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Potential for stratiform massive sulphide mineralisation in south-west England

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Potential for stratiform massive sulphide mineralisation in south-west England

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Front cover

Coombe Martin mine and spoil dumps, Exmoor in the distance.

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Summary

The aim of the work described in this report was to determine areas favourable for the occurrence of massive stratiform base-metal deposits in Devon and East Cornwall. Deposits of this type are major sources of zinc, lead and copper worldwide and they provide large targets, economically more attractive than the vein mineralisation which was the mainstay of metal mining in south-west England for many centuries. Assessment of the geology of the central part of the study region, between Bodmin Moor and Dartmoor, reveals many similarities with the Iberian Pyrite Belt (IPB) in southern Spain and Portugal, where numerous sediment-hosted massive sulphide (SHMS) deposits occur. In addition the geological environment of the Exmoor district is similar to the setting of the major polymetallic sulphide deposit at Rammelsberg in the Rhenish Massif in Germany. Furthermore the Middle Devonian volcanic rocks of south Devon contain minor sulphide mineralisation comparable with sedimentary exhalative (SEDEX) mineral deposits associated with bimodal volcanic rocks in intracontinental settings.

A large amount of exploration activity has been undertaken in the target region by commercial companies and by BGS and is reviewed in this report. Analysis of existing geological, geochemical, borehole and mineral occurrence data indicates that stratiform sulphide mineralisation occurs at more than 60 sites. A compilation of the mineral workings and trials in the region is provided in the report and has been used to identify the geological formations of particular interest. On this basis, and by analogy with the settings of major deposits elsewhere in Europe, the most prospective geological units are: Lower Carboniferous strata containing black shales in the central region and around the northern margins of the Bodmin Moor and Dartmoor granites; Devonian volcano-sedimentary formations in south Devon; and Middle–Upper Devonian slates on Exmoor. Summary geological logs for two boreholes north of Bodmin Moor and on Exmoor are provided in the report.

Previous drilling of a strong annular magnetic anomaly close to the northern margin of the Bodmin Moor and Dartmoor granites identified magnetic pyrrhotite as the likely cause of the magnetic anomalies. The pyrrhotite-bearing rocks generally exhibit a very low magnetic susceptibility but have been shown to have a variable, locally strong Natural Remanent Magnetisation (NRM) acquired at the time of granite intrusion. Remagnetisation of primary stratiform pyrite contained in prospective Fammenian-Tournaisian-Visean formations carrying mafic volcanic rocks and black shales implies that the magnetic anomaly can be interpreted to represent primary syngenetic sulphide deposits. In this study new interpretations of the regional magnetic data, including calculation of the analytic signal and 2D and 3D depth solutions, have identified the source depths and positions for many of these magnetic anomalies. In many cases these sources are relatively shallow (<500 m) and have not been tested by drilling. These parameters have been included as positive evidence in the assessment of the mineral potential of the area.

Extensive, but incomplete drainage geochemical surveys have been carried out across most of the prospective geological units. About 3000 stream sediment and panned concentrate samples provide evidential data for prospectivity analysis. The report provides a summary of these data. Stream-sediment data for Cu, Pb and Zn, filtered for proximity to known mineral workings, has been used in the analysis, together with anomalous panned-concentrate data for Sb, Ba, Mn, Ag and As.

The potential for the occurrence of stratiform sulphide deposits in the region has been assessed by knowledge-based prospectivity analysis using a binary weights of evidence model with criteria and weights derived empirically from established models for this style of mineralisation. New targets have been identified using selected geological, geophysical and geochemical data in conjunction with the distribution of known stratiform mineralisation. These targets occur primarily within the stratigraphical intervals identified as favourable on geological grounds or in regions where prospective formations are presumed to occur beneath shallow cover sequences.

The degree of confidence which can be placed in the prospectivity maps depends on the accuracy of the deposit models utilised, in terms of their applicability to the target area, and the availability of adequate reliable data of sufficient quality. The extent to which the mineral deposit model is represented by the available data is especially important. The quality of the analysis can be improved as more data become available or as the reliability of the deposit models is improved. Nevertheless several unexplored targets, located outside areas with designated planning restrictions, warrant further investigation. The recommended exploration approach will depend on the specific target deposit type and on the local geology. For targets in the central area, where IPB type deposits are to be expected, the exploration practice should include high-resolution gravity surveys. These should be followed by electrical surveys over positive gravity anomalies to define drilling targets.

1 Introduction

South-west England has a long history of metal mining from pre-Roman times. The main products were tin and copper, with subordinate lead, zinc, silver, arsenic, antimony, sulphur, iron and manganese. The total production from Devon and Cornwall is estimated at over 2 Mt of tin and over 2.5 Mt of copper (Dines, 1956). Most of the mines produced cassiterite from quartz veins and stockworks in or close to the Hercynian granites (Figure 1). This hydrothermal lode mineralisation is concentrated in the Cornish granites at Lands End (which accounts for 21% of total tin output) and Carnmenellis (67%). The East Cornwall and Devon granites were less productive: St Austell (7%), Bodmin Moor (3%) and Dartmoor (2%). Over 50% of the tin and copper production, and about 40% of the arsenic and sulphur, came from the Camborne–Redruth–St Day region of Cornwall (Dines, 1956).

The hydrothermal lodes close to the granites have been explored and intensively worked at many sites. Over 1500 names of mines are recorded in south-west England (Dines, 1956), although accessible documentation on many of these is limited. Not all the exploited mineralisation was of lode type and modern empirical and genetic models of ore deposit classifiaction have permitted re-examination of the former mining districts in relation to a variety of exploration targets and commodities. The aim of this study is to examine available multi-disciplinary geoscience data to assess the potential for the occurrence of stratiform base-metal mineralisation in East Cornwall and Devon.

The study region is located between British National Grid (BNG) lines 190 and 310 km East, and 30 and 150 km North (Figure 1), covering the area between Padstow in the west and Exeter in the east. This area was selected because it has known occurrences of stratiform mineralisation and because it provides a close geological analogy with the Iberian Pyrite Belt (IPB) of southern Spain and Portugal where major deposits of this type have been worked for many centuries (Leistel et al., 1998). In North Devon there is also a thick shallow-marine Devonian sequence which is comparable to the Harz Massif in Germany which hosts the major polymetallic sulphide deposits at Rammelsberg (Large and Walcher, 1999). The Middle Devonian volcanic rocks of south Devon contain minor stratiform sulphide mineralisation of the sedimentary exhalative (SEDEX) class of mineral deposits associated with bimodal volcanic rocks in intracontinental settings (Goodfellow et al., 1993).

This report is aimed primarily at the potential for the discovery of buried mineral deposits. This is because with a long history of mining most surface expressions have been explored and worked. In some cases, mineralisation previously considered to be epigenetic might now be interpreted as syngenetic and provide vectors to buried deposits of this type close by.

In this study previously unreleased data have been integrated with various archived and newly acquired datasets within a framework provided by modern published deposit models, modified where necessary according to local conditions. The key items of data incorporated into the prospectivity analysis are:

- legacy aeromagnetic data digitised and interpreted with new procedures
- revised geological models and new digital geological data
- drainage geochemistry data
- mine and mineral occurrence data

Knowledge-based prospectivity analysis has been used to integrate multiple digital datasets to produce maps that identify areas favourable for the occurrence of stratiform base-metal sulphides. The knowledge-based analysis system used allows the exploration geologist to determine the relative significance of the exploration data and then search for patterns which reflect the total effect of such significance. In practice this means selecting which data layers to use in the analysis and deciding the relative weight and pattern of influence that is assigned to each data layer.

Analysis of borehole records held by BGS for south-west England shows that drilling in the region is shallow, with 87% of the boreholes less than 50 m in depth. Considering the average size and thickness of typical stratiform sulphide deposits, together with the favourable geological setting and known occurrences, the premise underlying this study is that significant potential exists for new discoveries of mineralisation of this type in the target area.

