance. This extension is again visible on Fig. 9.2. A few samples were taken of alluvium from the stream bed. At a site just above where the road crosses the stream (Fig. 9.2) A. maritima and Minuartia verna grew in alluvium containing 5,750 ppm copper while 50 metres below the bridge M. verna grew in alluvium in the stream bed, this alluvium contained between 1,500 and 1,800 ppm copper. 25 metres below this point copper levels in the alluvium had fallen to 1,160 ppm and no indicator species were present.

Most of the work in the area was concentrated within the bog. Four transects were used and their approximate positions are shown in Fig. 9.2. Tr. 1 in the east crossed the bog from south to north; Tr. 2 began at the mouth of the level at the western end of the bog and crossed the bog parallel to Tr. 1, while Tr. 3 ran east to west down the centre of the bog, crossing the other transects more or less at right angles. The fourth transect, Tr. 5 crossed two of the mineralised areas on the hillside to the south of the bog and again ran from east to west. Tr. 5 is the least variable and complex of the transect lines and will be described first.
Determination of copper concentrations were made in two ways. One involved ashing before sieving and digestion in nitric acid, the other just sieving before digestion in acid. Details of the methods were discussed in Chapter 3. The two methods give broadly comparable results. In the following discussion when copper concentrations or copper to organic matter ratios (Cu/OM ratios) are mentioned these are determinations made in ashed soil.

Dolfrwynog Bog Tr. 5 (Fig. 9.3) crossed the hillside to the south of the bog and traversed the central and western indicator plant areas (Fig. 9.2) and an intervening region of background vegetation. From 20 to 70m the transect ran through a plantation of *Pinus sylvestris* L. and in this region the ground vegetation was recorded in alternate quadrats. Bare ground has been omitted from the diagram in this area because the presence of tree trunks, tree stumps and broken branches greatly confused the situation. The transect line ran with the contour and in consequence relief has not been plotted on Fig. 9.3. The slope across the transect line varied between $7^\circ$ and $19^\circ$, the areas with the indicator species were the most steeply sloping.

Fig. 9.3 shows that there are two well defined copper anomalies in the soil. Copper levels are lower in the eastern anomaly from 0 to 20m than in the western one. The eastern anomaly appears to have been rather more disturbed than the western one. On the eastern anomaly just to the north of the transect line (Fig. 9.2) there has been some relatively recent excavation and the sampled area may have been affected indirectly. In addition the track which runs southwards from a short distance to the north of Tr. 5 (Fig. 9.2) appears to have run down the eastern anomaly at some time in the past and will have crossed the line of the transect at some point. Precisely where is not certain but the area with substantial amounts of bare ground between 5 and 10 m seems the most probable. In contrast the western anomaly from 75 to 100m appears not to have been disturbed in the recent past.
GEOBOTANY

Mosses and Lichens
- Blechnum spicant
- Rubus fruticosus
- Cerastium vulgatum
- Rumex acetosa
- Potentilla erecta
- Galium saxatile
- Ulex gallii
- Vaccinium myrtillus
- Erica cinerea
- Lactuca vulgaris
- Festuca rubra
- Holcus lanatus
- Deschampsia flexuosa
- Agrostis tenula
- Armeria maritima
- Minuartia verna

GEOCHEMISTRY

WEIGHT LOSS ON ASHING

DOL-FRWYNOG BOG: TRANSECT 5

Figure 9.3
Minuartia verna is present in both anomalous areas but appears to be rather more frequent in the eastern anomaly. A striking feature of the region from 75 to 100m is the very high cover values which Armeria maritima attains in certain quadrats. Calluna vulgaris is generally present over the western anomaly but other species such as Vaccinium myrtillus L. and Ulex gallii Planchon are completely absent from the regions of high copper concentration.

It is evident from Table 9.2 that the concentrations of the bases are quite similar in both the anomalous areas as is the pH. Phosphorous levels also seem similar.

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Calcium (ppm)</th>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>10m</td>
<td>1,100</td>
<td>105</td>
<td>490</td>
<td>3,400</td>
<td>1,140</td>
<td>5.3</td>
</tr>
<tr>
<td>79m</td>
<td>1,550</td>
<td>125</td>
<td>600</td>
<td>3,300</td>
<td>1,040</td>
<td>5.3</td>
</tr>
<tr>
<td>91m</td>
<td>1,800</td>
<td>105</td>
<td>530</td>
<td>nd</td>
<td>nd</td>
<td>5.1</td>
</tr>
</tbody>
</table>

Particle size analysis of soil from the western anomaly (Table 9.3) shows it to be relatively fine in texture, more so than most spoil heap soils. The probability of a better moisture status in this substrate than on most spoil heaps probably accounts for the widespread presence of A. maritima.

<table>
<thead>
<tr>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.4%</td>
<td>4.1%</td>
<td>7.7%</td>
<td>35.8%</td>
<td>20.7%</td>
<td>25%</td>
</tr>
</tbody>
</table>

An interesting feature of the distribution of M. verna on the transect line is its greater frequency in the eastern anomaly from 0 to 20m than in the western one. Copper levels are generally lower in the eastern anomaly and it is noticeable that in the western anomaly M. verna is
absent from the area of the highest copper concentrations around 90m. It was suggested for the Aachen-Liege area that *M. verna* was absent from certain sites where *A. maritima* occurred due to excessive toxicity and this seemed a possibility on this transect line. In the 80 to 88m region however *M. verna* is generally absent from soils with copper levels lower than or equal to those of the 10 to 15m region in which the species occurs.

Inspection of Table 9.4 shows this more clearly. The samples from 85m and 97m show copper concentrations which are within the range of those occupied by the species in the 6 to 18m area. *M. verna*, however, was not present in the quadrats adjoining these sample points.

Dykeman and de Sousa (1966) observed that copper was present in a bog in New Brunswick at concentrations up to 7% but appeared to have no visible effects on the vegetation. This they related to the chelation of copper by organic matter in the soil. It thus seemed possible that the toxicity of the soil on this transect line was not a function of copper concentration alone but of a relationship between copper concentration and the organic matter content of the soil. Accordingly it was decided to calculate a Cu/OM ratio based upon the data for copper concentrations and using the figure for percentage weight loss on ashing as representative of the organic matter content of the soil (this was discussed in Chapter 3.)

Table 9.4 shows that the Cu/OM ratios for the samples from 85m and 97m where *M. verna* did not occur, even though their copper concentrations were similar to those of the 6 to 18m region, are much higher than those found in that region. It is clear from Table 9.4 that *M. verna* was not present on the transect line at a Cu/OM ratio greater than 312 and it seems probable that the absence of the species from the area between 85m and 97m is a function of the high Cu/OM ratios in that area.
Table 9.4  Copper concentrations, organic matter levels and the Cu/OM ratios of samples from the anomalous areas on Dolfrwynog Bog Tr. 5

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Copper (ppm)</th>
<th>Organic matter</th>
<th>Cu/OM</th>
<th>Minuartia verna</th>
</tr>
</thead>
<tbody>
<tr>
<td>2m</td>
<td>3,246</td>
<td>15%</td>
<td>216</td>
<td>-</td>
</tr>
<tr>
<td>6m</td>
<td>4,056</td>
<td>16%</td>
<td>254</td>
<td>+</td>
</tr>
<tr>
<td>10m</td>
<td>8,742</td>
<td>28%</td>
<td>312</td>
<td>+</td>
</tr>
<tr>
<td>14m</td>
<td>8,012</td>
<td>31%</td>
<td>258</td>
<td>+</td>
</tr>
<tr>
<td>18m</td>
<td>8,284</td>
<td>37%</td>
<td>224</td>
<td>+</td>
</tr>
<tr>
<td>20m</td>
<td>1,827</td>
<td>12%</td>
<td>152</td>
<td>-</td>
</tr>
<tr>
<td>76m</td>
<td>10,990</td>
<td>26%</td>
<td>423</td>
<td>-</td>
</tr>
<tr>
<td>79m</td>
<td>5,799</td>
<td>30%</td>
<td>193</td>
<td>+</td>
</tr>
<tr>
<td>83m</td>
<td>7,458</td>
<td>31%</td>
<td>241</td>
<td>+</td>
</tr>
<tr>
<td>85m</td>
<td>8,052</td>
<td>18%</td>
<td>447</td>
<td>-</td>
</tr>
<tr>
<td>88m</td>
<td>9,831</td>
<td>18%</td>
<td>546</td>
<td>-</td>
</tr>
<tr>
<td>91m</td>
<td>19,385</td>
<td>28%</td>
<td>692</td>
<td>-</td>
</tr>
<tr>
<td>94m</td>
<td>12,668</td>
<td>39%</td>
<td>325</td>
<td>-</td>
</tr>
<tr>
<td>97m</td>
<td>6,169</td>
<td>11%</td>
<td>561</td>
<td>-</td>
</tr>
</tbody>
</table>

+ M. verna present in adjoining quadrats
- M. verna absent in adjoining quadrats

Thus on this transect line although copper concentrations give an indication that M. verna may be excluded from certain regions by excessive toxicity the Cu/OM ratio appears to account rather better for the distribution of the species.

Dolfrwynog Bog Tr. 1 (Fig. 9.4) crossed the bog in the area to the east of the track. This region to the east of the track is not as disturbed as that to the west. On the transect line the track marked on the relief profile (Fig. 9.4) was little used and the only area of major recent disturbance is that of the ruts in the region of 50m. These ruts have
been produced by wheeled vehicles going to one of the drill holes put down in the bog during the Rio Tinto Finance and Exploration Ltd. drilling programme. Just beyond the ruts in the region from 55 to 60m was an area of hummocks. These are shown on Fig. 9.4. The hummocks are heaps of stones which probably were piled up in the course of peat cutting operations.

It is apparent from Fig. 9.4 that the highest copper levels are reached in the region of 55m and that in this area the indicator species A. maritima and M. verna are present. Molinia caerulea, generally the dominant grass in the bog, is largely replaced over the area of high copper values by Eriophorum vaginatum. A. maritima is more widespread along the transect line than M. verna, reflecting the greater competitive ability of the species.

<table>
<thead>
<tr>
<th>Table 9.5</th>
<th>pH determinations at intervals along Dolfrynog Bog Tr. 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6m</td>
</tr>
<tr>
<td>pH</td>
<td>5.0</td>
</tr>
</tbody>
</table>

pH values in the areas occupied by the indicator species, the samples from 6m, 48m, 51m and 57m (Table 9.5) are around 5.0. This is about the same level as that of the soil on Dolfrynog Bog Tr. 5. However the high weight loss on ashing percentages for many samples on this transect line (Fig. 9.4) indicate that the substrate contains more organic matter than that of Tr. 5 (Fig. 9.3). Several samples on Tr. 1 show organic matter contents in excess of 60%.

Again on Tr. 1 there is not a straightforward relationship between the incidence of the indicator species and copper concentrations. For example A. maritima occurs in the region of 5m at copper concentrations lower than those found in the 20 to 40m area where the species is for the most part absent. The samples at 3, 6 and 9m however all have low levels of organic matter and in consequence their Cu/OM ratios are
just in excess of 100. The sample from 9m for example contains only 727 ppm copper but with the low organic matter content of 7% appears sufficiently toxic to depress competition sufficiently to allow A. maritima to occur. In contrast the samples from 12 to 24m, even though they contain more copper, all show Cu/OM ratios less than 100. Neither A. maritima nor M. verna occurs on the transect line associated with a sample with a Cu/OM ratio less than 100. Certain sites however, 27m with a Cu/OM ratio of 213 is an example, have high Cu/OM ratios and neither indicator species is present.

As Fig. 9.4 shows a number of other species occur on the transect line, often growing on substrates with copper concentrations which are quite high. It appears that in many areas of the transect line organic matter levels are sufficiently high to greatly reduce the availability of the copper.

Dolfrwynog Bog Tr. 2 (Fig. 9.5) was an altogether more complex transect line than either Tr. 1 or Tr. 5. The transect ran from south to north and had its origin on spoil dumps at the mouth of the adit shown on Fig. 9.2. The transect may be divided into two discrete regions, the area of spoil material to 30m and the bog beyond.

Both A. maritima and M. verna were present on the spoil heap but M. verna was the more abundant. Copper concentrations in the spoil are between 1,000 and 6,000 ppm. These are about the same levels as those in the spoil from the Dolfrwynog Lodes (Sites 1 and 9) mentioned in Section 9.2. This appeared also to be the case for calcium (Table 9.6) although the magnesium level in this spoil is higher than at Site 1 (Table 9.1).
GEOBOTANY

Lichens
Mosses
Feltiaceae
Dryopteris filix-mas
Rumex acetosa
Orchis mascula
Rumex acris
Prunus spinosa
Papaver rhoeas
Gallium saxatile
Rumex acetosella
Ranunculus acris
Pinus sylvestris
Quercus robur
Carex stricta
Juncus effusus
Juncus inflexus
Erica vaginata
Vaccinium myrtillus
Erica tetralix
Calluna vulgaris
Deschampsia caespitosa
Agrostis capillaris
Molinia caerulea
Armeria maritima
Minuartia verna
Bare Ground

GEOCHEMISTRY

Cu, soil digested in 8H Nitric acid
Cu, extract soil digested in 8H Nitric acid

WEIGHT LOSS ON ASHING

RELIEF

DOL - FWYNOG BOG : TRANSECT 2

Figure 9.5
Table 9.6  Calcium, sodium, potassium, magnesium, phosphorous and pH determinations from 6m on Dolfrwynog Bog Tr. 2

<table>
<thead>
<tr>
<th>Calcium (ppm)</th>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>4,250</td>
<td>150</td>
<td>850</td>
<td>10,000</td>
<td>740</td>
<td>7.2</td>
</tr>
</tbody>
</table>

The relatively high percentage weight loss on ashing figures for the sample from 12 and 18m (Fig. 9.5) are not the result of peat accumulation in the soil but reflect the presence of considerable amounts of wood shavings. These wood shavings are derived from sawing operations by the Forestry Commission. The virtual absence of vegetation at 12 and 18m suggest that the wood shavings are having little ameliorative effect on spoil toxicity at the present time.

Beyond 30m on the transect line is the copper bog. The bog, as outlined previously, is in a valley floor which slopes towards the west. Due to this, as indicated on the relief profile (Fig. 9.5), water flows obliquely across the transect line.

Between 35 and 60m the bog was extremely wet. In certain places at the time of sampling it was possible to sink into the peat to a depth of about 30cm. The area from 50 to 55m at the time of survey was covered by slowly flowing water to a depth of about 2cm. At 40m M. verna grew, half submerged, in flowing water and the physical contrast between this site and a dry spoil heap must be considered extreme.

In the 35 to 60m area there were two regions of stronger water movement; the one at around 45m was the head of a small stream while the other at about 55m was just a place of generally increased flow. The water in both places appeared to be derived from the spoil heaps and the southern hillside but it was impossible to distinguish exact sources. Certainly, however, the water at 55m originated farther east than that at 35m. At 48m, as Fig. 9.5 shows, there is a much lower copper concentration than in nearby samples and it seems possible that this
is related to the position of the site between the two areas of water flow, both of which seem to be associated with high levels of copper.

In the 50m region there was some oil pollution, apparently related to water movement from the region of the Forestry Commission sawing site. Most of the mosses in this area appeared to be dying or dead but an effect on the vascular plants was not apparent.

The main region of occurrence of the indicator species on Tr. 2 was from 35 to 60m. This area appears to be divisible into two parts; the region from 38 to 46m in which M. verna predominates and the zone where A. maritima is most abundant from 50 to 60m. The two cover value peaks for M. verna in the 38 to 46m region were due to a pile of stones similar to those described from Tr. 1. Around this pile of stones M. verna grew in abundance in the stream channels. A. maritima appears to be more competitive than M. verna and when the two are present together A. maritima is normally present at higher cover values. The situation in the 38 to 46m region is thus unusual. It is possible that the low cover values for A. maritima in this area are related to the very wet nature of the site, the peat below the mass of M. verna was about 10 cms below water level. It seems possible that the rosette growth form of A. maritima might be a disadvantage in such a locality.

It is evident from Table 9.8 that the pH values in the main indicator plant community on this transect line are a little higher than the values of around 5.0 which prevailed in the equivalent area on Tr. 1.

Table 9.7  pH values in the 39 to 60m region on Dolfrwynog Bog Tr. 2

<table>
<thead>
<tr>
<th></th>
<th>39m</th>
<th>48m</th>
<th>54m</th>
<th>57m</th>
<th>60m</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.5</td>
<td>5.7</td>
<td>5.6</td>
<td>5.5</td>
<td>5.6</td>
</tr>
</tbody>
</table>
At 85m A. maritima occurred without M. verna. As inspection of Fig. 9.5 shows copper and organic matter levels in the substrate here are very similar to certain of those in the 39m to 60m region where M. verna was present in most quadrats. The pH at 84m however was 4.3, substantially lower than in the 39 to 60m area (Table 9.7) and lower also than in the region in which M. verna grew on Tr. 1 (Table 9.5). The absence of M. verna from the 84m region may be due to the greater mobility and availability of copper at the lower pH. According to Hawkes and Webb (1962) the mobility of copper is high below pH 5.5 although mobility is also affected by sorption to organic matter. It may be therefore that excessive toxicity excludes M. verna from this site. On the other hand a pH of around 5.0 is a limiting pH for many species due to toxicity from aluminium, manganese and hydrogen ions (Grubb, 1969) and it is possible that the absence of M. verna from this particular locality is not an effect of copper toxicity alone.

Dolfrwynog Bog Tr. 3 (Fig. 9.6) ran approximately from east to west through the bog, generally being some distance to the south of the major stream. As was indicated in the account of Tr. 2 the general drainage direction within the bog is from south east to north west and the transect crossed the drainage lines more or less at right angles, thus allowing the investigation of the association of the indicator species with water and seepage courses. Inspection of the relief profile on Fig. 9.6 shows the existence of a number of seepages and also drain lines, drains and streams. The streams were clearly incised channels occupied at the time of survey by flowing water while the drains are water courses excavated by man. The latter are quite deep trenches, about 150cm in depth. Seepages are regions where water clearly flows at times but they did not contain flowing water at the time of the survey. The seepages were sometime very wet and often occupied a poorly defined depression. The drain lines were rather more defined than seepages and showed some water flow but were without a well defined channel.
GEOBOTANY

Spergula arvensis

Spergula arvensis

Poa annua

Rumex acetosa

Succisa praealtis

Pedicularis sylvatica

Picea sitchensis

Pinus seedlings

Belula seedlings

Ulex gallii

Vaccinium myrtillus

Erica cinerea

Erica faflara (dead)

Calluna vulgaris (dead)

Carex echinala

Eriophorum vaginatum

Juncus effusus

Antennaria dioica

Agrostis tenuis

Holcus lanatus

Arum maculatum

Molinia caerulea

Sphagnum marsh

New Growth

GEOCHEMISTRY

WEIGHT LOSS ON ASHING

RELIEF

DOL-FRWYNOG BOG: TRANSECT3

Figure 9.6
As on the other transects on Dolfrwynog Bog Tr. 3 *A. maritima* was more widely distributed and also generally present at higher cover values than *M. verna*. *Silene maritima*, infrequent in the bog, occurred in three places on Tr. 3.

Fig. 9.6 demonstrates that the indicator species *A. maritima* and *M. verna* are closely associated with the regions of water flow and it is apparent that at certain of these places copper concentrations are higher than in nearby samples. This is the case at the stream at 10m and again in the region of the seepages at 20m. Not every seepage however shows high copper concentrations, for example the seepage at 75m has a soil copper level similar to those of adjacent samples. While copper concentrations in certain of the regions of water flow are higher than elsewhere it is clear that there are still high copper levels in the substrates between these places, this is the case in the region between 40 and 70m.

Mehrtens et al (1972) pointed out that copper rich waters emerged within the bog after having passed through mineralised ground some distance to the east and that this resulted in the impregnation of the peat by copper. Presumably these copper bearing waters are responsible for the copper in the many samples from the bog with copper concentrations below 10,000 ppm. It seems probable that the high copper concentrations in certain seepages are derived from sources nearer to the bog itself, perhaps from the mineralised areas on the southern hillside which were investigated by Tr. 5. Copper deposited from water derived from such sources may be superimposed upon the general background level prevailing in the bog producing places on certain seepages with concentrations of copper in excess of 10,000 ppm. It seems probable that certain seepages will drain the copper rich areas on the southern slopes and others will not and this may account for the high degree of mineralisation of certain seepages and not others. This is not to suggest that all the seepages on the transect line have their origin on
the southern hillside, some do not and appear to originate within the
bog itself. The situation is complex due to the difficulty of tracing the
seepages to their sources, this was discussed in relation to Tr. 2
where it was observed that it was impossible to identify the places of
origin of the copper rich waters on that transect line.

A major community of the indicator species on the transect line is that
in the 40 to 60m region. The samples from 40 to 50m show moderate
levels of copper but low amounts of organic matter, in consequence
the soils here are relatively toxic. Table 9.8 shows the Cu/OM ratios
of these and immediately adjacent samples.

Table 9.8  The Cu/OM ratios of soil from the 35 to 60m region on
Dolfrwynog Bog Tr. 3

<table>
<thead>
<tr>
<th></th>
<th>35m</th>
<th>40m</th>
<th>45m</th>
<th>50m</th>
<th>55m</th>
<th>60m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu/OM</td>
<td>104</td>
<td>249</td>
<td>323</td>
<td>365</td>
<td>206</td>
<td>121</td>
</tr>
</tbody>
</table>

It is apparent that the presence of M. verna in the 45 to 50m region is
associated with substrates of high Cu/OM ratios (Table 9.8) even though
copper concentrations in this area are no higher than in adjacent
samples (Fig. 9.6). The situation in this region is, however, some-
what confused due to disturbance related to a nearby drillhole. Thus
the occurrence of M. verna and A. maritima in the 40 to 60m region
is probably related to a combination of high toxicity and some dis-
turbance. It is evident from Fig. 9.6 that in the 40 to 60m Eriophorum
vaginatum shows high cover values while Molinia caerulea is present
at only low values. It appears to be the case that M. caerulea is more
affected by toxicity than E. vaginatum and that the latter species, like
the indicators, greatly benefits from the reduction in competition.

At around 105m all three indicator species occur together on the road.
Table 9.9 shows a number of analyses of road material and these are
very similar to those of the spoil from the spoil heap of Tr. 2 (Table
9.6). It appears that the road has been constructed from spoil from
that source.
Table 9.9  Calcium, sodium, potassium, magnesium, phosphorous and pH determinations from the road at 106m on Dolfrwynog Bog Tr. 3

<table>
<thead>
<tr>
<th>Calcium (ppm)</th>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,750</td>
<td>210</td>
<td>1,300</td>
<td>8,900</td>
<td>1,200</td>
<td>6.1</td>
</tr>
</tbody>
</table>

In contrast to the spoil heap of Tr. 2 the road on Tr. 3 showed considerable species diversity. In the two quadrats from 104 to 106m on Tr. 3 eleven species, excluding mosses and lichens, were present while in the two quadrats from 5 to 7m on Tr. 2, the quadrats adjoining the sampled point, only five species were recorded. The spoils of the road and of the heap are very similar in copper concentration and origin but appear different in the nature of the opportunities which they offer for colonizing species. The major difference between the two sites seems to be that the road receives water from the bog and is probably less susceptible to drought. It appears that this has resulted in more rapid colonization and succession in this locality.

In the area from 100m to 200m there has been considerable disturbance mainly related to drainage operations. These deep drains appear to have the effect of conducting the copper rich waters from the bog more rapidly and may well be a development in the area detrimental to the long term stability of the indicator species communities. In a few places in the 180m region trees appeared to be establishing themselves (Fig. 9.6). This may be related to a general drying out of this area of the bog.

At 255m and 285m the transect line crossed the major stream which drains the bog. The indicator species were present in rather unstable alluvium on both sides of the stream. The copper concentration in the alluvium at 255m is not particularly high but organic matter levels are low also and the toxicity of the substrate, combined with its instability, seems sufficient to provide a habitat for the indicator species.
9.4 Observations on the indicator species and metalliferous habitats of the Dolfrwynog region

The Dolfrwynog region contains a variety of habitats for the indicator species ranging from spoil heaps and apparently undisturbed vein mineralisations to the copper rich peat bog. The copper bog has been greatly affected by peat cutting, mining activity and disturbance associated with the drainage operations of the Forestry Commission but nevertheless remains a very interesting locality for the indicator species. No site like this appears to exist anywhere else in the British Isles and the copper bog is a unique habitat for the indicator species.

Within the Dolfrwynog district A. maritima is the most widespread of the indicator species and occurs at most of the mineralised sites. Within the bog itself A. maritima is the most generally occurring of the indicator species, a reflection of its greater competitive ability. M. verna on the other hand appears to be restricted to rather more toxic soils than those of many of the sites in which A. maritima occurs but there is also some evidence that the species is affected by excessive toxicity in certain places. This appeared to be the case on Tr. 5 where M. verna was absent from substrates with Cu/OM ratios greater than 312. Given the absence of M. verna from soils with high Cu/OM ratios on Tr. 5 it is interesting to notice that on Tr. 1 M. verna grew in soil with a Cu/OM ratio of 399. It appears that a high Cu/OM ratio on Tr. 5 reflects more toxicity than a high one in the bog.

A feature of the occurrence of M. verna in the Dolfrwynog area is its growth on substrates with pH values as low as 4.8. This appears to be due to the considerable organic matter levels in many of these soils which have the effect of reducing the availability of the copper. It is apparent that the spoils in the area upon which M. verna grows show pH values, unless there is some organic matter accumulation, of just above 7.0, the normal pH of spoils on which the species occurs.
Silene maritima is not abundant within the bog. Tr. 3 indicated that the species occurred on substrates with copper concentrations similar to those found in other places where the plant was not present. It may be the case that S. maritima is absent from many areas in the bog due to an inability to grow in wet conditions, the sites where it occurred on Tr. 3 were relatively dry as were also the other sites in the Dolfrwynog district (Fig. 9.1). On the other hand the species is also absent from the hillside anomalies of Tr. 5 and many areas of spoil material, it was not for example present on the spoil in the first 30m of Tr. 2 nor on the spoil at Sites 1 and 9. S. maritima has been seen to grow on spoil in the Mendips and it is difficult to see why the species should be absent from much of the spoil at Dolfrwynog. Again in the Mendips the species grew on the slag at Charterhouse which, with substantial lead concentrations and a pH of 5.5, appeared to be too toxic for M. verna and M. verna grows in many places at Dolfrwynog where S. maritima is absent. It may be the case that S. maritima is rather less resistant to copper toxicity than it is to lead toxicity. This might account for the absence of the species from most of the spoil heaps and also the Tr. 5 region at Dolfrwynog.

At Eller Beck and at Malham heavy metal refugia for the indicator species have been identified. The copper rich bog and adjacent habitats at Dolfrwynog seem to be another type of heavy metal refugium. Ernst (1969) has demonstrated by pollen analysis that the indicator plants have been present in the area since the Twelfth Century and it appears probable that they have lived there for much longer. At the present day trees do not occur on the veins on the hillside to the south of the bog nor in most areas of the bog itself and it seems probable that toxicity would have prevented them from establishing themselves in the copper rich areas in the past. Ernst (1969) observed that prior to peat cutting operations at Dolfrwynog the indicator species were more abundant in the bog area, it seems clear that although still a highly interesting metalliferous locality the Dolfrwynog copper rich peat bog of the present day is only a shadow of its former self.
CHAPTER 10

THE INDICATOR PLANTS ELSEWHERE IN ENGLAND AND WALES

10.1 Introduction

In addition to the localities already described the indicator species occur in other places in England and Wales. In Cornwall Armeria maritima is present on copper rich mining spoil and in Wales Thlaspi alpestre grows in alluvium containing lead and zinc in the valley of the Afon Ystwyth near Aberystwyth and on spoil from mines in the Llanrwst district. Minuartia verna occurs on spoil at Halkyn Mountain in North Wales, and near Creggill in the Northern Pannines T. alpestre, M. verna and A. maritima grow in association on a few spoil heaps. These sites have been visited and will now be described.