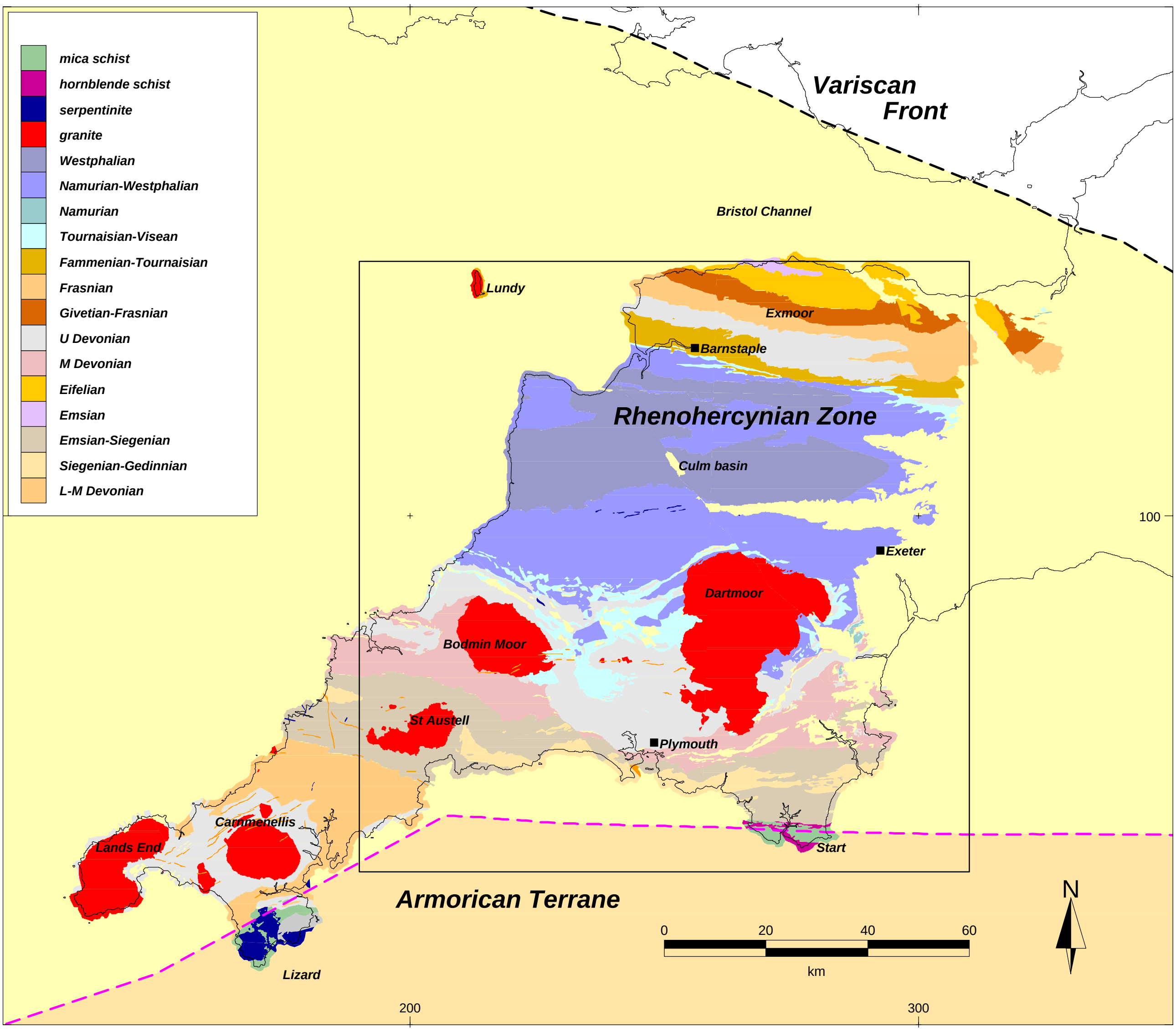

Figure 1 Simplified geology of south-west England showing the location of the study region

2 Geology

South-west England forms part of the outer and northernmost zone of the Variscan orogen, known as the Rhenohercynian terrane (Figure 1). The Variscan orogenic belt marks the collision between Gondwana and Laurasia along a broad zone within which terranes docked against each other along major suture zones. The Rhenohercynian terrane extends across Europe from the edge of the Carpathian mountains in northern Bohemia, westwards through Germany and Belgium, beneath the younger rocks of Kent and Wessex, and on into south-west England. The same belt passes southwards from Cornwall into Brittany, via the Massif Central, and into northern Spain.

The Devonian and Carboniferous strata of south-west England and South Wales (Figure 2) show evidence of Variscan (Westphalian-Stephanian) deformation. The approximate northward limit of this deformation is known as the Variscan Front (Figure 1). Low pressure metamorphism affected these strata between 325 and 295 Ma (Dodson and Rex, 1971). Extensive post-tectonic granite plutons associated with post-collision thermal recovery, were emplaced in south-west England between 295 and 275 Ma (Chen et al., 1993) and form the main components of the igneous rock suite in the region (Figure 3).

Subsequent erosion of the newly emergent Variscan mountains provided material for the development of the widespread Culm-facies flysch of Lower and Upper Carboniferous age over much of Europe, including south-west England. Continued erosion from Upper Carboniferous times and during the Permian and Triassic eras led to the widespread formation of terrestrial molasse laid down as thick deposits as the basins subsided.

2.1 DEVONIAN AND EARLY CARBONIFEROUS

The outcrops of Devonian and Carboniferous rocks in the study region are shown in Figure 2.

2.1.1 South Devon to north Cornwall

The oldest rocks of this district are the Dartmouth Group of Pragian (Early Devonian) age, which are of continental origin and originally included lacustrine clays with interbedded mass flows succeeded by mud-dominated fluvial sediments. These consist of interbedded purple slates, siltstones and fine-grained sandstone or quartzites. Later in Pragian times, marine conditions were established and continued into the Emsian, forming the slates and turbidite sandstones of the Meadfoot Group, locally succeeded by the thick fluvio-deltaic sandstones of the Staddon Formation in Emsian times. Volcanic activity in the Early Devonian is marked by bimodal lavas and tuffs in the Dartmouth Group and by local basic lavas in the Meadfoot Group.

During the Middle and Late Devonian, sedimentation occurred in basin and rise structures, with thick deposits of mud and silt in basinal conditions, and volcanic rocks and reef limestones on the intervening rises. These basins were developed in advance of a major, northward-migrating compressional event, which produced thrust-bounded nappe structures throughout the province. Basinal conditions are exemplified by the slates and siltstones of the Saltash Formation in the Plymouth district, and by the Trevose Slate Formation of the Trevone Basin in north Cornwall. The Middle and Upper Devonian Tamar Group represents the Plymouth 'high' succession, which is dominated by limestones, with local developments of basic lava, bedded hyaloclastite and tuff. In the Torbay district, the high successions are represented by the Torquay Limestone, the Brixham Limestone and the Ashprington Volcanic formations.

During Lower Carboniferous times, sedimentation over much of this district was attenuated, with the Famennian slates passing upwards into Tournaisian and Visean dark grey or black shales, commonly with much syngenetic sulphide. The Early Carboniferous sequence in the central part of the region comprises grey and green slates, overlain by dark grey to black pyritic shales (Barras Nose Formation, Meldon Shale and Quartzite, Combe Shale), passing upwards into brown, locally calcareous shale or slate with chert beds and local thin lenses of limestone (Meldon Chert, Teign Chert). The dark shales are associated with dolerite sills and basic volcanic rocks and the cherty beds with spilitic lavas and tuffs. Towards the south, the Lower Carboniferous includes local developments of sandstone and siltstone, derived from the advancing high to the south: this is exemplified by the St. Mellion Formation of east Cornwall.

The first Variscan compressional event culminated at the end of the Lower Carboniferous and before the onset of sedimentation in the Culm Basin.

2.1.2 North Devon to west Somerset

The oldest strata in this district are the Early to Middle Devonian Lynton Slates, mostly grey slates and siltstones of shallow marine origin. These are succeeded by the continental Hangman Grits, comprising sandstones of fluvio-deltaic type, with interbedded siltstones and slates. A return to marine conditions took place in the succeeding Ilfracombe Slates and Morte Slates, with thin and local beds of limestone present just above the Middle to Upper Devonian boundary in the lower part of the Ilfracombe Slates. Alternations of marine and continental conditions are seen in the overlying sequence of Pickwell Down Sandstones, Upcott Slates and Baggy Sandstones, while the shallow marine Pilton Shales span the Devonian-Carboniferous boundary. Visean times are represented by the cherts, shales and thin limestone lenses of the Codden Hill Cherts.