10.2 Cornwall

The south west peninsula of which Cornwall is a part is mainly composed of non calcareous Devonian and Carboniferous sediments which have been intensely folded. These are generally known as the killas. In places within the sediments and more or less contemporaneous with them are layers of basic and ultra basic intrusive and extrusive rocks known collectively as greenstones. During the Armorican orogeny in Permo-Carboniferous times a granite batholith was intruded into the sediments. Large scale metamorphism and mineralisation accompanied this intrusion (Hosking, 1964).

The granite appears to have been gradually laid bare during the Mesozoic period. During the Tertiary episodes of planation followed by uplift occurred and the area today is one of deep V shaped valleys alternating with flat topped interfluvies, the interfluvies rising in a step like manner inland from the coast (Balchin, 1964). Standing above the planation surfaces are the more resistant granite masses, attaining heights of in excess of 750m.
The general consensus of opinion is that the south west peninsula was not glaciated during the Pleistocene period. The area was, however, subjected to several episodes of periglacial conditions and head, the product of periglacial frost shattering transported by solifluxion, mantles many of the slopes, especially on the granites, at the present day.

The climate of Cornwall is one of high rainfall, mild winters and strong winds. Most areas, and this is true of the Camborne-Redruth district under consideration here, experience a mean annual rainfall of around 1000mm. Mean temperatures at an altitude of around 120m, the altitude of the Camborne-Redruth orefield, are in the region of January, 7°C and July 16°C (based on data for Penzance).

Clayden (1964) has stated that inherently acid, well drained soils of the brown earth type occupy much of the county of Cornwall. The brown earths of the granite outcrops, generally developed in head, show a pH throughout the profile of around 4.5. These soils are normally thin, around 60cm in depth.

Acidic grassland with Festuca and Agrostis species or a heathland involving Calluna vulgaris is normal over the granite outcrop and adjoining metamorphic aureole. Pteridium aquilinum is abundant in places. Ulex europaeus and Calluna vulgaris are important species on the waste ground left by mining operations in the orefield.

The mineralisations of the orefields of Cornwall are generally believed to be of Armorican age. Hosking (1964) suggests that any subsequent mineralisation, mainly related to the Alpine orogeny, is essentially due to redistribution of ore minerals of Armorican age. Ores of copper and tin are the most important in the Camborne-Redruth orefield and quartz is the predominant gangue although calcite, barytes and fluor spar occur in places.
Tin mining in Cornwall has a long history but not until the Eighteenth Century were the copper deposits worked to any considerable extent (Barton, 1968). In the early part of the Nineteenth Century more than half the world's production of copper came from Devon and Cornwall, much of it from the Camborne-Redruth district. As with lead in the latter part of the century large deposits were discovered elsewhere and the industry declined rapidly.

The toxicity of the spoil heaps of the orefield is mainly the result of high copper concentrations and *Armeria maritima* grows in places on the waste dumps.

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Copper (ppm)</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0m</td>
<td>1,470</td>
<td>20</td>
<td>80</td>
<td>5,750</td>
<td>6.5</td>
</tr>
<tr>
<td>2m</td>
<td>2,180</td>
<td>30</td>
<td>88</td>
<td>4,850</td>
<td>nd</td>
</tr>
<tr>
<td>4m</td>
<td>2,550</td>
<td>30</td>
<td>109</td>
<td>8,700</td>
<td>7.5</td>
</tr>
<tr>
<td>6m</td>
<td>2,900</td>
<td>30</td>
<td>100</td>
<td>7,950</td>
<td>nd</td>
</tr>
<tr>
<td>8m</td>
<td>1,070</td>
<td>10</td>
<td>65</td>
<td>6,000</td>
<td>6.6</td>
</tr>
<tr>
<td>10m</td>
<td>3,000</td>
<td>30</td>
<td>94</td>
<td>5,250</td>
<td>nd</td>
</tr>
<tr>
<td>12m</td>
<td>4,100</td>
<td>41</td>
<td>118</td>
<td>6,500</td>
<td>7.4</td>
</tr>
<tr>
<td>14m</td>
<td>2,500</td>
<td>62</td>
<td>109</td>
<td>5,750</td>
<td>nd</td>
</tr>
</tbody>
</table>

On Piece Tr. 1 near Camborne in Cornwall *A. maritima* grew on spoil with species such as *Festuca ovina*, *Rumex acetosa*, *Lotus corniculatus*, *Achillea millefolium* L., and *Calluna vulgaris*. As Table 10.1 demonstrates copper is the important heavy metal of the spoil, the pH of which was between 6.5 and 7.5.

Particle size analysis (Table 10.2) of spoil from Piece Tr. 1 shows the spoil here to be rather coarse in texture, more so than that of spoils on which *A. maritima* has been encountered elsewhere.
Table 10.2  Particle size analysis of spoil from 6m on Piece Tr. 1

<table>
<thead>
<tr>
<th></th>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>28.9%</td>
<td>21.5%</td>
<td>18.8%</td>
<td>18.4%</td>
<td>10.1%</td>
<td>2.5%</td>
</tr>
</tbody>
</table>

In addition to those from the Piece transect analyses are available from spoil elsewhere in the Camborne-Redruth district. These are shown in Table 10.3. Sites 2, 4, 6 and 7 were of spoil on which A. maritima was not present. It is apparent that these sites show lower pH values than sites 1 and 2 and the spoil of Piece Tr. 1 (Table 10.1) where A. maritima grew. It appears that even though copper concentrations are relatively low in some of the sites where A. maritima was not present the toxicity of the spoil at the low pH excludes the species. Some of the A. maritima plants at Chacewater S. 5, the A. maritima locality with the lowest pH, showed chlorotic symptoms. The spoil of pH below 5.0 on which A. maritima did not occur was occupied mainly by Calluna vulgaris. It appears from the widespread distribution of Calluna vulgaris and the general scarcity of A. maritima on spoil heaps in the Camborne-Redruth orefield that spoil of low pH is normal in the district.

Table 10.3  Heavy metal, calcium and pH determinations from spoil heaps in the Camborne-Redruth district.

<table>
<thead>
<tr>
<th>Site</th>
<th>Copper (ppm)</th>
<th>Calcium (ppm)</th>
<th>pH</th>
<th>Armeria maritima</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. 1. Cusgarne</td>
<td>3,000</td>
<td>2,950</td>
<td>5.9</td>
<td>+</td>
</tr>
<tr>
<td>S. 5. Chacewater</td>
<td>7,900</td>
<td>6,000</td>
<td>5.7</td>
<td>+</td>
</tr>
<tr>
<td>S. 2. Cusgarne</td>
<td>200</td>
<td>2,000</td>
<td>3.8</td>
<td>-</td>
</tr>
<tr>
<td>S. 4. Chacewater</td>
<td>460</td>
<td>2,000</td>
<td>3.7</td>
<td>-</td>
</tr>
<tr>
<td>S. 6. Piece</td>
<td>400</td>
<td>3,300</td>
<td>4.2</td>
<td>-</td>
</tr>
<tr>
<td>S. 7. Piece</td>
<td>1,100</td>
<td>3,150</td>
<td>4.0</td>
<td>-</td>
</tr>
</tbody>
</table>

+ A. maritima present
- A. maritima absent
The Afon Ystwyth drains an area of Silurian rocks to the east south east of Aberystwyth in Wales. In the Nineteenth Century the area inland from Aberystwyth was an important mining region and the remains of the old mines are visible in many places today. The largest mine in the catchment of the Ystwyth appears to have been that by the river at Cwmystwyth about 22km inland from Aberystwyth and in the Nineteenth Century and perhaps earlier much alluvial material containing heavy metals was washed downstream from mines such as Cwmystwyth to pollute the lower floodplain of the river. Pollution association with mining operations appears to have been widespread in this area of Wales in the Nineteenth Century, Griffiths (1918) records the severe effects of heavy metal pollution on agricultural land and livestock in the region.

The floodplain of the lower Ystwyth near Aberystwyth is almost at sea level and the area experiences a climate very similar to that of Aberystwyth. Rainfall at Aberystwyth averages over 900mm annually and mean temperatures from 1926 to 1950 were January, 5.3°C and July, 15.5°C.

*Thlaspi alpestre* occurs today at two places in Wales; in the Llanrwst orefield and on the floodplain of the Afon Ystwyth associated with toxic alluvium. *Silene maritima* is also present on the floodplain of the Ystwyth, extending for some distance inland. *S. maritima* was associated with *T. alpestre* at some of the sites in which samples were taken. Table 10.4 shows the locations of and analyses from the sampled sites.

The vegetation of the surface of the floodplain of the Afon Ystwyth showed no obvious evidence of heavy metal toxicity, there were, for example, no areas with a substantial amount of bare ground and *T. alpestre* did not occur on the floodplain. All the sites shown on Table 10.4, with the exception of Site 3, were on steep and unstable river
cliffs. At Site 3 _T. alpestre_ grew with _S. maritima_ on a flood retaining bank of apparently recent construction. _T. alpestre_ was not present at Sites 5 and 6, these are samples from places where _S. maritima_ grew.

As Table 10.4 shows the heavy metal concentrations in the alluvium are not high, they do not attain the concentrations seen in the alluvium from Eller Beck, but pH values are below 6.0. At these pH values the alluvium seems sufficiently toxic to provide a habitat for _T. alpestre_ but only in unstable situations on river cliffs, or, as in the case of Site 3, in recently disturbed habitats.

The sites in Table 10.4 represent all the places at which _T. alpestre_ was found in the course of a thorough search of 4km of river bank. Some sites will have been missed but it is believed not many and the species must be considered rare on the floodplain of the Ystwyth today. As an example between Llanfarian and the coast where recent river canalisation works have probably affected the habitat of _T. alpestre_ only two plants were found along 2km of river bank.

Table 10.4 Heavy metal, calcium, pH and organic carbon analysis of alluvium from the floodplain of the Afon Ystwyth

<table>
<thead>
<tr>
<th>Site</th>
<th>Grid reference</th>
<th>Copper (ppm)</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>pH</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>592776</td>
<td>47</td>
<td>1,790</td>
<td>710</td>
<td>1,760</td>
<td>5.9</td>
<td>9.3%</td>
</tr>
<tr>
<td>2</td>
<td>592776</td>
<td>37</td>
<td>1,680</td>
<td>560</td>
<td>1,540</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>3</td>
<td>582776</td>
<td>47</td>
<td>1,450</td>
<td>620</td>
<td>1,230</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>4</td>
<td>598766</td>
<td>37</td>
<td>2,350</td>
<td>770</td>
<td>2,145</td>
<td>5.4</td>
<td>8.6%</td>
</tr>
<tr>
<td>5</td>
<td>607756</td>
<td>42</td>
<td>1,900</td>
<td>560</td>
<td>2,250</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>6</td>
<td>609755</td>
<td>26</td>
<td>2,020</td>
<td>500</td>
<td>1,450</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>7</td>
<td>584795</td>
<td>42</td>
<td>2,700</td>
<td>530</td>
<td>1,355</td>
<td>5.5</td>
<td>5.7%</td>
</tr>
<tr>
<td>8</td>
<td>584797</td>
<td>26</td>
<td>2,350</td>
<td>300</td>
<td>2,180</td>
<td>nd</td>
<td>nd</td>
</tr>
</tbody>
</table>
The Llanrwst orefield

A general account of the regional geology and structure of the North Wales area in which the orefield lies has already been given in Chapter 9. In the Gwydyr region (Fig. 10.1) between Llanrwst and Betws-y-Coed rocks of the Crafnant Series are most important. These are rhyolites and tuffs resulting from volcanic activity dating from the Lower Bala times of the Ordovician period.

In the Gwydyr region, as at Dolfrwynog, glaciation was essentially a local process and was here related to ice movement from the Snowdon massif towards the valley of the Conway. This ice excluded the major Irish sea ice moving from the north (Smith and George, 1961). For this reason the thin glacial tills of the Gwydyr district are of local origin.

Most of the orefield lies at an altitude of 200-300m and is in the lee of the Snowdon massif. Precipitation is therefore likely to be lower than at similar altitudes to the windward of Snowdon and an annual rainfall total around 1,250mm seems probable. Adjustment for altitude of the mean temperature figures for Llandudno suggests a mean temperature for July of the order of 14.7°C and for January of 4.8°C.

There is little information available on the soils of the district but Ball et al (1969) have shown that highly leached brown earths occur on rhyolitic drift in the Snowdon area and this is probably also the case in the Gwydyr region.

Much afforestation by the Forestry Commission has taken place in the Gwydyr district and today the spoil dumps and mine buildings are to be found amidst plantations of various coniferous trees. Small areas have remained unplanted and are under acidic grassland while certain of the areas greatly disturbed by mining activity have been colonized by Calluna vulgaris.
THE LLANRWST OREFIELD

Figure 10.1
Mineralisation in the orefield appears to be of Armorican age (Smith and George, 1961) and Archer (1958) has provided a summary of the important mines and the nature of mineralisation in the region. He states that the mineral content of the various lodes is generally similar; the ore minerals galena, blende and marcasite occur in a gangue of varying proportions of quartz and calcite.

Lewis (1957) states that the mines near Llanrwst were working in the Seventeenth Century but that little attempt was made to work the deposits properly until the 1850's. It is probable and in some cases certain that some of the spoil heaps may be more recent than those in other orefields. Mining continued in the area intermittently until 1954 when the Parc Mine closed because the workings became uneconomic.

Fig. 10.1 shows the distribution of *T. alpestre* in the Llanrwst orefield and it is apparent that the species does not occur on all the spoil heaps in the district. There is a specimen of *T. alpestre* in the Herbarium at Kew from an old wall in the Llanrwst area but otherwise all the records refer to the association of the species with lead mine spoil.

At the Hafna Lead Mine (Fig. 10.1) *T. alpestre* occurs in places around the mine buildings which adjoin the minor road. The workings extend uphill along the vein for some distance behind the mine buildings but the spoil heaps here were almost devoid of vegetation and *T. alpestre* was not present. A short transect was run across a spoil heap on which *T. alpestre* grew on the hillside to the west of the mine chimney. Table 10.5 shows the results of analyses of spoil from this site. All the copper concentrations were below 125 ppm and have not been included.
Table 10.5  Heavy metal, calcium, pH and organic carbon determinations from the Hafna Lead Mine Tr. 1

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>pH</th>
<th>Organic carbon</th>
<th>Thlaspi alpestre</th>
</tr>
</thead>
<tbody>
<tr>
<td>0m</td>
<td>23,100</td>
<td>9,100</td>
<td>3,330</td>
<td>6.4</td>
<td>nd</td>
<td>+</td>
</tr>
<tr>
<td>1m</td>
<td>36,000</td>
<td>13,200</td>
<td>4,437</td>
<td>6.4</td>
<td>7.3%</td>
<td>+</td>
</tr>
<tr>
<td>2m</td>
<td>28,500</td>
<td>14,000</td>
<td>4,280</td>
<td>6.5</td>
<td>11.9%</td>
<td>+</td>
</tr>
<tr>
<td>3m</td>
<td>28,500</td>
<td>12,000</td>
<td>1,390</td>
<td>6.2</td>
<td>9.2%</td>
<td>+</td>
</tr>
<tr>
<td>4m</td>
<td>21,800</td>
<td>7,700</td>
<td>1,840</td>
<td>6.0</td>
<td>8.2%</td>
<td>+</td>
</tr>
<tr>
<td>5m</td>
<td>13,500</td>
<td>5,000</td>
<td>1,020</td>
<td>5.9</td>
<td>nd</td>
<td>-</td>
</tr>
<tr>
<td>6m</td>
<td>11,200</td>
<td>6,200</td>
<td>714</td>
<td>6.1</td>
<td>1.4%</td>
<td>-</td>
</tr>
<tr>
<td>7m</td>
<td>21,400</td>
<td>7,100</td>
<td>1,190</td>
<td>6.0</td>
<td>nd</td>
<td>-</td>
</tr>
<tr>
<td>8m</td>
<td>5,300</td>
<td>1,680</td>
<td>1,840</td>
<td>6.1</td>
<td>5.6%</td>
<td>+</td>
</tr>
<tr>
<td>9m</td>
<td>16,800</td>
<td>9,400</td>
<td>1,390</td>
<td>6.2</td>
<td>nd</td>
<td>+</td>
</tr>
<tr>
<td>10m</td>
<td>11,200</td>
<td>3,300</td>
<td>515</td>
<td>5.6</td>
<td>3.0%</td>
<td>-</td>
</tr>
<tr>
<td>11m</td>
<td>14,500</td>
<td>3,000</td>
<td>675</td>
<td>5.7</td>
<td>nd</td>
<td>-</td>
</tr>
</tbody>
</table>

+  Thlaspi alpestre present
-  Thlaspi alpestre absent

Lead (Table 10.5) is the more important heavy metal in the spoil heap but zinc is present in moderate concentrations in certain samples. Along the transect line there is also variability in calcium levels and pH values, pH and calcium concentrations are higher in the first few metres than at 10 and 11m where calcium is below 700 ppm and the pH below 6.0.

The symbols in the T. alpestre column of Table 10.5 indicate the presence or absence of the species in the quadrats adjoining a sample site. It appears that T. alpestre was absent in all places where the calcium concentration was below 1,300 ppm and present in all quadrats where the calcium level was above this figure. The species does not show a precise relationship with pH but is certainly not present in those places.
where the pH is below 6.0. It appears that on this transect line at these heavy metal levels *T. alpestre* is excluded by toxicity when the calcium concentration falls below 1,300 ppm and the pH below 6.0. The suggestion of greater toxicity in the areas not occupied by *T. alpestre* is supported by the organic carbon analyses, these are lower at 6m and 10m where the species was absent than in all the places where the species was present.

The Hafna Lead Mine was one of the few sites on the orefield where *T. alpestre* occurred in any relative abundance, elsewhere just a few plants grew in scattered localities on spoil heaps. Table 10.6 shows analyses from these sites while Table 10.7 shows the analyses from other spoil heaps where *T. alpestre* was not present. Copper concentrations in these samples were similar to those from the Hafna Lead Mine and have not been included. The locations from which the samples were taken are shown on Fig. 10.1.

**Table 10.6** Heavy metal, calcium, pH and organic carbon determinations from spoil with *T. alpestre* in the Llanrwst orefield

<table>
<thead>
<tr>
<th>Site</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>pH</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>56,500</td>
<td>62,000</td>
<td>7,805</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>7</td>
<td>4,400</td>
<td>10,300</td>
<td>1,505</td>
<td>6.1</td>
<td>3.7%</td>
</tr>
<tr>
<td>8</td>
<td>90,000</td>
<td>24,200</td>
<td>9,150</td>
<td>6.6</td>
<td>3.0%</td>
</tr>
<tr>
<td>14</td>
<td>19,000</td>
<td>12,900</td>
<td>5,980</td>
<td>7.2</td>
<td>3.9%</td>
</tr>
<tr>
<td>16</td>
<td>3,200</td>
<td>50,000</td>
<td>11,925</td>
<td>6.6</td>
<td>3.6%</td>
</tr>
<tr>
<td>19</td>
<td>22,500</td>
<td>25,700</td>
<td>36,850</td>
<td>7.0</td>
<td>6.8%</td>
</tr>
<tr>
<td>20</td>
<td>32,700</td>
<td>8,800</td>
<td>10,600</td>
<td>6.7</td>
<td>nd</td>
</tr>
<tr>
<td>21</td>
<td>17,900</td>
<td>15,500</td>
<td>33,250</td>
<td>7.2</td>
<td>1.3%</td>
</tr>
</tbody>
</table>
Table 10.7  Heavy metal, calcium, pH and organic carbon determinations from spoil without *T. alpestre* in the Llanrwst orefield

<table>
<thead>
<tr>
<th>Site</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>pH</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90,600</td>
<td>50,000</td>
<td>1,700</td>
<td>6.9</td>
<td>1.1%</td>
</tr>
<tr>
<td>2</td>
<td>425</td>
<td>1,400</td>
<td>1,110</td>
<td>5.7</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>415</td>
<td>500</td>
<td>790</td>
<td>3.8</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>5,500</td>
<td>1,300</td>
<td>1,110</td>
<td>3.5</td>
<td>1.0%</td>
</tr>
<tr>
<td>5</td>
<td>15,800</td>
<td>1,060</td>
<td>515</td>
<td>4.0</td>
<td>0.5%</td>
</tr>
<tr>
<td>10</td>
<td>28,200</td>
<td>4,100</td>
<td>2,040</td>
<td>6.3</td>
<td>4.2%</td>
</tr>
<tr>
<td>11</td>
<td>16,800</td>
<td>1,000</td>
<td>1,040</td>
<td>7.1</td>
<td>2.8%</td>
</tr>
<tr>
<td>12</td>
<td>16,800</td>
<td>1,300</td>
<td>870</td>
<td>4.7</td>
<td>9.0%</td>
</tr>
<tr>
<td>13</td>
<td>26,000</td>
<td>2,700</td>
<td>1,500</td>
<td>4.5</td>
<td>2.9%</td>
</tr>
<tr>
<td>15</td>
<td>26,000</td>
<td>77,000</td>
<td>9,100</td>
<td>6.7</td>
<td>1.5%</td>
</tr>
<tr>
<td>17</td>
<td>2,350</td>
<td>62,000</td>
<td>10,420</td>
<td>7.3</td>
<td>2.6</td>
</tr>
<tr>
<td>18</td>
<td>49,700</td>
<td>36,000</td>
<td>1,450</td>
<td>6.9</td>
<td>4.4%</td>
</tr>
</tbody>
</table>

The samples of Table 10.7 show considerable variability in pH values and it is apparent that in this orefield certain spoil heaps are very acidic. Sites 3, 4 and 5 show spoil with pH values of 4.0 and below. *Calluna vulgaris* grew on these heaps and they may be considered similar to the acidic spoil heaps of Cornwall described previously. Several of the sites in Table 10.7 show pH values above 6.0 but did not support populations of *T. alpestre*. The reasons for this are not apparent from the available analyses.

All the sites at which *T. alpestre* occurred (Table 10.6) showed a pH above 6.0 and a calcium concentration above 1,300 ppm, the same parameters which appeared to delimit the distribution of the species on the Hafna Lead Mine Tr. 1. It appears from the analyses for the Llanrwst orefield that *T. alpestre* is excluded by toxicity from spoil materials with a pH below 6.0 and calcium concentrations below 1,300 ppm but does not occur everywhere where pH and calcium exceed these values.
The mineralisation at Halkyn Mountain is part of an orefield associated with rocks of Carboniferous age which outcrop in a broad arc from Prestatyn to beyond Oswestry.

The Carboniferous Limestone in the region attains a thickness in places of between 750 and 1000m and is essentially a coral or shelly limestone. Millstone Grit times brought a change in the nature of the facies and the Cefn-y-fedw sandstone was deposited in the Halkyn district. Although of Millstone Grit age this sandstone is, initially at least, somewhat calcareous (Smith and George, 1961).

Following the deposition of the Carboniferous rocks North Wales was subjected to folding and faulting associated with the Armorican earth movements. As mentioned previously North Wales acted during the orogeny as a stable and resistant block. Folding in the Carboniferous rocks of North Wales is therefore relatively gentle but much faulting occurred, often conforming to the trend of the underlying Palaeozoic structures. Mineralisation accompanied or closely followed this episode of Armorican faulting (Smith and George, 1961).

The mine dumps at Halkyn Mountain are at an altitude of around 140m and adjustment of the temperature data for Llandudno suggests a January mean of the order of 5.1°C and a July mean of 15°C. Annual precipitation averages about 1100mm (Bowen, 1957).

Halkyn Mountain has been very greatly disturbed by mining operations and is today for the most part waste land. Ulex europaeus has colonized large areas of the disturbed ground.

Mineralisation in the district is almost completely restricted to the Carboniferous Limestone and Cefn-y-fedw Sandstone. It is probable that, as in other areas, the mineralisation is the result of upward movement along joints and faults of hydrothermal solutions.
derived from a deep seated source (Smith and George, 1961). The main ore minerals were galena and blende, associated with calcite, fluor-spar and barytes gangues.

It is known that the Romans worked lead in the area (Lewis, 1967). Mining at Halkyn reached its zenith in the Nineteenth Century but continued longer than elsewhere in Britain. The last mine closed in 1958, for economic reasons rather than due to shortage of ore (Lewis, 1967).

A short transect (Tr. 1, Table 10.8) on a spoil heap on Halkyn Mountain showed *M. verna* occurring with a normal assemblage of associated species including *Festuca ovina*, *Thymus drucei*, *Euphrasia officinalis*, *Linum catharticum* and *Hieracium pilosella*. Bare ground in most quadrats was of the order of 50%.

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Copper (ppm)</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>Ca/HM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1m</td>
<td>97</td>
<td>62,900</td>
<td>16,100</td>
<td>33,250</td>
<td>0.71</td>
</tr>
<tr>
<td>3m</td>
<td>97</td>
<td>29,700</td>
<td>11,500</td>
<td>25,350</td>
<td>0.71</td>
</tr>
<tr>
<td>5m</td>
<td>67</td>
<td>70,700</td>
<td>8,200</td>
<td>26,150</td>
<td>0.35</td>
</tr>
<tr>
<td>7m</td>
<td>67</td>
<td>54,100</td>
<td>5,900</td>
<td>28,950</td>
<td>0.51</td>
</tr>
<tr>
<td>9m</td>
<td>102</td>
<td>71,900</td>
<td>12,000</td>
<td>35,000</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Table 10.8 indicates that lead is the predominant heavy metal of the spoil heap and that copper, as in most spoil heaps derived from workings in the Carboniferous Limestone, is present in insignificant amounts.

Potassium and magnesium (Table 10.9) on this heap are in lower amounts than is usual for Carboniferous Limestone spoil but phosphorous is present at a normal concentration.
Table 10.9 Sodium, potassium, magnesium, phosphorous and pH determinations from 5m on Halkyn Mountain Tr. 1

<table>
<thead>
<tr>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>850</td>
<td>660</td>
<td>1,160</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Near to the transect line a very interesting site for *M. verna* was found on a track composed of mine spoil. The track was covered for the most part by a short *Festuca ovina* sward. In a small area, about 1 sq. m., the *F. ovina* turf had been removed in the same way that turf is cut for lawns. *M. verna* grew in the bare area produced by turf removal but not in the surrounding *F. ovina* sward. Soil samples were taken along a short transect line (Tr. 2) which ran from the *M. verna* area to the surrounding *F. ovina* sward. The samples in the *F. ovina* sward were taken from a depth equivalent to that of the base of the depression in which *M. verna* occurred, about 7 cm. Table 10.10 shows the results of these analyses.

Table 10.10 Heavy metal, calcium and Ca/HM ratio determinations from Halkyn Mountain Tr. 2

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>Ca/HM</th>
<th>Minuartia verna</th>
</tr>
</thead>
<tbody>
<tr>
<td>0m</td>
<td>29,700</td>
<td>4,400</td>
<td>104,200</td>
<td>3.27</td>
<td>-</td>
</tr>
<tr>
<td>0.5m</td>
<td>40,700</td>
<td>9,100</td>
<td>119,200</td>
<td>2.61</td>
<td>+</td>
</tr>
<tr>
<td>1m</td>
<td>39,700</td>
<td>10,600</td>
<td>113,700</td>
<td>2.54</td>
<td>+</td>
</tr>
<tr>
<td>1.5m</td>
<td>51,800</td>
<td>11,200</td>
<td>132,700</td>
<td>2.31</td>
<td>+</td>
</tr>
<tr>
<td>2m</td>
<td>41,800</td>
<td>15,200</td>
<td>135,100</td>
<td>2.73</td>
<td>+</td>
</tr>
<tr>
<td>2.5m</td>
<td>41,700</td>
<td>8,500</td>
<td>108,150</td>
<td>2.35</td>
<td>-</td>
</tr>
<tr>
<td>3m</td>
<td>38,500</td>
<td>11,200</td>
<td>113,700</td>
<td>2.58</td>
<td>-</td>
</tr>
<tr>
<td>3.5m</td>
<td>23,00</td>
<td>15,200</td>
<td>155,300</td>
<td>5.08</td>
<td>-</td>
</tr>
<tr>
<td>4m</td>
<td>25,200</td>
<td>18,700</td>
<td>155,300</td>
<td>4.49</td>
<td>-</td>
</tr>
</tbody>
</table>

+ *M. verna* present
- *M. verna* absent
It is evident from Table 10.10 that on Tr. 2 lead and zinc are present in lower concentrations than on Tr. 1 (Table 10.8) but especially significant is that calcium is present in much higher concentrations. In consequence the Ca/HM ratios are very different and the spoil of Tr. 2 appears to be much less toxic than that of Tr. 1.