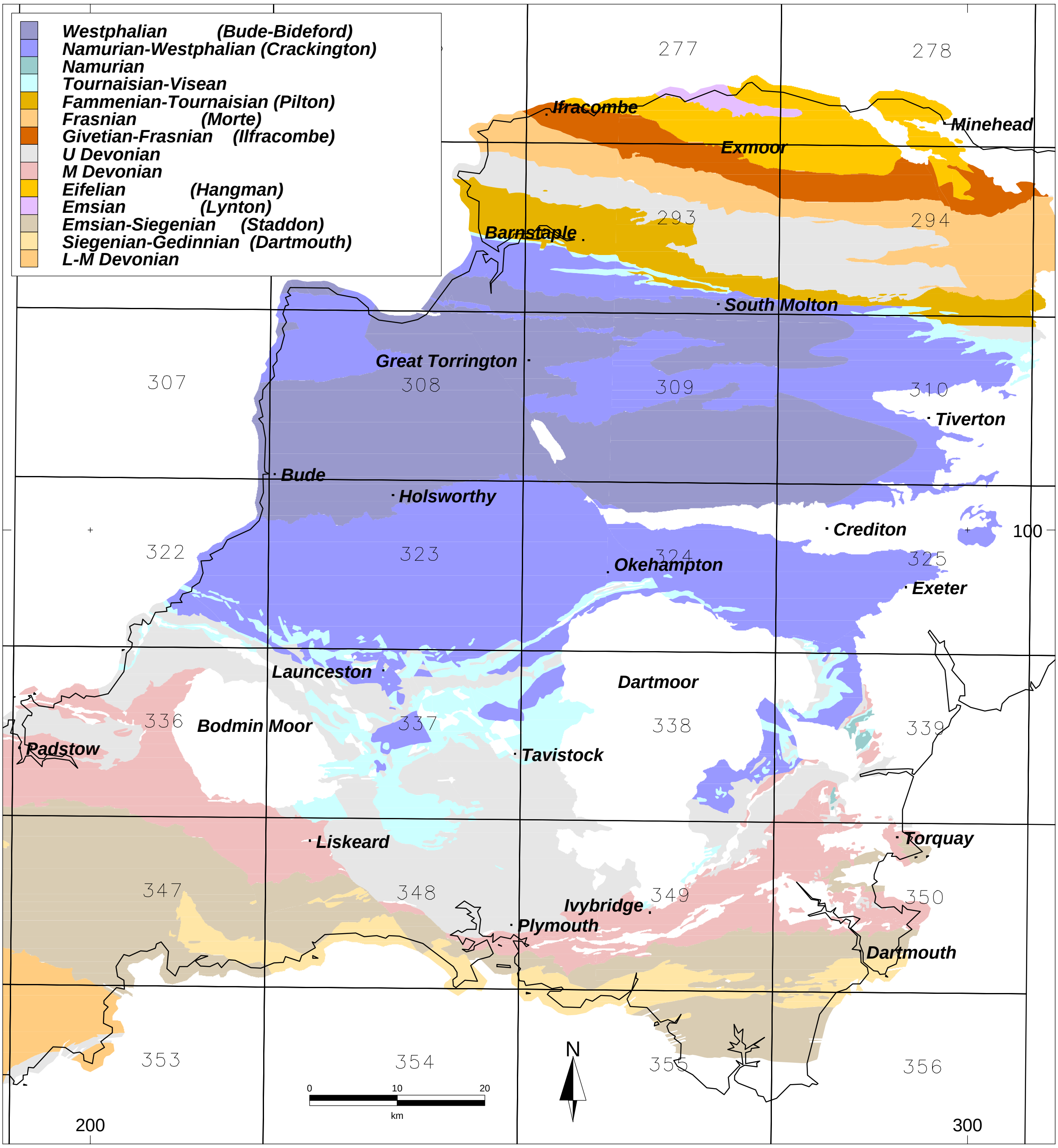

Figure 2 Distribution of Devonian and Carboniferous rocks in the study region. The layout and numbers of the 1:50 000 scale geological map sheets are also shown

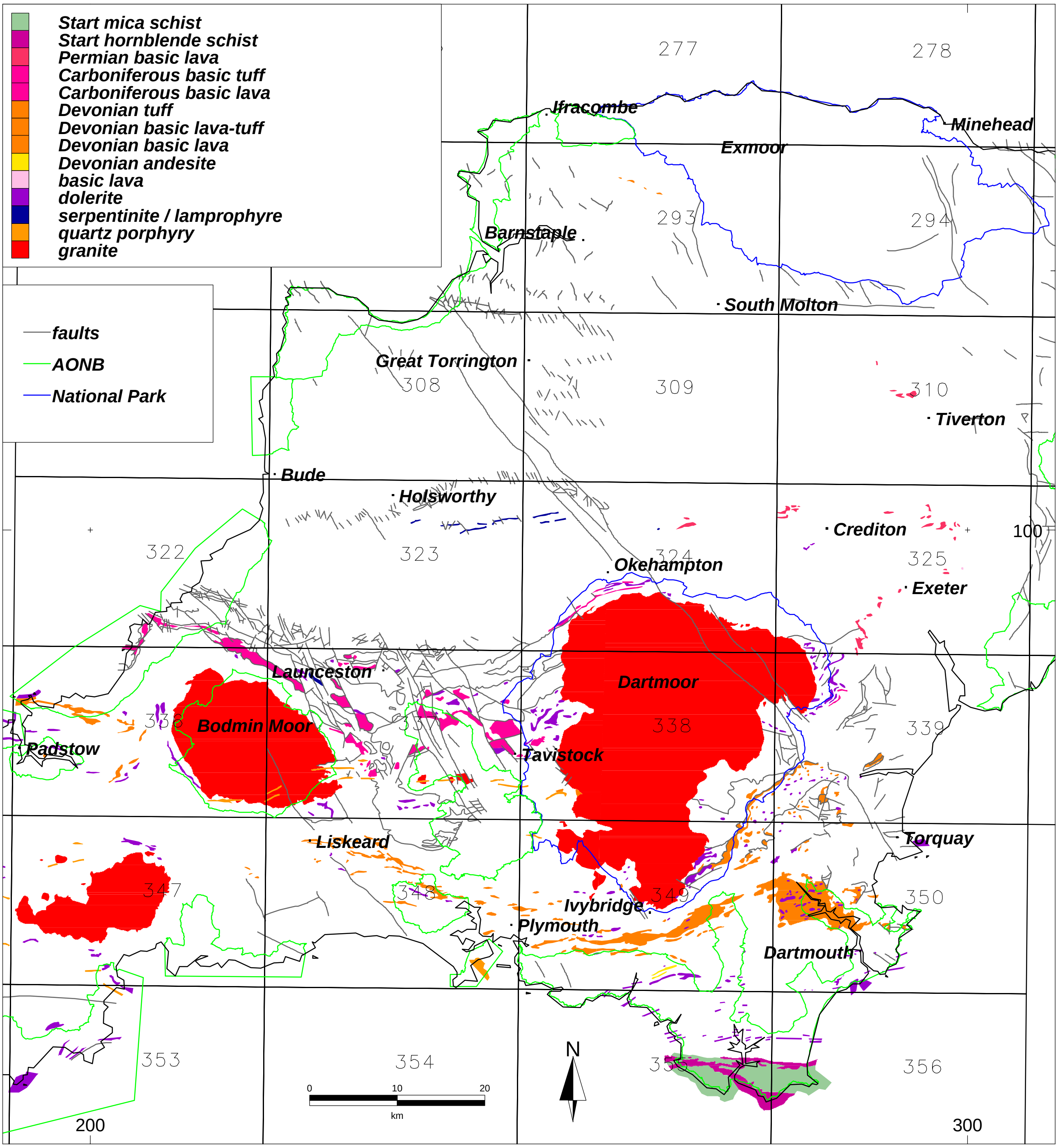

Figure 3 Distribution of igneous rocks and major fault structures in the study region and the locations of National Parks and Areas of Outstanding Natural Beauty (AONB)

North-east of the Quantock Hills, there are almost 1000 m of Early Carboniferous limestone, including a thick unit of Waulsortian reef facies carbonates, in faulted contact to the south with Middle to Late Devonian strata, the older rocks being partly concealed beneath Triassic cover (British Geological Survey, 1988).