The samples (Table 10.10) from 2.5 and 3m below the closed F. ovina sward show Ca/HM ratios of the order of those in the area from 0.5 to 2m where the F. ovina turf had been removed and M. verna was present. This site appears to provide evidence of exclusion of M. verna in the process of succession on spoil materials, the removal of the turf has set succession back to an earlier stage and it appears that M. verna has recolonized the site. The spoil here probably dates from late last century, this was the period of maximum mining activity in the area, and the evidence from Tr. 2 suggests that at a Ca/HM ratio of 2.5 M. verna has been excluded in the course of succession within a period of 100 years. In contrast on the spoil heap of Tr. 1 with its higher toxicity there is still much bare ground and M. verna occurred all along the transect line.

10.6 The Carrigill area in the Northern Pennines

On the Alston Block in the Northern Pennines the lower Carboniferous is represented by rocks of the Yoredale facies and mineralisation in the area is normally associated with the limestone horizons in the Yoredales. The Alston Block is bounded on the west by the Pennine Fault which is responsible for the steep western wall of Cross Fell and from the summit of Cross Fell at just under the 900m the country slopes eastwards, drained by the Rivers Tees, Wear and South Tyne. In the Alston region limestone is subordinate in the general topography and not dominant as in the Malham district to the south and large areas of the fells are mantled by thin glacial deposits of local origin.
Manley (1936) stated that the "North Pennine moorlands comprise the most consistently elevated and chilly part of England". He points out that "spring approaches slowly in the area, 50°F (10°C) may not be expected until late March and even a day or two in May will have maxima below 40°F (4.4°C)." He suggests that the climate is comparable with that of southern Iceland. Manley (1945) stated that the length of the growing season at Moor House (561m) was 165 days. He calculated that the length of the growing season in the Northern Pennines decreases by one day for each 7.9m rise in altitude. It thus appears that the length of the growing season at Garrigill is about 17 days longer.

Millar (1964) presented temperature data for Moor House for the period 1953 to 1962. This data indicates a January mean of -0.3°C and a July mean of 11.1°C. These figures suggest a climate colder than the estimated figures in Manley (1943) for the period 1906 to 1935, 0.6°C and 11.6°C respectively. Mean temperatures in the Garrigill area, about 135m lower in altitude, will be no more than 1°C greater.

Glasspoole (1932) has provided details of rainfall totals in the Northern Pennines. He demonstrated a rapid increase in rainfall westwards from Middleton in Teesdale; Middleton records about 890mm annually and Cronkley Fell about 1300mm while the fell summits reach more than 1780mm each year. Annual precipitation at Garrigill is probably around 1400mm.

Much of the Northern Pennine district is covered by thin tills and in the conditions of high rainfall and low temperatures peat formation occurs on many sites. Even where limestone is near to the surface leaching of the upper horizons of the soil has occurred and in consequence calcareous grassland is unusual. The peats and peaty soils are occupied by Calluna vulgaris moors and Nardus stricta grassland and a Festuca ovina - Agrostis tenuis grassland occurs where limestone is nearer to the surface. In places Molinia caerulea flourishes in acidic flushes.
The region is famous for the communities of Arctic-Alpine plants which occur in calcareous flushes in the headwaters of the Tees. Pigott (1956) in considering these plant refugia of Upper Teesdale suggested that the low summer temperatures combined with the rarity of prolonged drought, especially in wet localities, were important operative factors in the habitats of the Arctic-Alpine species.

Mineralisation in the Northern Pennines dates from the Armorican period and the productive veins were generally normal faults of small throw and a north east to south west trend. The main ore of the mineral field was galena, zinc blende occurred only sporadically. Fluorspar was important in Weardale but to the south barytes and calcite were the predominant gangues (Dunham, 1948).

The Romans are thought to have worked lead in the Northern Pennines and mining is believed to have continued throughout the Middle Ages. The Northern Pennines was the centre of operations of the great mining companies of the Eighteenth and Nineteenth Centuries and large mines, entered by horse levels from the deep valleys, were a feature of the district (Raistrick and Jennings, 1965).

Near to Garrigill in the Northern Pennine orefield Armeria maritima, Minuartia verna, Thlaspi alpestre, Cochlearia officinalis and Parnassia palustris grow on spoil heaps derived from workings in the Crag Green North vein.

Fig. 10.2 refers to a short transect on the south facing slope of the spoil heap and it is apparent that the indicator plants are accompanied by several of those species characteristic of Carboniferous Limestone spoil heaps. The spoil in this region sloped at about 32° and was quite unstable, the instability being due in part to trampling by cattle.
GARRIGILL: GEOBOTANY
TRANSECT 1.

GEOCHEMISTRY

RELIEF

Figure 10.2
Table 10.11  Heavy metal, calcium and Ca/HM ratio determinations from Garrigill Tr. 1

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>Ca/HM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0m</td>
<td>1,520</td>
<td>2,200</td>
<td>5,250</td>
<td>2.0</td>
</tr>
<tr>
<td>2m</td>
<td>6,290</td>
<td>5,600</td>
<td>8,700</td>
<td>0.96</td>
</tr>
<tr>
<td>4m</td>
<td>6,750</td>
<td>9,700</td>
<td>14,900</td>
<td>1.28</td>
</tr>
<tr>
<td>6m</td>
<td>6,620</td>
<td>17,500</td>
<td>35,500</td>
<td>2.31</td>
</tr>
<tr>
<td>8m</td>
<td>3,970</td>
<td>4,700</td>
<td>12,650</td>
<td>2.0</td>
</tr>
</tbody>
</table>

The Ca/HM ratios (Table 10.11) indicate a spoil of moderate toxicity and Table 10.12 demonstrates that potassium concentrations in many samples are high for a Carboniferous Limestone spoil but that phosphorous is present at a level lower than the normal figure of around 1,000 ppm.

Table 10.12  Sodium, potassium, magnesium, phosphorous and pH determinations from Garrigill Tr. 1

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0m</td>
<td>150</td>
<td>3,060</td>
<td>890</td>
<td>nd</td>
<td>7.0</td>
</tr>
<tr>
<td>2m</td>
<td>175</td>
<td>2,850</td>
<td>nd</td>
<td>nd</td>
<td>7.1</td>
</tr>
<tr>
<td>4m</td>
<td>210</td>
<td>4,700</td>
<td>1,260</td>
<td>680</td>
<td>7.2</td>
</tr>
<tr>
<td>6m</td>
<td>450</td>
<td>8,280</td>
<td>nd</td>
<td>nd</td>
<td>7.1</td>
</tr>
<tr>
<td>8m</td>
<td>240</td>
<td>1,905</td>
<td>3,070</td>
<td>nd</td>
<td>7.0</td>
</tr>
</tbody>
</table>

A particle size analysis from 2m on Garrigill Tr. 1 (Table 10.13) shows the spoil here to be relatively fine in texture compared to many derived from workings in the Carboniferous Limestone.
Table 10.13  Particle size analysis of spoil from 2m on Garrigill Tr. 1

<table>
<thead>
<tr>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.1%</td>
<td>6.2%</td>
<td>20.7%</td>
<td>37.6%</td>
<td>16.9%</td>
<td>9.0%</td>
</tr>
</tbody>
</table>

On the north facing slope of the spoil heap another transect (Tr. 2) crossed an area with an overall species composition very similar to that of Tr. 1. The ground was much less disturbed here than on Tr. 1 and bare ground in the quadrats averaged 23%, in contrast to 51% on Tr. 1. The spoil on Tr. 2 (Table 10.14) is rather more toxic than that on Tr. 1, mainly due to higher lead concentrations.

Table 10.14  Heavy metal, calcium and Ca/HM ratio determinations from Garrigill Tr. 2

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Lead (ppm)</th>
<th>Zinc (ppm)</th>
<th>Calcium (ppm)</th>
<th>Ca/HM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0m</td>
<td>13,000</td>
<td>5,000</td>
<td>9,750</td>
<td>0.63</td>
</tr>
<tr>
<td>2m</td>
<td>10,700</td>
<td>4,300</td>
<td>9,600</td>
<td>0.75</td>
</tr>
<tr>
<td>4m</td>
<td>14,200</td>
<td>4,700</td>
<td>16,500</td>
<td>1.0</td>
</tr>
<tr>
<td>6m</td>
<td>12,000</td>
<td>5,000</td>
<td>7,700</td>
<td>0.53</td>
</tr>
<tr>
<td>8m</td>
<td>15,200</td>
<td>4,700</td>
<td>8,500</td>
<td>0.48</td>
</tr>
</tbody>
</table>

As Table 10.15 shows nutrient concentrations and pH values on Tr. 2 are very similar to those of Tr. 1 (Table 10.12) with the exception of potassium, present in lower concentrations.

Table 10.15  Sodium, potassium, magnesium, phosphorous and pH determinations from Garrigill Tr. 2

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Sodium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Phosphorous (ppm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0m</td>
<td>210</td>
<td>1,650</td>
<td>850</td>
<td>nd</td>
<td>6.8</td>
</tr>
<tr>
<td>2m</td>
<td>175</td>
<td>1,540</td>
<td>nd</td>
<td>nd</td>
<td>7.1</td>
</tr>
<tr>
<td>4m</td>
<td>225</td>
<td>2,140</td>
<td>1,260</td>
<td>640</td>
<td>7.3</td>
</tr>
<tr>
<td>6m</td>
<td>150</td>
<td>1,860</td>
<td>nd</td>
<td>nd</td>
<td>6.9</td>
</tr>
<tr>
<td>8m</td>
<td>195</td>
<td>1,540</td>
<td>470</td>
<td>nd</td>
<td>7.0</td>
</tr>
</tbody>
</table>
On Tr. 2 Cochlearia officinalis was present in 6 out of 8 quadrats, unlike Tr. 1 where the species was only seen in 1 quadrat, and Parnassia palustris, absent on Tr. 1 was also present in 6 quadrats. This distribution does not seem to be related to toxicity, the spoil of Tr. 2 is rather more toxic than that of Tr. 1. Nor are there substantial differences in nutrient status or pH between the two areas. Parnassia palustris is a species of wet habitats, Clapham et al (1952) give the habitat as marshes and wet moors. It seems probable that P. palustris is present on the north facing slope of this spoil heap and absent on the south facing Tr. 1 side as a function of microclimate. The spoil heap will be cooler and show a better moisture status in the substrate on the northern side. The habitat of Cochlearia officinalis in Derbyshire was stated in Clapham (1969) to be north facing cliffs on the Carboniferous Limestone, again a suggestion of a requirement for cooler and moister habitats, and the difference in frequency of the species on the two sides of the spoil heap is probably again a microclimatic effect.

As was shown in the Eller Beck region Armeria maritima and C. officinalis tend to be restricted to the wetter sites. At Eller Beck Parnassia palustris, present on the spoil heap, was associated with A. maritima and C. officinalis in the metalliferous riparian habitats. At Garrigill all three species occur together on spoil. It seems probable that this occurrence of these three species on a spoil heap is due to the favourable textural characteristics of the substrate at this site, the spoil is of relatively fine texture, a factor augmented by the rarity of prolonged drought in the Northern Pennine region which Pigott (1956) referred to.
PART 3

FACTORS INFLUENCING THE DISTRIBUTION OF THE HEAVY METAL TOLERANT INDICATOR SPECIES
CHAPTER 11

THE OCCURRENCE OF MINUARTIA Verna IN RELATION TO REGIONAL VARIATIONS IN SUBSTRATE TOXICITY

11.1  Introduction

Minuartia verna has been found growing on spoil derived from workings in the Carboniferous Limestone in seven discrete areas, the Aachen-Liege orefield, the Mendips, Halkyn Mountain, the Southern Pennines, the Malham District, Eller Beck in Wensleydale and in the Northern Pennines. In certain of these areas, especially the Twinbottom Scar district at Malham the spoil contained relatively little calcium and appeared to be very toxic. In such places M. verna tended to be present more or less everywhere on the spoil heaps. Elsewhere calcium was in higher concentration, the spoils appeared less toxic and M. verna was often restricted to certain parts of the spoil heaps. On these spoil heaps it was possible to establish a toxicity threshold for the occurrence of M. verna and the geographical variation in the threshold for the species will now be considered.

11.2  The occurrence of Minuartia verna in relation to the Ca/HM ratio in different orefields

In the Aachen-Liege orefield M. verna was not found on spoil with a Ca/HM ratio greater than 0.7 and at this ratio M. verna was occurring at only low cover values in the associated quadrats. One site was found in the Aachen-Liege area where M. verna occurred at a Ca/HM ratio of 15.95 but this was on the highly calcareous, arid and unstable side of an excavated vein and it was suggested that this was not a habitat comparable with spoil heaps.
In the Mendips *M. verna* was present at Charterhouse and at Stock Hill. The Charterhouse site was not on spoil material but at Stock Hill *M. verna* showed a very clear relationship with the Ca/HM ratio on Tr. 1 and was not present at a Ca/HM ratio in excess of 0.4. At Charterhouse *M. verna* was again present at Ca/HM ratios of less than 0.4 and in this locality disturbance by trampling seemed an important factor in the maintenance of its habitat, even at the quite high toxicity.

At Halkyn Mountain two localities where *M. verna* grew were sampled, one on a relatively bare spoil heap (Tr. 1) and the other in an area where *M. verna* had apparently been replaced by other species in the course of succession but had returned following the removal of turf (Tr. 2). The Ca/HM ratio of the area where *M. verna* had been replaced by succession was of the order of 2.5 and on the spoil heap the species grew at Ca/HM ratios between 0.5 and 1.0. A precise figure for a *M. verna* threshold cannot be advanced on the basis of the evidence available but an intermediate figure of around 1.75 seems reasonable.