2.2 LATE CARBONIFEROUS

The Late Carboniferous strata of south-west England, the 'Culm Measures,' accumulated in the Culm Basin, a synclinal structure extending across west and central Devon from the Atlantic coast to the Exe Valley. Sedimentation commenced in the early part of the Namurian with the marine shales and interbedded turbidite sandstones of the Crackington Formation. In the southern parts of its outcrop, the Crackington Formation is shale-dominated, with subordinate distal turbidite sandstone and siltstone beds, while to the north, the abundance and thickness of the sandstone beds increases (Freshney and Taylor, 1972, Freshney et al., 1972). Overlying the Crackington Formation is the more sandstone-rich Bude Formation, with proximal turbidite and deltaic sedimentation interbedded with shale and siltstone. Only developed in north Devon, and situated between the Crackington and Bude Formations, is the Bideford Formation, characterised by sedimentation in shallow conditions with deltaic sandstones and local anthracite seams. No volcanic activity is recorded in the late Carboniferous rocks of south-west England.

Sedimentation in the Culm Basin ceased after Westphalian C times, and the region was subjected to a second major north–south compressional regime, which produced large-scale deformation in the Late Carboniferous rocks and modified earlier structures in the older rocks. This folding, characteristically on east–west trending axes, is most intensely developed in the shale-rich strata of the southern Culm Basin, with more open and upright structures in the sandstones to the north. Most of the rocks in the Culm Basin show the effects of late diagenetic alteration or low anchizone regional metamorphism.

2.3 POST-OROGENIC RED BEDS

In east Devon and west Somerset, the deformed Devonian and Carboniferous strata are overlain, with marked disconformity, by a thick development of continental red beds, including sedimentary breccias and conglomerates, fluvial and aeolian sandstones, and lacustrine mudstones. These rocks, sometimes called the 'New Red Sandstone', form the western margin of the Wessex Basin: they are relatively undeformed, with gentle dips and most show only diagenetic alteration rather than metamorphism. The age of the New Red Sandstone has been the subject of considerable interest, particularly because of the almost total absence of fossils. Recent work, summarised in Edwards and Scrivener (1999) and based on detailed mapping, palynology and isotope geochemistry, has demonstrated that the earliest red beds are older than 290 Ma and therefore of Late Carboniferous (Stephanian) age, with sedimentation extending into the Early Permian. Further, that above a considerable disconformity, two superincumbent major fining upward cycles (Exeter Group + Aylesbeare Mudstone Group and Sherwood Sandstone Group + Mercia Mudstone Group) span the Late Permian to Early Triassic, and Early to Late Triassic respectively. Within the earliest red beds of the Crediton Trough and Exe Valley areas are examples of lamprophyric and alkali basalt lavas, the Exeter Volcanic Rocks.

Outliers of red bed breccias and sandstone occur in north Devon (Portledge), west Devon (Hollacombe) and east Cornwall (Cawsand and Withnoe). These attest the former, much wider coverage of the south-west region by New Red Sandstone rocks, now removed by erosion. There are also major developments of Permian and Triassic red beds in the submarine basins, which flank the region to north (Bristol Channel and central Somerset Basin) and south (Plymouth Bay Basin). These considerations are significant in that the red-bed sediments are now considered (Scrivener et al., 1994) to be the source of low-temperature, high-salinity brines, which have been potent agents in regional-scale hydrothermal mineralisation.

2.4 GRANITES AND MINERALISATION

Towards the end of the Variscan orogeny, crustal thickening coupled with high heat flow from the mantle caused large-scale melting of the lower part of the crust. In the post-orogenic north–south extensional regime, during Stephanian and Early Permian times, the crustal melt migrated upwards and crystallised at a high level in the crust. The Dartmoor and Bodmin Moor granites represent separate upward migrations of magma emplaced between about 295 and 270 Ma. The intrusion of the plutons was accompanied by locally intense hydrothermal mineralisation of four main types:

1. skarn deposits: formed by the alteration of calcium-rich rocks in the metamorphic aureoles of the granites and subsequent invasion by high-temperature hydrothermal fluids of direct magmatic origin. Such deposits are only found in close proximity to the granite margins and have yielded small to medium tonnages of iron (as magnetite), copper and arsenic, with minor tin and tungsten.
2. greisen-bordered veins: quartz veins with cassiterite and wolframite, also minor sulphide and arsenide minerals. The veins are enclosed by distinctive selvedges of white mica-quartz-topaz alteration. These formed at various scales, most typically as parallel or interlacing swarms of narrow veins, 'sheeted vein complexes' or 'stockworks'. Locally these bodies supported significant mining operations. They include large tonnage, low-grade deposits, such as the Hemerdon tin-tungsten stockwork of southern Dartmoor.
3. tourmalinite veins: these veins have a restricted mineralogy of tourmaline-quartz-cassiterite-hematite, with characteristic wallrock alteration of red or pink secondary feldspar. They have locally been important for tin production.
4. 'Main-stage' polymetallic veins: these veins can be of considerable size and they have yielded much of the tin, copper, arsenic, zinc and lead of the Cornwall and Devon mining districts. Individual veins or vein complexes may show evidence of zoning, with tin occurring close to, and within, the granites, while arsenic and base metals are found in the envelope rocks. Elsewhere, they may show 'telescoping', with

successive generations of minerals present in the same vein section.

Types 1–3 are products of the egress of magmatic ore fluids, and they tend to be localised within, or close to, their parent granites. In contrast, type 4 veins are considered to involve the larger scale and protracted convective circulation of hydrothermal brines, with some meteoric component.

2.5 TECTONICS

The strata in the Rhenohercynian zone have undergone low-grade metamorphism and Variscan deformation. High-grade mica and hornblende schists associated with the Armorican terrane outcrop in south-west England at Start Point (Figure 3), Dodman Point and the Lizard. The northern boundary of the Rhenohercynian zone is the Variscan Front which marks the approximate limit of Variscan (Westphalian-Stephanian) deformation. The position of the Variscan Front is generally considered to be on the north side of the Bristol Channel (BGS, 1996). The nature of the basement to the Rhenohercynian zone is uncertain: in the north a series of stacked thrusts which have affected Devonian and Carboniferous strata probably rest on a basement which is part of the Avalonian terrane amalgamated with Laurentia and Baltica during the Caledonian orogeny. The extent of movement on these major structures is uncertain, but much of the Devonian-Carboniferous sequence of the region might be parautochthonous rather than autochthonous.

The Devonian and Lower Carboniferous rocks in the central part of the region of study are disposed in a broad synclinal structure of Variscan age. The Devonian-Silesian rocks have been folded into a series of isoclinal upright and overturned structures dissected by thrusts (Isaac et al., 1982; Isaac, 1985).

Away from the coast exposure is very poor and detailed mapping of fold structures is not therefore possible. In north Devon exposures of Lynton Slates of Emsian age form the cores of large antiform structures. Further south on Exmoor outcrops of Famennian age Baggy Sandstone and Pickwell Down Sandstone define synclines and anticlines north of the Culm Basin. The thickly-bedded massive sandstones of the Bude and Bideford Formations are up to about 1500 m thick, while the turbidite sandstones of the Crackington Formation are about 1000 m thick. Faulting at the northern margin of the east–west Permian Crediton Trough is displaced by later dextral faulting on the Sticklepath-Lustleigh fault. At Petrockstow the dextral faulting also shows dip-slip movement down to the north-east. Dips in the Crackington Formation are commonly moderate to steep, often steep overturned. At the southern margin of the Culm Basin Tournaisian and Visean rocks, including shales, cherts and quartzites with basic volcanic lavas and tuffs, are locally thrust over Crackington Formation strata and over Upper Devonian purple, green and grey slates. Between Bodmin Moor and Dartmoor the general disposition of the Lower Carboniferous chert-bearing formations is an open syncline although the north margin of this package is generally mapped as a thrust. Crackington Formation strata locally form outliers along the axis of this open syncline, but here the northern contacts of these outcrops have also been mapped as thrusts. Outcrop vectors are generally highly convolute, characteristic of shallow-dipping strata or thrust packages.