In the Southern Pennines *M. verna* was found growing on spoil up to a Ca/HM ratio of 7.52. It was however demonstrated that where *M. verna* occurred at high Ca/HM ratios there was some disturbing factor in the environment, rabbits, trampling by man and substrate instability were identified in various places. On the relatively stable transect on the River Bradford at Alport *M. verna* was not found growing in any quadrat with a Ca/HM ratio in excess of 3.5 and in only one with a Ca/HM ratio greater than 3.0. None of the spot samples from relatively stable sites in the Southern Pennines showed *M. verna* at a Ca/HM ratio in excess of 3.0 and this figure is proposed as a toxicity threshold for the species in the region.

As mentioned previously many of the spoil heaps in the Malham area are very toxic but at Proctor High Mark, Grassington Moor and Appletreewick *M. verna* grew on spoils with high Ca/HM ratios. At Proctor High Mark *M. verna* was present in every quadrat on a
transect line with Ca/HM ratios ranging from 3.5 to 8.16 and at Grassington Moor the species occurred on unstable spoil at a Ca/HM ratio of 16.62. The species was not found on stable spoil on Grassington Moor at a Ca/HM ratio in excess of 4.96. At Appletreewick M. verna grew on stable spoil at a Ca/HM ratio of 12.12. A few additional sites from Gunnerside Gill to the north of Swaledale which have not been mentioned previously showed M. verna occurring at Ca/HM ratios from 0.19 to 17.2, the latter site was unstable, the spoil heap was being undercut by a stream. The sample contained 9,150 ppm calcium and only 650 ppm zinc and 207 ppm lead. It appears that the toxicity threshold for M. verna in the Central Pennines is at least at a Ca/HM ratio of 6 and may be somewhat higher.

There thus appears to be a regional variation in the toxicity of the substrates on which M. verna occurs, less toxicity being necessary to support a population in the north of England than in the Mendips and the Aachen-Liege area. This variation has been expressed in terms of the Ca/HM ratio but it is reasonably evident if heavy metal concentrations alone are considered. Table 11.1 shows the lead and zinc concentrations in the spoils on which M. verna grows on five transects in the different orefields. It is evident that there are higher concentrations of heavy metal in the spoil on which M. verna grows in the Aachen-Liege area and at Stock Hill in the Mendips than in the Southern Pennines and on Proctor High Mark.

11.3 *Minuartia verna* and interspecific competition

The generally accepted explanation for the absence of species such as *Minuartia verna* from many areas of lowland Britain is one involving exclusion by competition from other species. Among the competitors grasses are probably pre-eminent and seem as a group to be most effective in mesic lowland environments. Grubb et al (1969) in their discussion of the vegetation of chalk heath suggest that the exclusion
<table>
<thead>
<tr>
<th></th>
<th>13,000-15,000</th>
<th>2000</th>
<th>Zn ppm</th>
<th>Lead ppm</th>
<th>Transition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proctor High Mark TR.</td>
<td>19,700-33,000</td>
<td>0</td>
<td>629.29</td>
<td>700</td>
<td></td>
</tr>
<tr>
<td>River Bradford TR.</td>
<td>5,900-17,000</td>
<td>0</td>
<td>68,500-95,000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Hawk's Mountain TR.</td>
<td>2,400-9,000</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stock Hill TR.</td>
<td>8,500-10,000</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Calamine TR.</td>
<td>68,000-115,000</td>
<td>0</td>
<td></td>
<td></td>
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</tbody>
</table>

**Table II.** The ranges of lead and zinc concentrations in spoil on which *M. Verna* grows in the various orefields.
of many calcicole species from soils of pH 5-7 in the British lowlands is due to the competitive efficiency of the grasses on the predominantly clay lowland soils.

Heavy metal concentrations in the substrate appear to be associated with the reduction of the efficiency of grass competitors. Even though certain grasses have heavy metal tolerant ecotypes the presence of heavy metals appears to have a disproportionate effect on them allowing the ingress of various forbs. It is possible that the apparently disproportionate effect on the tolerant grasses is not the result of heavy metal toxicity per se but due to other environmental peculiarities often associated with heavy metals, the aridity or the low nutrient status of spoil materials for example. Over certain undisturbed metalliferous anomalies the increase in heavy metal concentration in the soil is not apparently associated with any other radical environmental change. Ivy Scar Transect 3 (Fig. 7.10) is an example of this. Associated with such an anomaly the indicator species increase and grasses decrease and an explanation for this other than one associated with heavy metal concentrations is not apparent. The situation is one in which controlled growth experiments are necessary to weigh the relative importance of chemical and physical factors in the reduction of the competitive ability of the grasses. Whatever the reason however for the competitive disadvantage of grasses on many metalliferous soils the disadvantage itself is evident.

Grime (1974) considered the relative importance of competition, disturbance and stress within plant communities. He suggested that although competition is not restricted to productive habitats its importance in unproductive habitats is small relative to the direct impact of environmental stress. Nevertheless it does occur. Grime (1974) calculated a competitive index for a number of species. This index is based upon assigning numerical values to the height and lateral spread of a species and also its ability to produce a persistent layer of litter on the ground surface. Species with a high
score following addition of the numerical values for these parameters are potentially highly competitive. He also presented data on maximum relative growth rates and points out that there is a relationship between maximum relative growth rate and the stress tolerance of a species, those species of lower growth rates being able to withstand greater environmental stress. He presented measurements for Festuca ovina which showed a competitive index of 2.5 and a growth rate of 0.95 R max gm/gm/week. He did not present data for M. verna but he points out that the majority of species show similar competitive indices and growth rates to species with which they have strong ecological affinities. Species such as Thymus drucei, Helianthemum chamaecistus and Campanula rotundifolia on which he presented information are often associated with M. verna and appear to be more competitive than M. verna. These three species showed a competitive index of around 2 and a growth rate of 0.7 R max gm/gm/week and it is probable that the values for M. verna are slightly less. If this assumption is correct then it appears that M. verna is less competitive than Festuca ovina but more able resist environmental stress.

Grime (1974) went on to discuss the stress tolerant strategy and pointed out that in addition to small stature a general characteristic of herbaceous plants in environments experiencing continuous and severe stress is a low potential growth rate. He suggested that this generalisation held for a wide variety of stresses including those associated with nutrient deficiency, shading and desiccation. He did not specifically mention stress associated with adverse climatic conditions but it seems reasonable to suppose that the general principle applies.
The significance of the relationship between the occurrence of Minuartia verna and the Ca/HM ratio

It is apparent from the data presented in Section 11.2 that a more or less progressive decrease in the toxicity of the spoil necessary to sustain a M. verna population occurs from Belgium to the Central Pennines. Evidence from Halkyn Mountain Tr. 2 suggests that M. verna has ceased to occur in certain spoil areas due to the process of succession to a more developed and sometimes closed community in which grasses such as Festuca ovina and F. rubra are especially important. Analyses from Stock Hill Tr. 1 in the Mendips showed that succession, as measured by the organic carbon concentration of the spoil, had advanced further in the less toxic areas of the spoil heap than in the region of highest toxicity where M. verna occurred.

It appears to be the case that succession on spoil heaps to the point of exclusion of M. verna has extended to higher toxicities in the Aachen-Liege area and in Belgium than in the Southern and Central Pennines. In other words M. verna and the competitors of M. verna have been more successful in colonizing spoil of high toxicity in the south than in the north, this colonization and the attendant succession leading to the exclusion of M. verna from all areas but those of the highest toxicity in the south.

This is not to suggest that M. verna was at some stage present everywhere on the spoil heaps and has since been excluded by succession. On some spoil heaps there are areas where there is still a substantial amount of bare ground, La Calamine Tr. 2 for example, but where M. verna does not occur. It may be that on spoil which is not particularly toxic M. verna never managed to establish itself in the first wave of colonizers but the evidence from Halkyn Mountain Tr. 2 does suggest that the species occurred formerly on spoils which were less toxic than those on which it now grows.
<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Proctor High Mark Tr.</th>
<th>1' 450</th>
<th>1' 3,260</th>
<th>1' 700</th>
<th>1' 6,920</th>
<th>1' 4,800</th>
<th>1' 3,600</th>
<th>1' 2,550</th>
<th>1' 1,800</th>
<th>1' 660</th>
<th>1' 160</th>
<th>1' 040</th>
</tr>
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<tbody>
<tr>
<td>0.00</td>
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<tr>
<td>0.10</td>
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<td>0.16</td>
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<tr>
<td>0.99</td>
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<tr>
<td>0.40</td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

Table 11.2 Phosphorous, Magnesium and Phosphorous determinations of spoil from the various orefields.
Why should colonization and success in the southern orefields than in the north? One possibility is that the spoils in the south have a higher nutrient status than those in the north and therefore growth and success proceeds more rapidly. Table 11.2 shows the results of analyses for potassium, magnesium and phosphorous concentrations in spoil from the orefields. There is some variability in potassium and magnesium concentrations but phosphorous is very constant. There seems to be no suggestion in the analyses of any geographical trend in the concentrations of these three nutrients. The same can also be said of the pH and texture of the spoils, there is some variation especially in texture, but no consistent regional trend.

As the occurrence of M. verna seems to be related to the success of its competitors in colonization and success then a greater age for the spoil heaps in the south might result in the restriction of M. verna to the sites of higher toxicity. Spoil heaps are very difficult to date, the spoil even on the same one may not necessarily be contemporaneous and as was pointed out in Chapter 2 many of them may have been disturbed subsequent to their deposition for reworking purposes. Table 11.3 presents estimates of the ages of the spoil heaps in the various orefields. These are essentially based upon the date at which mining ceased in a particular area, information on this has been presented in the various chapters.

It seems very probable that the spoil heaps at La Calamine, the River Bradford and Halkyn Mountain are between 75 and 100 years old and that the spoil at Proctor High Mark and Stock Hill is perhaps 100 years older. There appears to be no consistent trend in the ages of the spoil heaps.
Table II.3  Estimated ages of the spoil heaps

<table>
<thead>
<tr>
<th>Location</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>La Calamine</td>
<td>75 - 100 yrs</td>
</tr>
<tr>
<td>Stock Hill</td>
<td>175 + yrs</td>
</tr>
<tr>
<td>Halkyn Mountain</td>
<td>75 + yrs</td>
</tr>
<tr>
<td>River Bradford</td>
<td>85 + yrs</td>
</tr>
<tr>
<td>Proctor High Mark</td>
<td>150 + yrs</td>
</tr>
</tbody>
</table>

The one consistent change from the southern orefields to those in the north is of the external influence of climate, the climate is much colder in the Central Pennines than in the Aachen-Liege area. Fig. II.1 shows the postulated Ca/HM thresholds for _M. verna_ occurrence plotted against accumulated day degree (°F) totals. The method of calculating accumulated day degrees was discussed in Chapter 3. The figure of 3,300 day degrees for the Aachen-Liege orefield is estimated from the data in Shellard (1959) for the British Isles. It is not possible to compute a precise figure by the method used for the other areas because the necessary data on standard deviations of monthly mean temperature is not available.

It appears from Fig. II.1 that there is a relationship between the Ca/HM thresholds for _M. verna_ in the various orefields and the accumulated day degree totals. It seems that with increasing climatic stress the competitors of _M. verna_, of which the grasses _Festuca ovina_ and _F. rubra_ are probably the most important, become, relative to _M. verna_, less efficient. It was pointed out earlier in the discussion of the work of Grime (1974) that _F. ovina_ appears to have less resistance to environmental stress than _M. verna_. Thus with worsening climate the level of toxicity which is necessary to diminish competition sufficiently to enable _M. verna_ to occur decreases. Because colonization of spoil by _M. verna_ and its competitors results in succession on the spoil which in certain places probably results in the replacement of _M. verna_ then this relationship also implies that succession on spoils in the northern areas is slower.
The postulated Ca/HM threshold levels for Minuartia verna occurrence plotted against accumulated day degree totals.

Figure 11.1

Accumulated day degree totals (°F) above 42°F (5.6°C)
The curved nature of the relationship in Fig. 11.1 suggests that northwards heavy metal concentration in the substrate becomes increasingly less important in the provision of a habitat for *M. verna* and this accords with evidence available on the distribution of the species. The spoil from the unstable site in Gunnerside Gill with a Ca/HM ratio of 17.72 is probably not very toxic. In the Northern Pennines where accumulated day degree totals fall to around 2,000 *M. verna* is known from the refugia of Upper Teesdale where heavy metals seem to be unimportant.

These findings are in accordance with the views expressed by Halliday (1960) in relation to certain sites occupied by *M. verna* on spoil materials in the Northern Pennines. He suggested that some spoil heaps showed no evidence of heavy metal toxicity and emphasised the importance of the physical characteristics of the substrate in the provision of a habitat for *M. verna*.

The apparent relationship between the rate of successsion, toxicity and climate may go some way towards explaining the appearance of spoil heaps in the orefields. In the Mendips the spoil heaps are for the most part completely colonized by herbaceous vegetation while on Grassington Moor and at Gunnerside Gill in the Central Pennines large areas of bare spoil may be seen. The spoil heaps of the Mendips however are probably somewhat older than many of those in the Central pennines and this will also be a factor in their almost complete colonization. The age of the spoil in the Mendips may explain why *M. verna* shows a lower Ca/HM ratio threshold in the Mendips than in the Aachen-Liege orefield, even though the Aachen-Liege area is warmer (Fig. 11.1).
There seems to be an analogy here with the situation prevailing on serpentine substrates in the British Isles. Discussion has long continued upon the nature of the problem for plant growth on serpentine soils, a controversy about the relative importance of the low calcium to magnesium ratio and the high levels of chromium and nickel. Whichever is the case serpentine causes difficulties for plants due to its chemical composition and the habitat is often compared with those high in heavy metals.

Coombe and Frost (1956) working on the Lizard in Cornwall and Proctor (1969) in Scotland both described localities in which the soil appeared to be wholly derived from serpentine rock but upon which the characteristic serpentine vegetation was absent. Proctor (1969), as mentioned in Chapter 1, described one such site near Loch Lomond as bearing "a mundane heath vegetation." He stressed the importance of climate and soil instability in the maintenance of the characteristic serpentine ecosystem on the hilltops of Scotland and suggested that these factors were of similar importance to the chemical nature of the substrate.