In the central and southern part of the region the Lower Devonian parautochthon consists of a series of tectonic units or nappes stacked in a sequence which is poorly documented. This structural framework is best observed in the region where distinctive formations occur, notably between and adjacent to Bodmin Moor and Dartmoor. The tectonic separation of many formations has made the application of sequence stratigraphy in the region difficult and has created serious problems of map unification and matching.

Prospective host formations for stratiform sulphide deposits occur in both the parautochthonous and the allochthonous sequences. On the Plymouth map sheet, all formation boundaries are tectonic (BGS, 1998). On the provisional Tavistock 1:50 000 Geological Map (BGS, 1993) a stack of five nappes is recognised in the zone between Bodmin Moor and Dartmoor: Greystones, Petherwith, Tredorn, Blackdown, Boscastle. Within these nappes and the parautochthon there are more than 30 formations spanning the stages from Famennian to Namurian. Many of these formations include black shale members including the Bealsmill, Lydford, Meldon Chert, Trambley Cove, Barras Nose and Cotehele Sandstone Formations. Much of the central and south-east part of the Tavistock district consists of the Tavy Formation of green and grey slates. These strata are considered to be part of the parautochthonous sequence. The more variable Brendon Formation, often in contact with the Tavy Formation, includes grey and black slates with siltstones and volcanic rocks and may also be partly parautochthonous.

3 Mineralisation

South-west England is best known for metal deposits related to the Cornubian granites, most notably the tin-copper-zinc hydrothermal vein systems. These were worked at numerous locations until mining activity in the region finally ceased in 1999 with the closure of the South Crofty mine at Redruth in Cornwall. Most previous exploration was focused on the search for similar vein deposits. However, since 1970, exploration carried out by BGS and industry has led to the identification of mineralising systems and mineral occurrences not directly related to the granites (Colman and Cooper, 2000).

Three main styles of mineralisation have been identified:

1. Stratiform or stratabound metal enrichments within folded Devonian and Carboniferous rocks, commonly associated with volcanic activity. Locally these may reach ore grade.
2. Stratiform mineralisation redistributed and concentrated by tectonic and/or hydrothermal processes.
3. Low-temperature mineralisation related to the Permian and Triassic red-bed basins.

The following sections describe the main mineral occurrences in stratigraphical order.

3.1 DEVONIAN

Drainage geochemical surveys over Lower Devonian strata in South Devon identified locally high values of gold and PGE (platinum-group elements) over the outcrop of the Dartmouth Slate (Leake et al., 1990). There are also local drainage anomalies in arsenic, antimony, tin and mercury. Borehole samples from the Early Devonian acid volcanic rocks demonstrate widespread silicification and early hydrothermal veining consistent with exhalative mineralisation (Leake et al., 1985).

Near the boundary between the Middle and Late Devonian, there are substantial developments of basic volcanic rocks including spilitic lavas and volcaniclastic rocks such as tuffs and hyaloclastites. In south Devon, between Plymouth and Torbay, local outcrops of limestone, which formed as reefs around the volcanic seamounts are partly lateral equivalents. Early hydrothermal activity, related to the volcanic activity was responsible for metal enrichments within the Middle to Late Devonian sequences. Examples in south Devon are the massive pyrite-carbonate SEDEX type deposit of the Ivybridge district, associated with As, Sb, Ba geochemical anomalies (Beer et al., 1981) and the Bulkamore iron deposit (Dines, 1956), in which pyrite and magnetite partially replace volcaniclastic rocks. Drainage geochemical surveys around the Middle to Late Devonian boundary in North Cornwall and South Devon have identified extensive As, Sb, Ba and Au anomalies (Jones, 1981; Jones et al., 1987; Leake et al., 1985).

In north Devon, the Middle to Late Devonian boundary occurs above a substantial thickness of fluvial and deltaic sandstones (the Hangman Grit), within a marine sequence dominated by slates, with thin limestone beds in the lowest part (Figure 2). In the Combe Martin district these slates contain stratiform lead-zinc-silver deposits which provided the basis of the historic mining industry in that area (Scrivener and Bennett, 1980). Along strike to the east, drilling of the same general horizon at Honeymead Farm identified disseminated Fe-sulphide (pyrrhotite) mineralisation beneath the high ground of Exmoor (Edmonds et al., 1985). Further to the east, in the Quantock Hills and in the Cannington Park borehole north-west of Bridgewater, the Middle to Late Devonian strata (including the Leighland Beds) show pervasive low-grade hematite and base-metal sulphide mineralisation. Middle Devonian rocks are close or adjacent to Visean-Namurian rocks near Cannington Park, possibly above a Variscan thrust structure (Chadwick et al., 1983). In the Doddington Mine, to the north of the Quantock Hills, disseminated Pb mineralisation is present within Devonian limestone concealed beneath Triassic sandstone cover.

3.2 EARLY CARBONIFEROUS

There are numerous occurrences of mineralisation within the Early Carboniferous strata of south-west England (Dines, 1956), most notably the skarn orebodies to the north and east of the Dartmoor Granite (copper-arsenic-tin near Meldon and Belstone, and magnetite near Ilsington). There are also stratiform manganese silicate-carbonate ores within the chert beds, derived from contemporaneous submarine hydrothermal activity. Commercial exploration drilling near Egloskerry in rocks of Late Devonian to Early Carboniferous age identified stratiform lead-zinc mineralisation. In the Teign Valley, drainage geochemical surveys demonstrated considerable heavy metal enrichment in Early Carboniferous shales and cherts, especially the Combe Shale and Teign Chert (Beer et al., 1992). Also in this district, the distribution of north–south-trending lead-zinc-silver-baryte 'cross-course' veins hosted by Early Carboniferous strata is considered to be controlled by the host-rock stratigraphy (Scrivener et al., 1994).

In north Devon the Early Carboniferous shales and sandstones of the Pilton Beds are host to scattered lead-zinc-baryte-arsenic vein deposits which show clear evidence of stratigraphical control.

Drainage sampling and regional lithogeochemistry have demonstrated that the Early Carboniferous shales and cherts of south Devon to east Cornwall are considerably enriched in Pb-Zn-Ba-As. In addition to the geochemical data, BGS regional geophysical surveys have shown that the some Carboniferous shales to the north of Dartmoor and Bodmin Moor give rise to high amplitude magnetic anomalies due to the thermal alteration of pyrite to pyrrhotite in the vicinity of the Cornubian Batholith.

3.3 PERMIAN AND TRIASSIC

Mineralisation of replacement origin occurs within the Permian and Triassic sequence. This includes iron ores formerly worked in the Minehead district, and manganese ores which were produced from a series of small workings along the southern boundary of the Crediton Trough. These occurrences, and the basement ‘crosscourses’ (north-south veins), are ascribed to the movement of low-temperature, high salinity brines within the Permo-Triassic basins.

Geochemical investigations have demonstrated the presence of gold in Permian and basement rocks close to the basal disconformity of the red bed sequence and within the Exeter Volcanic Rocks (Cameron et al., 1994; Leake et al., 1994). The genesis of this mineralisation is related to transport of gold by oxidising and chloride-rich basinal brines and subsequent deposition at redox boundaries with the underlying reduced Carboniferous strata.

4 Previous exploration work

Extensive exploration activity, ranging from regional reconnaissance surveys to detailed resource investigations, has been carried out in the study area. The major sources of information about this work are:

- reports and data releases from the DTI-funded Mineral Reconnaissance Programme (MRP), carried out between 1971–1993.(Table 1; Figure 4).
- reports on commercial exploration, including work carried out under the Mineral Exploration Incentive Grant Aid (MEIGA) scheme (Table 2; Figure 5).
- The BGS 1:10 000 scale mapping programme and associated regional gravity and aeromagnetic surveys (BGS, 1997 and 1998), also provide a large amount of relevant data that underpins exploration and assessment of the mineral resources in the region.

Table 1 Reports of work carried out under the Mineral Reconnaissance Programme (MRP) in south-west England. (locations of report areas are shown in Figure 4).

Report No	Title	Authors
1	The concealed granite roof in south-west Cornwall	K E Beer, A J Burley and J M C Tombs (1975)
2	Geochemical and geophysical investigations around Garras Mine near Truro, Cornwall	R C Jones and J M C Tombs (1975)
12	Mineral investigations in the Teign Valley, Devon. Part 1 - Barytes	K E Beer and T K Ball (1977)
25	Mineral investigations near Bodmin, Cornwall. Part 1- Airborne and ground geophysical surveys	J M C Tombs (1978)
32	Investigations at Polyphant, near Launceston, Cornwall	M J Bennett, K Turton and K E Rollin (1980)
34	Results of a gravity survey of the south-west margin of Dartmoor, Devon	J M C Tombs (1980)
41	Metalliferous mineralisation near Lutton, Ivybridge, Devon	K E Beer and others (1981)
44	Reconnaissance geochemical maps of parts of south Devon and Cornwall	R C Jones (1981)
45	Mineral investigations near Bodmin, Cornwall. Part 2 - New uranium, tin and copper occurrences in the Tremayne area of St Columb Major	B C Tandy and others (1981)
48	Mineral investigations near Bodmin, Cornwall. Part 3 -The Mulberry and Wheal Prosper area	M J Bennett and others (1981)
49	Seismic and gravity surveys over the concealed granite ridge at Bosworgy, Cornwall	K E Rollin, C F O'Brien and J M C Tombs (1982)
79	Volcanogenic and exhalative mineralisation within Devonian rocks of the South Hams district of Devon	R C Leake and others (1985)
81	Investigations for tin around Wheal Reeth, Godolphin, Cornwall	K E Beer and others (1986)
82	Mineral investigations near Bodmin, Cornwall. Part 4 - Drilling at Royalton Farm	K E Beer, K Turton and T K Ball (1986)
83	Mineral investigations near Bodmin, Cornwall. Part 5 - The Castle-an-Dinas Wolfram Lode	K E Beer, T K Ball and M J Bennett (1986)
89	Geochemical and geophysical investigations of the Permian (Littleham Mudstone) sediments of part of Devon	J H Bateson, C C Johnson and A D Evans (1987)
90 *	Geochemical and geophysical investigations in Exmoor and the Brendon Hills	R C Jones, K E Beer and J M C Tombs (1987)
95	Mineral reconnaissance at Menear, St Austell, Cornwall	K E Beer, B C Tandy and G S Kimbell (1988)
98	Exploration for gold between the lower valleys of the Erme and Avon in the South Hams district of Devon	R C Leake and others (1988)
101	Skarn-type copper mineralisation in the vicinity of Belstone Consols Mine, Okehampton, Devon	K E Beer, G S Kimbell and M J Bennett (1989)
103	Exploration for volcanogenic mineralisation in Devonian rocks north of Wadebridge, Cornwall	R C Leake and others (1989)

Report No	Title	Authors
105	Investigations at Lambriggan Mine, near St Agnes, Cornwall	K E Beer and K E Rollin (1989)
107	Mineral investigations near Bodmin, Cornwall. Part 6 - The Belowda area	K E Beer, B R Mountford and R C Jones (1989)
108	Geochemical investigations around Trewalder, near Camelford, Cornwall	K E Beer and R C Jones (1989)
110	Mineral investigations near Bodmin, Cornwall. Part 7 - New uranium occurrences at Quoit and Higher Trenoweth	T K Ball, B C Tandy and K Turton (1990)
111	Gold and platinum group elements in drainage between the River Erme and Plymouth Sound, South Devon	R C Leake, D G Cameron, D J Bland and M T Styles (1990)
113	Mineral investigations at Tredaule, near Launceston, Cornwall	R C Jones and K E Beer (1990)
117	Exploration for vanadiferous magnetite and ilmenite in the Lizard complex, Cornwall	R C Leake, M T Styles and K E Rollin (1992)
121	Exploration for gold in the South Hams district of Devon	R C Leake and others (1992)
123	Mineral investigations in the Teign Valley, Devon. Part 2: base metals.	K E Beer and others (1992)
129	Mineralisation in the Middle Devonian volcanic belt and associated rocks of South Devon	R C Leake and G E Norton (1993)
133	Exploration for gold in the Crediton Trough, Devon. Part 1 - regional surveys	D G Cameron and others (1994)
134	Exploration for gold in the Crediton Trough, Devon. Part 2 - detailed surveys	R C Leake and others (1994)
144	The potential for gold mineralisation in the British Permian and Triassic red beds and their contacts with underlying rocks	R C Leake and others (1997)
1015#	An appraisal of the gold potential of mine dumps in the North Molton area, North Devon	D G Cameron and D J Bland (1994)
1016#	Exploration for stratabound mineralisation around Chillaton, Devon	R C Leake, K Smith and K E Rollin (1994)
	# data release only * associated data release	

The following sections summarise the principal results of previous exploration in each part of the study region.

4.1 CENTRAL AREA

The central area of Devon and east Cornwall has a prominent high-frequency aeromagnetic anomaly (BGS, 1998) which approximately follows the mapped outcrop of Lower Carboniferous strata along the northern margins of the Dartmoor and Bodmin Moor granites. This magnetic anomaly comprises a strong positive component to the north and a strong negative component to the south. This polarity is opposite to that of most anomalies in the northern hemisphere and indicates that the source of the anomaly has a magnetisation vector different to the induced magnetisation vector in the earth field.

The complexity of the magnetisation of the Carboniferous rocks on the north side of the Dartmoor granite has been described by Cornwell (1967). His principal observations may be summarised as follows:

1. Natural Remanent Magnetisation (NRM) intensity and magnetic susceptibility varies rapidly.
2. NRM intensity is typically 0.2–0.5 A/m, locally greater than 5 A/m, with NRM generally much greater than induced magnetisation, sometimes by a factor of more than 100.
3. the NRM directions around Okehampton show no simple relationship to intrusive history, structure and remagnetisation.
4. the plane of maximum anisotropy of magnetisation appears to lie in the bedding or cleavage direction.

The most important ferromagnetic mineral in the area was shown to be pyrrhotite which has a Curie temperature in the range 270–330° C, dependent on composition. The pyrrhotite appears to have been formed at the time of granite intrusion, either by metasomatism (Cornwell, 1967) or by recrystallisation of syngenetic pyrite (Beer and Fenning, 1976).

In the Okehampton district the NRM of the pyrrhotite post-dated folding and intrusion of the granite, but directions are not always consistent with the Late Carboniferous–Permian palaeomagnetic field. Some of the variation in NRM directions may be due to later movement along north-east-trending structures such as the Sticklepath and Prewley Faults (Holloway and Chadwick, 1985). At Okehampton the NRM anisotropy ratio of most samples is close to 1.27 and was explained by the structure and growth of the pyrrhotite crystals. Pyrrhotite growth is most likely to occur with the basal planes of the crystals perpendicular to the direction of strain, generally along cleavage planes and bedding. These planes are also the planes of maximum magnetic anisotropy.