The relationship investigated here between M. verna and climate and spoil toxicity, with its implications for succession, has expressed the additional difficulties for colonizing vegetation in the more northern orefields in terms of reduced temperatures. This is not to suggest that all the regional variability is a function of temperature alone. Proctor (1969) mentioned also the importance of soil instability in the maintenance of the characteristic upland serpentine ecosystem and it is probable that on spoil heaps at higher altitudes in the Central and Northern Pennines processes such as frost heaving will be of greater influence than in the southern orefields. Such processes will operate along with lower temperatures in reducing competition and the rate of succession in favour of species such as M. verna but it is not possible to evaluate here the relative importance of these essentially interrelated factors.
Proctor (1969) stressed the importance of climate and instability in the maintenance of the characteristic upland serpentine ecosystem in the face of the process of succession. The situation on calcareous spoil heaps seems analogous, from the evidence presented here it is apparent that the long term survival of the communities of open vegetation with heavy metal tolerant indicator species characteristic of calcareous spoil heaps is most likely to occur in the colder northern orefields.
CHAPTER 12

THE DISTRIBUTION OF THE INDICATOR SPECIES AND OTHER ASPECTS OF THE METALLIFEROUS ENVIRONMENTS IN THE STUDY AREAS

12.1 Minuartia verna

Minuartia verna is the most widespread and abundant indicator species in the British Isles on spoil derived from workings in the Lower Carboniferous, mainly the Carboniferous Limestone or limestones of the Yoredale facies. In certain places M. verna is found growing on metalliferous substrates other than spoil, at Eller Beck the species occurs on alluvium on the flood plain of the stream, the plant is present on limestone scarps at Twinbottom Scar and at Eller Beck and at Dolfrwynog bog in Wales it grows on peat and peaty soils which contain substantial amounts of copper.

In places at Dolfrwynog M. verna grows on peat which appears to be almost perennially waterlogged and at times the communities of M. verna may be almost submerged. The contrast between this environment and those of arid spoil heaps and limestone scarps is marked and it emphasises the broad physiological amplitude of the species in respect of the physical factors of the metalliferous environment. Unlike certain other indicators there appears to be no suggestion that M. verna is ever absent from a metalliferous environment due to physical difficulties of the substrate, unless these totally preclude any plant growth. At High Rake in Derbyshire for example the species grew in spoil which was so unstable that many of the plants were partially buried.
This ability to exist on an unstable substrate is not an attribute which M. verna shows only in metalliferous environments, the plant occurs with Festuca ovina on the metamorphosed and rapidly eroding sugar limestone of the Upper Teesdale area. The similarity between the sugar limestone environment and that of certain spoil heaps is pronounced. The sugar limestone of Upper Teesdale however contains little heavy metal, an analysis of a sample showed lead and zinc at concentrations below 300 ppm.

M. verna, in its habitats in the British Isles which do not appear to be associated with heavy metals, is essentially a calcicole species. The plant grows in the calcareous flushes of the Arctic-Alpine refugia of Upper Teesdale, on the sugar limestone in Upper Teesdale and in certain places in Snowdonia and the Lake District where calcite veins outcrop. In certain metalliferous habitats however, at Malham and especially at Dolfrwynog, the plant extends to substrates of pH around 5. At Dolfrwynog M. verna grows with plants such as Calluna vulgaris which are calcifuge. It was pointed out in Chapter 1 that Rune (1953) had noted the association of calcicoles and calcifuges on serpentine soils and this association is probably due to the low competition conditions in such environments which allow certain species to extend to substrates with pH values higher or lower than those on which they normally grow. It appears that at Dolfrwynog M. verna grows on substrates with pH values lower than those on which it normally occurs due to the lower competition in this copper rich environment.

Although M. verna appears to have a broad physiological amplitude in relation to physical aspects of the environment the plant appears to be somewhat more affected by high toxicity than some of the other indicator species. M. verna has been found growing on spoil containing high concentrations of copper, lead or zinc, sometimes occurring in combination, but has rarely been found where the pH of the spoil was
below 7.0, unless there were concentrations of organic matter which
tend to result in a slightly lower pH. At Plombières and Stolberg
in the Aachen-Liege orefield spoil unaffected by organic matter
accumulation, in other words spoil in the "as dumped" state, showed
pH values below 6.7 and often below 6.0. These spoils had high heavy
metal concentrations and it was suggested that *M. verna* was absent
due to excessive toxicity related to the greater availability of the heavy
metals at the lower pH. At Dolfrynog the species appeared to be rather
more affected by high copper toxicity in the soil than *Armeria*
*maritima*. In addition *M. verna* did not grow on the dumps of slag at
Charterhouse, this slag contained high concentrations of lead and
had a pH of around 5.0.

In the British Isles *M. verna* is absent from certain places where the
other indicator species grow, Cornwall where *A. maritima* grows on
the spoil heaps, the alluvium of the lower Afon Ystwyth where
*Thlaspi alpestre* and *Silene maritima* are present and the Llanrwst
orefield in North Wales where *T. alpestre* occurs. The toxic alluvium
of the flood plain of the lower Afon Ystwyth showed pH values between
5.5 and 5.9 and it seems very probable that this material is too toxic
for *M. verna*.

In Cornwall and at Llanrwst in North Wales however certain samples
showed pH values and calcium concentrations within the range on
which *M. verna* has been found growing on spoils in other orefields.
It seems probable that *M. verna* could grow on this spoil but the species
is absent at the present day. A factor to take into consideration in
this type of situation is the possibility of *M. verna* surviving in a
heavy metal refugium until spoil heaps were available for colonization.
The presence of a few calcareous spoil heaps does not imply that the
survival sites for indicator species in the area were suitable for
the growth of *M. verna*. If they were not then the only way in which
*M. verna* could colonize the spoil heaps in these areas would be by
long distance dispersal from a heavy metal tolerant population and
heavy metal tolerant populations of the species are rather remote from both Cornwall and the Llanrwst district. Populations which are probably not tolerant for copper or lead are rather nearer although still several miles away. *M. verna* occurs on serpentine on the Lizard in Cornwall and grows at high altitude on Snowdon but it seems highly unlikely that individuals from one of these populations could successfully colonize mining spoil.

An interesting aspect of the distribution records for *M. verna* is that they appear to provide evidence for contraction of range in respect of riparian metalliferous habitats. Lees (1888) in his Flora of West Yorkshire states *M. verna*, in the area, to be a species of limestone crags and spoil heaps and also to occur as an adventive on river banks. He mentions a record from the Yore below Hackfall in Yorkshire where a dozen or more plants occurred in 1871. Modern records, those of the B.S.B.I., contain only one mention of *M. verna* in a similar situation today, the occurrence on the floodplain of Eller Beck described in Chapter 7.

It was suggested in Chapter 7 that at the height of mining activity at Eller Beck rather more alluvium containing heavy metal was transported downstream than is the case at the present day. In Chapter 2 it was pointed out that there was considerable pollution of water courses in the Mendips at the time of smelting activity in the Nineteenth Century and the floodplains of the Afon Ystwyth in Wales and the River Gheul in Belgium and Holland testify to the fact that considerable quantities of metalliferous alluvium were transported down these streams also. It seems probable that at the zenith of lead mining in the Pennines considerable quantities of ore tailings found their way into the streams of the area and were deposited at lower altitudes. *M. verna* may well have migrated downstream in response to these newly available toxic sites. Perhaps the Eller Beck area, apparently the only place in the Pennines where *M. verna* occurs today as an adventive on river banks, is a last example of a once more widespread phenomenon.
Armeria maritima in the metalliferous habitats in which it occurs appears to be more competitive than M. verna and Thlaspi alpestre. On the floodplain of Eller Beck the species grew over wider areas and at lower toxicities than either T. alpestre or M. verna. At La Calamine A. maritima grew on Tr. 2 on spoil from which it was suggested that M. verna was excluded due to excessive competition resulting from insufficient toxicity. At Dolfrwynog bog in Wales A. maritima extended to sites with lower toxicity than those occupied by M. verna and the plant was also found in many of the scattered mineralised localities in the area from which M. verna was absent. A. maritima is of course widespread in coastal situations around the British Isles where it apparently competes successfully with other species found in these situations.

That A. maritima seems to be more competitive than M. verna is perhaps not surprising, although low growing it is a rather more robust plant than M. verna and appears to have considerable ability for lateral spread. Ability to spread laterally was one of the parameters included in the competitive index calculated by Grime (1974) and discussed in Chapter 11 and although he did not consider A. maritima it seems probable that the species would show a higher competitive index than M. verna.

In addition to being more competitive than M. verna A. maritima appears to be able to grow on substrates of higher toxicity. In the Aachen Liege orefield the species occurred on the spoil at Stolberg and Plombieres, spoil with pH values below 6.7 and often below 6.0, and at Dolfrwynog bog in Wales A. maritima grew on substrates which appeared to be more toxic than those occupied by M. verna. There was, however, evidence from Cornwall that A. maritima was absent due to excessive toxicity from spoils with pH values around 4.0.
Although of higher competitive ability than *M. verna* *A. maritima* is an indicator plant of rather restricted range on British metalliferous sites. The species appears to have the ability to develop tolerance of the heavy metals copper, lead and zinc and variation in heavy metal concentration and type does not seem to be implicated in its restricted range. *A. maritima* is generally found in the British Isles on metalliferous substrates with comparatively low calcium concentrations but the species grew on La Calamine Tr. 2 on spoil with calcium concentrations in excess of 100,000 ppm, and on the Great Orme near Llandudno in Wales *A. maritima* grows on copper rich spoil heaps with calcium concentrations of the same order.

The pH of the spoil at La Calamine Tr. 2 was around 7.5, pH values very similar to those of many Carboniferous Limestone spoil heaps. The concentrations of magnesium, potassium and phosphorous in the substrates on which *A. maritima* has been found are very similar to those of metalliferous substrates in other areas where the species does not occur. The absence of *A. maritima* from orefields such as the Mendips and the Southern Pennines does not appear to be the result of the chemical characteristics of the spoils in these areas.

Where *A. maritima* has been found growing on spoil the spoil was often of rather fine texture. This was the case on La Calamine Tr. 2 and it was suggested that *A. maritima* was absent from La Calamine Tr. 1 due to the coarse texture of the spoil in that situation. This was in agreement with the observation by Lambrinon and Auquier (1964) that *A. maritima* was a plant of the spoils of higher moisture status.

At Garrigill in the Northern Pennines the spoil on which *A. maritima* grew was again fine in texture and there the plant was accompanied on parts of the spoil heap by *Parnassia palustris*, most definitely a species of more moist habitats and indicative of the high moisture status on this spoil heap. Indeed the Garrigill spoil heap in the presence of *Cochlearia officinalis, Parnassia palustris* and *A. maritima* showed similarities to the riparian metalliferous communities of the moist alluvial sites along Eller Beck.
The spoil heaps at Eller Beck are quite instructive in relation to the
distribution of *A. maritima*. The species was only present in one small
area on the spoil heaps and this appeared to be a wetter than normal
site, elsewhere *A. maritima* was absent from the rather coarse textured
spoil. There can be no suggestion at Eller Beck that *A. maritima* is
absent from the spoil heaps due to dispersal difficulties and it seems
probable that the physical characteristics of the spoil which lead to
aridity at certain times are the reason for the absence of the species.
It must however be observed that the spoil at Piece in Cornwall where
*A. maritima* occurred was rather more coarse textured than that at
Eller Beck but this site is in an area of high atmospheric humidity
where drought is less frequent and severe than in Central England.

It appears probable that *A. maritima* could not grow on many of the spoil
heaps in areas such as Derbyshire and the Mendips due to their
excessive aridity. There may however be certain places in these
orefields where the species could grow but where it is not present
due to dispersal difficulties. If, as has been suggested, the indicator
plants colonized the spoil heaps in certain of the orefields from heavy
metal refugia then the characteristics of the refugia would control the
indicator species which could survive in them. If, as appears
probable, the heavy metal refugia in the Central Pennines were of the
sort seen on the limestone scarps at Eller Beck, then *A. maritima*,
not present in such localities at Eller Beck, would probably not have
managed to survive in them. This is an interesting point. If long
distance dispersal of the indicator species is rejected as a widely
operating phenomenon then the species complement of an orefield
at the present day may be a function of the nature of the refugium
rather than of the sites at present available.
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12. 3 Thlaspi alpestre

On metalliferous substrates associated with the Carboniferous Limestone, T. alpestre is more widespread than A. maritima but of less regular occurrence than M. verna. In the Pennines it is unusual to find a spoil heap where bare spoil is still present but M. verna is absent. This is not true for T. alpestre and especially so in the northern part of the Southern Pennine orefield where T. alpestre is absent from a large area. A possible explanation for this was discussed in Chapter 7.

T. alpestre appears to be more tolerant of high toxicity than M. verna. The species occurred on the spoil heaps at Plombieres and Stolberg in the Aachen-Liege orefield which appeared to be quite toxic and also on the slag at Charterhouse in the Mendips where M. verna was not present. In the Llanrwst orefield T. alpestre grew on spoil with pH values above 6.0 and calcium concentrations above 1,300 ppm. There was evidence in this locality that where pH and calcium values fell below these levels T. alpestre was excluded by excessive toxicity.

T. alpestre is often found growing where there is substantial organic matter accumulation in the spoil. This was the case at Shipham in the Mendips and at Bonsall Moor and Brassington in the Southern Pennines. In these Southern Pennine localities organic carbon was present in amounts exceeding 20%. M. verna is generally absent in this type of site.

T. alpestre tends to be of rather sporadic occurrence. M. verna is often present on spoil in fairly extensive communities but it is not unusual to find T. alpestre as isolated individuals occurring here and there. It is difficult to detect a consistent trend in the distribution of this species. In Derbyshire for example the species tended to occur on the sites with low Ca/HM ratios suggesting that it might be less competitive than M. verna but at Shipham in the Mendips T. alpestre grew on spoil on which colonization was well developed and from
which *M. verna* seemed to be excluded by excessive competition related to insufficient toxicity. In the Mendips *T. alpestre* was present at Shipham and Charterhouse but not on the apparently suitable toxic spoil at Stock Hill. There are dispersal problems for this species which were discussed in Chapter 7 and these may restrict its distribution. Essentially, having stated that heavy metal concentrations in the substrate are important in determining the overall distribution of *Thlaspi alpestre* it is difficult to proceed much further. It seems possible that quite minor variations in the physical and chemical nature of the metalliferous substrates may greatly influence the distribution of *T. alpestre*.

As with *M. verna* there appears for *T. alpestre* to be evidence for recent contraction of range. Lees (1888) in his Flora of West Yorkshire mentions the occurrence of the species on "earthy banks and foot of walls in Malham village and down by the stream (the River Aire) nearby to Airton". The date of the record is 1737. Contemporary records do not mention the presence of the species in Malham village and a search of the river bank to Airton failed to locate the species. The record predates by 70 years the use of buildings in Malham village for calcining ore from the Calamine Mine and heavy metal toxicity, if that was the controlling factor in the occurrence of the species at Malham, could not have been derived from that source. It seems possible that there is for Malham village a long history of ore treatment and the 1737 occurrence may be related to a previous mining episode. Alternatively toxic material could conceivably have been washed down to Malham through the subterranean drainage system from ore treatment operations elsewhere. If toxicity is taken to be the cause of the occurrence of *T. alpestre* in Malham village in the past and this seems reasonable in view of the close association of the species with metalliferous habitats in the area, then this old record may well represent a further indication of the quite widespread dissemination of toxicity in the neighbourhoods of the orefields formerly.
12.4 Silene maritima

This indicator species was found only in the Mendips, on the Afon Ystwyth and at Dolfrwynog in Wales. In the Mendips the species grew on spoil with high lead or zinc concentrations and at Dolfrwynog S. maritima grew on substrates with high levels of copper. The species thus appears to have an ability to develop tolerance to the heavy metals copper, lead and zinc.

At Stock Hill in the Mendips S. maritima was widespread on the most coarse textured spoil encountered in the course of this study and it does not appear to be the case that the species is absent from the spoil heaps in many areas due to an inability to grow in relatively acid environments. At Stock Hill the species was widespread on the spoil heap while M. verna was restricted to a relatively small area and it appears that S. maritima may be more competitive than M. verna. At Charterhouse in the Mendips S. maritima grew on the toxic slag produced by Nineteenth Century reworking operations and it appears that the species is rather more resistant to toxicity than M. verna.

It is difficult to explain why S. maritima should be absent from many spoil areas in the Pennines which have heavy metal, calcium and nutrient concentrations and textural characteristics very similar to those of its sites in the Mendips. It seems possible that the absence of S. maritima from most spoil heaps on the Carboniferous Limestone areas of the Pennines is due to difficulties of dispersal to these localities.

12.5 Cochlearia officinalis

Cochlearia officinalis has been found growing in metalliferous localities at Eller Beck, Dirtlow Rake in Derbyshire and Garrigill in the Northern Pennines. Unlike the other indicator species C. officinalis has not been found growing in substrates containing substantial concentrations of copper.
At Eller Beck C. officinalis was only found in sites which appeared to be relatively moist ones and it has been suggested previously that the spoil heap at Garrigill has similar characteristics. At Garrigill C. officinalis was present in greater abundance on the north side of the spoil heap than on the south side and at Dirtlow Rake in Derbyshire C. officinalis was confined to a north facing unstable slope on the spoil. Clapham (1969) observed that in Derbyshire C. officinalis was a species of spoil heaps and north facing cliffs on the Carboniferous Limestone.

It appears that C. officinalis is rather sensitive to aridity and it appears that, as was the case for A. maritima, this is probably the reason for the absence of the species from many spoil heaps.

12.6 The "heavy metal refugium"

In various chapters the hypothesis of the metalliferous survival site, the "heavy metal refugium" has been advanced. As mentioned in Chapter 1 Heimans (1960) and Schultz (1912) suggested a former widespread distribution in the late Glacial of the indicator species and postulated their survival till recently on the outcrops of ore-bodies, now mined out, on the spoil heaps of which they occur today. Antonovics et al (1971) suggested that many orebodies had no surface expression and could not be survival sites for the indicator species and hypothesised dispersal from distant populations to the lowland mine sites of North Western Europe. These viewpoints are diametrically opposed.

The objections to the suggestions of Antonovics et al (1971) were put forward in Chapter 1 and, to reiterate, the basic problem with long distance dispersal is one of credibility. It is felt it is or should be a "hypothesis of last resort," and in this case there appears to be no reason to resort to it. The explanations of Schultz (1912) and Heimans (1960), with modifications, appear quite adequate.
One of the buttresses of the argument of Antonovics et al (1971) was that many orebodies had no former surface expression. This observation appears for many British mineralisations in the Carboniferous Limestone quite reasonable but the situation in the Aachen-Liege area may have been different. Raymond (1887) cites a paper by Braun (1854) referring to the calamine vegetation of the Aachen-Liege area. Braun (1854) wrote "in company with Viola calaminaria are found several other plants characteristic for the calamine hills, among which I will specially name Alsine verna (Minuartia verna), Armeria vulgaris (Armeria maritima) and Thlaspi alpestre" and went on to state "the occurrence of Viola calaminaria in a relation so constant to the zinc-contents of the soil that successful mining explorations are undertaken on this sign alone has led me......". It appears from this that Viola calaminaria may well have indicated the presence of zinc deposits in the Aachen-Liege area but the situation in relation to the other indicator species is ambiguous. It is very much suspected that the author in using the phrase calamine hills is referring to spoil heaps. If not then the implication is that the other indicator species occurred widely on ore outcrops.

Whatever the situation in the Aachen-Liege area there appears to be no documentary evidence for the use of the indicator species in the search for ore bodies on the Carboniferous Limestone in Britain and the inference to be drawn from this is that they did not occur sufficiently widely to be so employed.

There is additional evidence of a circumstantial nature. The accumulation of peat and turf on the Roman mining waste at Charterhouse and the development of closed herbaceous vegetation on some of the quite toxic spoil heaps investigated in the course of this study throws doubt upon the long term effectiveness of toxicity alone in the maintenance of indicator plant communities. Additionally in some areas the ore deposits were covered by glacial till, in others by materials of aeolian
origin and in the Northern Pennines by peat, hence the use of hushing to facilitate their discovery. In many areas the veins were narrow and subject to shading by trees and lastly the Reverend Joseph Glanvil of Frome (in Gough, 1930) wrote that there was to his knowledge no sure surface indication of mineralisation. All in all there seems no reason to suppose that the veins traversed the countryside, cut across the general plant communities, and were covered by indicator plants.

The study has shown the indicator species to persist on certain spoil heaps where instability is present when surrounding areas are completely colonized to their exclusion. In addition toxicity levels in such localities are sometimes amongst the lowest recorded in the particular orefield, the High Rake transect in Derbyshire for example. Thus in a natural situation where even moderate toxicity coincided with instability certain indicator species could have survived from the Late Glacial period to the time of onset of mining activity, unaffected by succession associated with organic matter accumulation in the soil and also shading by trees. The modification of the suggestion of Heimans (1960) that the indicator plants survived in metal rich areas where trees could not grow is the postulation of a particular type of site in which the evidence suggests this could have occurred. From these heavy metal refugia the indicator species subsequently spread to the mining spoil heaps upon which they are abundant today. A feature inherent in the refugium hypothesis is that the indicator species complement of an orefield at the present day might be related to the habitat characteristics of the refugium rather than to the nature of contemporary metalliferous sites.

The "heavy metal refugium" most typical of Carboniferous Limestone areas would be the mineralised outcrop on a limestone scarp, a habitat similar to those on Haw Bank and Ivy Scar at Eller Beck at the present but refugia offering instability associated with river courses
may have been present on the Afon Ystwyth and again at Eller Beck. The mineralised peat bog at Dolfrwynog represents a further, and for the British Isles apparently unique, type of refugium.

This is not to suggest that all heavy metal tolerant populations of indicator species have survived from the Late Glacial in a refugium of one sort or another. Where metalliferous sites are adjoined by areas supporting non-tolerant populations of the indicator species there seems no reason to suppose that more recent development of tolerance may not have taken place.

12.7 The role of heavy metal substrates in the total range of the indicator species

Three of the indicator species, Armeria maritima, Silene maritima and Cochlearia officinalis are widespread in coastal situations in the British Isles and North Western Europe, occurring on shingle banks, sea cliffs and salt marshes. Heavy metal toxicity does not appear to influence the distributions of the species in such situations.

Inland these three species and also Minuartia verna and Thlaspi alpestre grow in a number of places, certain of which appear not to be associated with high concentrations of heavy metal in the soil. M. verna occurs in apparently unmineralised localities on mountain tops in Snowdonia and the Lake District and also in the Arctic-Alpine refugia of Upper Teesdale where A. maritima is also present.

In other areas however heavy metals seem very important in the provision of sites for the indicator species. In the Mendips M. verna appears to occur only on sites where there are substantial heavy metal concentrations in the soil and this appears to be also the case for S. maritima and T. alpestre in the area.
In Derbyshire *T. alpestre* seems to be very closely associated with metalliferous substrates and it appears very probable that the species only occurs in the county on substrates which contain substantial amounts of heavy metals. The situation for *M. verna* in the area is less clear. There appear to be some quite firm records from places in Derbyshire where *M. verna* was not found on mine spoil but as has been demonstrated it is possible that these localities are metalliferous and have not been recognised as such.

Northwards in the Pennines from Derbyshire there are many more records for the indicator species *T. alpestre* and *M. verna*, especially the latter, from sites which do not appear to be mineralised. As has been mentioned the soils of the refugia of Upper Teesdale where *M. verna* grows appear not to contain high concentrations of heavy metals but as has been shown in the Malham district both *M. verna* and *T. alpestre* frequently occur in localities which have every appearance of being normal but in which heavy metal concentrations may be slightly or in some cases substantially above background levels. It may be the case that concentrations of heavy metals in the soil are an even greater influence on the distribution of these two species than has previously been recognised.

At Eller Beck *A. maritima* and *C. officinalis* were only found growing on substrates with above normal concentrations of heavy metals. Both these species occur in other places in the Pennines which have not been visited in the course of this study and it seems possible that certain of these sites are also mineralised.

12.8 *The indicator species as indicators of heavy metals*

In many places in England, Wales and the Aachen-Liege area the indicator species are operating as indicators of old mines rather than of unworked mineralisations. At Dolfrwynog, Eller Beck and in the Twinbottom Scar area however the indicator species have been shown
to indicate undisturbed and naturally occurring mineralisations and it seems that in certain places such mineralisations may be detected by their use.

Although there is no record of the British indicator species having been used for prospecting in the past, with, perhaps, the exception of A. maritima at Dolfrwynog, it appears probable that they must in certain places have indicated high grade mineralisations. However most of the mineralisations of this type appear to have been mined already.

The future of British mining seems to be in the large scale exploitation of low grade ore bodies and it is interesting to note that in the Dolfrwynog region the indicator species provide evidence of the existence of such a deposit.

12.9 Conservation of the indicator plant localities

As Antonovics et al (1971) observe metalliferous localities in their relative simplicity offer many opportunities for the investigation of ecological problems. In addition to this these plant communities are of considerable general interest and it would be unfortunate if these habitats were to disappear.

In the case of the copper bog at Dolfrwynog in Wales the locality has been designated a Site of Special Scientific Interest and seems to have an assured future in the short term although the long term situation in view of the presence in the area of an economically viable copper deposit is less certain. The plant communities at Eller Beck are within the Yorkshire Dales National Park and will be protected from gross disturbance but a simple act such as the liming of the flood plain soils could easily result in the disappearance of the riparian indicator plant communities. The addition of a relatively small amount of calcium would probably result in quite a drastic
reduction in the range of the indicator species along the beck. As was pointed out in Chapter 4 this appears to have happened already along the River Gheul in Belgium and Holland.

The interesting indicator plant communities of the Malham district are again within the National Park and are remote from agricultural influences and should be safe but some of the spoil heaps of the Derbyshire area are being removed for the fluorspar and other minerals they contain and while this is resulting in the reclamation of derelict land it is to be hoped that some examples of the indicator plant communities in the area will survive.

The metalliferous communities at Charterhouse in the Mendips are within a local nature reserve and seem assured of preservation but the spoil heaps at La Calamine in Belgium, of great interest in view of the presence together in one place of all the indicator species, are, as far as is known, unprotected.

In relation to spoil heap areas, especially those in the southern orefields, quite rapid succession appears to be occurring and it is apparent that any decision to preserve examples of these habitats would have to take this into account. Many plant communities are rather susceptible to disturbance but it seems clear from the observations presented here that in relation to the indicator species some substrate disturbance, retarding as it does the process of succession, is advantageous.
12.10 Conclusions

The study has attempted a geographical appraisal of the distribution of the indicator species on metalliferous sites in England, Wales and the Aachen-Liege area and has gone some way towards explaining certain of the patterns of distribution shown by them. It is apparent that for certain indicators the physical characteristics of the habitat exert the controlling influence on their distribution on metalliferous substrates.

A long standing problem in the distribution of the indicator species has been that of where they grew before metalliferous sites created by mining activity became available. It is believed that the concept of migration from heavy metal refugia within the orefields as advanced here offers a reasonable explanation of the method by which the indicator species colonized the spoil dumps in many areas although, as has been mentioned previously, the concept of the survival of the indicator species in heavy metal refugia from the Late Glacial period until the onset of mining does not exclude the possibility that where non tolerant populations grew adjacent to mine sites later development of tolerance may have occurred.

An observation of great interest has been that of the association of the indicator species with substrates containing heavy metals but which appear to be entirely normal habitats. It is difficult to convey in words just how similar to many other places which do not contain above normal concentrations of heavy metals certain of these localities appear and only the occurrence of one or more of the indicator species betrays the metalliferous nature of the soil. It seems probable that a number of sites where the indicator species occur are mineralized and have not been recognised as such and it is apparent that any future study related to the ecology or distribution of these species should take this into account and include analyses for heavy metals, if only to exclude the possibility of their influence.
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