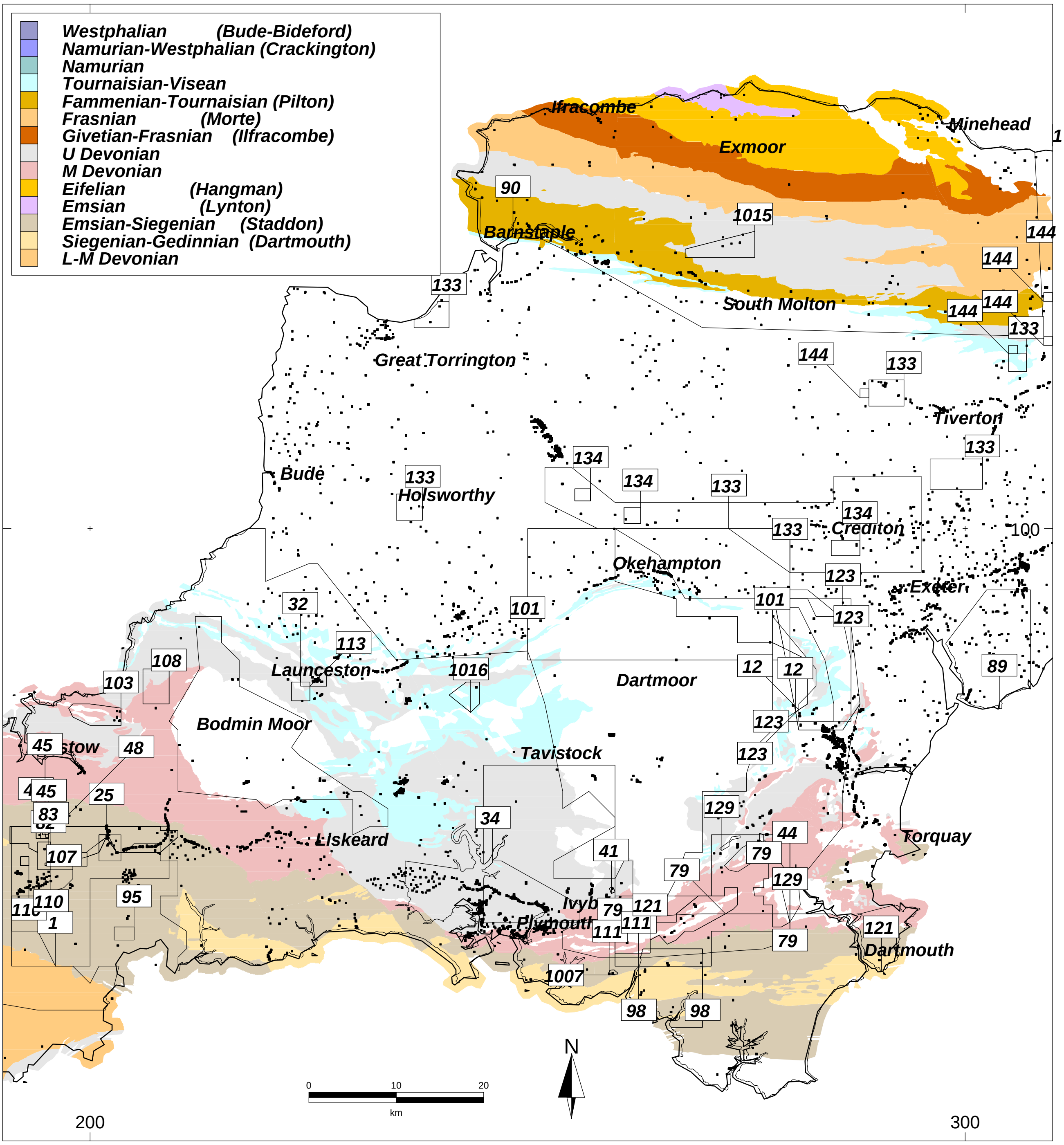

Figure 4 The location of all boreholes (black squares) and Mineral Reconnaissance Programme (MRP) survey areas in the study region. The numbers refer to MRP reports listed in Table 1

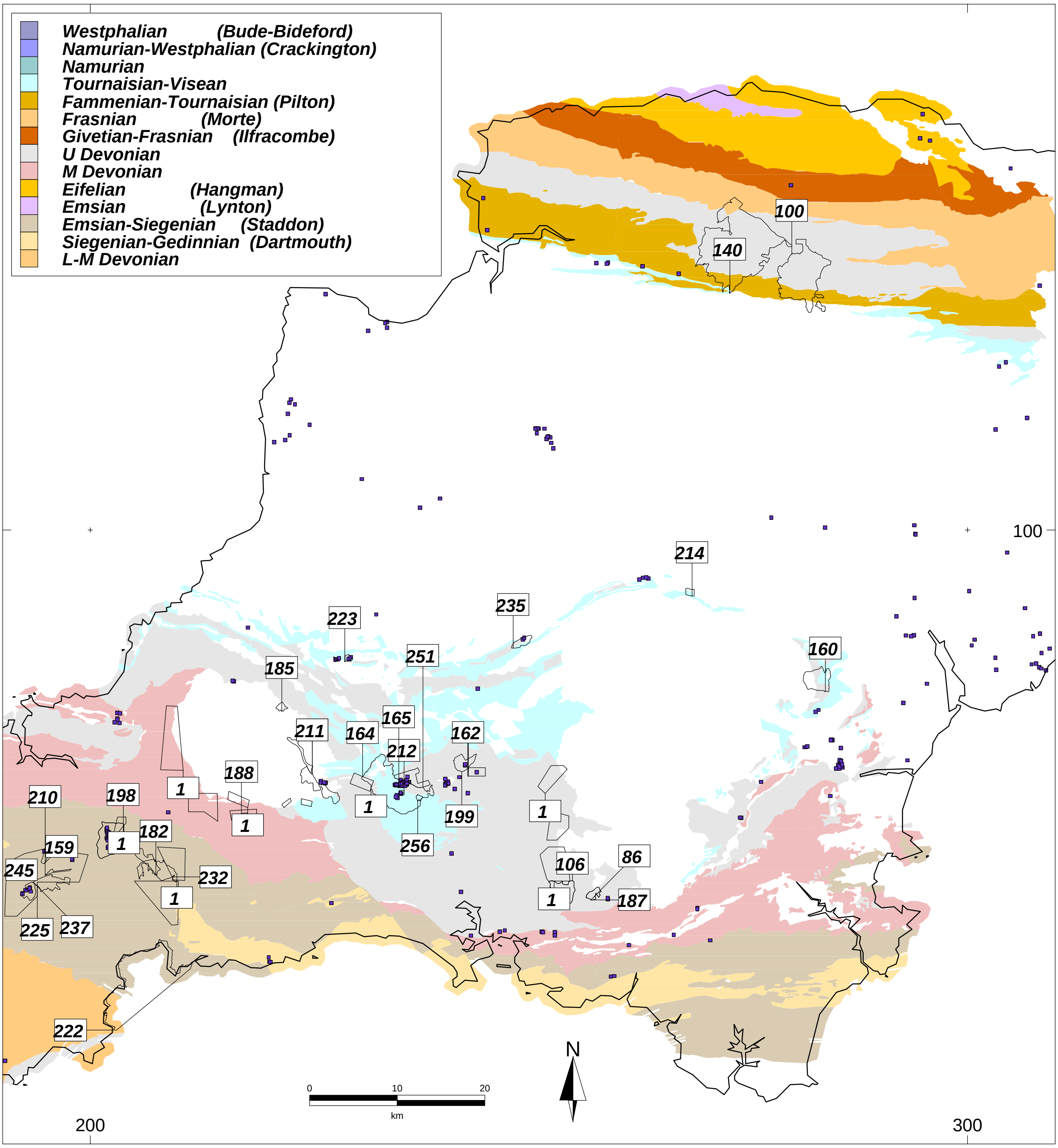

Figure 5 The location of boreholes deeper than 50 m (black squares) and the distribution of exploration surveys supported by MEIGA in the study region. The numbers of the MEIGA areas refer to projects listed in Table 2

In the Tavistock district, the NRM directions are more consistent (Cornwell, 1967), despite a variety of dipping structures. Here the NRM vector declination (D) of 189° and inclination (I) of -21° is similar to that for the Exeter Lavas (D=188°, I=-13°) which were formed at the time of granite intrusion (c. 280 Ma). The highest NRM intensities, exceeding 11 A/m, occur in albite dolerites in which the main opaque mineral is ilmenite and the volume susceptibility is less than 0.005 SI. This implies a Q ratio (NRM magnetisation/induced magnetisation) in excess of 500.

The Okehampton region was further explored with detailed gravity traverses, total field magnetic traverses, electrical resistivity, electromagnetic (EM) (440Hz) and self-potential (SP) surveys (Edmonds et al., 1968; Beer and Fenning, 1976). Anomalies from the regional aeromagnetic survey with amplitude between 500 and 770 nT were shown to have amplitudes of 900–1400 nT at ground level. SP anomalies of about –400 mV correlated well with EM anomaly cross-overs and with zones of low (<60 ohm-m) apparent resistivity. However, detailed gravity profiles with a station separation of 7.5 m did not show significant positive anomalies. The geophysical anomalies were explained by disseminated, bedding concentration, fracture-coating and vein mineralisation of pyrrhotite-pyrite proved in 5 drill holes (average depth about 50 m) at Sourton Tors (Beer and Fenning, 1976). Typical styles of mineralisation include: syngenetic bedded pyrite converted to pyrrhotite; reticulate veinlets of pyrrhotite-pyrite (5:1) filling tension fractures 1-5 mm wide; later pyrite veins and barren quartz or carbonate veinlets. Chalcopyrite is rare but locally sphalerite forms up to 3% of the sulphide in veins and fractures. The richest zones in drillcore contain 7–8% pyrrhotite and pyrite. Susceptibility measurements in one borehole showed a general correlation with density, although susceptibility values were generally less than 0.01 SI. It was concluded that most of the magnetic anomaly is a result of high NRM intensities. The pyrrhotite is considered to have formed mainly by recrystallisation of syngenetic pyrite at the time of granite intrusion with perhaps only a small metasomatic contribution (Beer and Fenning, 1976).

North of the Bodmin Moor granite similar regional magnetic anomalies were explored using ground magnetic, resistivity and electromagnetic (EM) surveys (McKeown et al., 1973). The northern positive component of the magnetic anomaly of amplitude about 500 nT is linked to the negative component of about –600 nT. A regional positive magnetic anomaly south of this was attributed to the Tintagel Volcanic Formation which has a mean magnetic susceptibility of about 0.016 SI (Table 11). Locally, susceptibility is much higher, about 0.055 SI at Trebarwith Strand (McKeown et al., 1973) with individual samples up to about 0.2 SI. To support the geological mapping programme in the area about 35 ground magnetic traverses were surveyed across the outcrop of the Tintagel Volcanic Formation. A dual frequency airborne EM anomaly near Halwill Barton was explored using ground SP, EM and magnetic methods. Vertical force magnetic anomalies of 250–300 nT and SP anomalies of about –800 mV were interpreted as relating to a south-dipping source. The Halwill Barton borehole [21245 08879] penetrated grey and black Lower Carboniferous slates with abundant pyrite occurring as fine disseminations and on cleavage and joint fractures to a depth of 28 m (McKeown et al., 1973). Pyrrhotite occurred in the lower part of this sequence and also in the underlying Upper Devonian slates to a depth of 45 m. The EM anomaly was interpreted in terms of a resistivity contrast between the black slates (200 ohm-m) and the north-dipping Devonian slates (600 ohm-m), although the SP anomaly had suggested a southerly dip for the source.

It is of interest that the regional reversed magnetic anomaly was initially interpreted, using simple prism shapes, as due to a source with an upper surface at a depth of 0.45–0.90 km near the north Devon coast and between 0.9–2.1 km at the eastern margin of the Boscastle region (McKeown et al., 1973). The thickness of the source was estimated at 2–4 km. The Wilsey Down borehole [21797 08890] drilled in 1968 (McKeown et al., 1973) was sited in the negative part of the regional magnetic anomaly close to the maximum horizontal gradient in the magnetic field anomaly and encountered pyrrhotite from 76–259 m (Appendix 1), at a much shallower depth than postulated by the early interpretation. However, the Wilsey Down borehole is very close to a local maximum in the analytic signal of the residual magnetic field where 2D and 3D depth solutions for the magnetic field are relatively shallow and no NRM measurements were made on the borehole core. This would suggest that high intensity NRM in pyrrhotite might be an explanation of the magnetic anomaly.

Overall, on the basis of the numerous surveys across magnetic anomaly of the central belt, pyrrhotite with a significant NRM, has been identified as the likely source. The importance of metasomatism associated with granite intrusion relative to recrystallisation of syngenetic sulphide remains uncertain. If metasomatism is limited, then the regional magnetic anomaly, after transformation, may provide a guide to primary stratiform mineralisation in the Lower Carboniferous sequence. However, it appears that very low concentrations of pyrrhotite may give high NRM intensities, so no reliable indication of sulphide content can be inferred.

Geological examination, shallow boreholes and geochemical soil sampling over the small Polyphant ultrabasic igneous body situated between Bodmin Moor and Launceston, indicate marked variations in composition, with at least two types of peridotite and two of gabbro (Bennett et al., 1980). The distribution of Ni, Co and Cr in overlying soil mimics macro-layering within the peridotite, but the concentrations of these metals, and of Cu, are close to background levels for these lithologies. No significant mineralisation was indicated by the investigations, but high induced polarisation (IP) values at the southern margin of the complex may be due to minor sulphide concentrations.

Further MRP investigations over the Lower Carboniferous strata were carried out by Leake et al. (1994). Reconnaissance soil traverses at Chillaton, 8 km north-west of Tavistock, were supported by induced polarisation (IP), self-potential (SP) and VLF surveys. The soil geochemical data helped to elucidate the local geology of the volcanic and sedimentary succession and identified weak base-metal enrichments. Strong IP, SP and VLF anomalies were associated with anomalous As values in soil but without attendant base metal anomalies. Two boreholes intersected pyritiferous black shale above a chert-shale sequence with dolerite intrusions. The upper section of borehole 2 contained a highly fossiliferous overturned sequence spanning the conformable Famennian-Tournaisian boundary (Selwood et al., 1982). The black shales are enriched in Mo and As, but not in base metals or Mn. The evolved intrusive rocks have high Ti values but are depleted in Cr and Ni, whereas more primitive sub-volcanic intrusions show enrichment in Cr and Ni. High Mn values in the boreholes correlate with chert horizons and with intrusive dolerites. Some of the dolerites show enrichment in As (maximum 160 ppm), with one sample also containing minor gold enrichment (49 ppb).

Two detailed gravity surveys have been carried out in the central area:

1. A detailed gravity survey (station distribution c. 5 km^2) of the south-west margin of Dartmoor (Tombs, 1980), including the Hemerdon tin-tungsten stockwork, was interpreted to indicate the depth to buried granite. The results show that the Hemerdon Ball granite is an isolated block that does not extend to depth and that no vertically continuous shallow granite occurs at any distance from the known outcrop. These data were not utilised for any appraisal of potential massive sulphide deposits.
2. A detailed gravity survey over 1800 km^2 between Dartmoor and Bodmin Moor, with an average station distribution of about 3.25 km^{-2}, was interpreted in terms of the depth to the buried Cornubian granite (Rollin, 1988). Large areas were defined where the granite surface lies within 1 km of sea level; in contrast, the north-eastern edge of the Bodmin granite dips steeply to depths of at least 3 km. A closed minimum Bouguer gravity anomaly at Lamerton, north-west of Tavistock, has a negative residual anomaly of about 2 mGal. This was interpreted as a Tertiary basin filled with argillaceous sediments. A shallow piston core to a depth of about 15 m, together with a resistivity depth sounding, supported the sedimentary basin interpretation of the Lamerton anomaly, and suggests a thickness of about 150 m of Tertiary clays in a fault-bounded basin, elongated to the north-west.

Extensive geochemical prospecting was carried out by RioFinex over the Lower Carboniferous succession in this central area, together with much of north Cornwall and Devon, in 1980. Initial roadside soil sampling was followed up by deep overburden sampling using Cobra percussion drilling. A high tenor geochemical anomaly was found at Egloskerry, situated two miles west of Launceston, Cornwall. RioFinex subsequently investigated this anomaly for stratiform lead-zinc in the early 1980s, with funding support from the MEIGA scheme (MEG 223).

In the Egloskerry area the overburden sampling comprised 14 north–south traverses, spaced at 200–300 m over an east–west tract of approximately 3 km. The samples, collected at 30 m intervals, were analysed for Cu, Pb, Zn and Mn. Anomalous Pb values, in excess of 4000 ppm, were encountered at two localities which were subsequently drilled. Zinc, and to a lesser extent Cu and Mn, were also markedly enriched at these sites. Extremely high Zn values, up to a maximum of 29800 ppm, also occurred in the floodplain of the River Kensey, near BH1. These near-surface anomalies may be attributable to hydromorphic upgrading.

In 1981, five diamond drill holes were drilled to investigate the principal soil anomalies at Egloskerry. Three holes were situated in the vicinity of Westend Farm, in the valley of the River Kensey [228 085], while the others were located approximately 1.5 km east-north-east, in the vicinity of Trewithick Farm [229 085]. Borehole EG1 intersected significant lead mineralisation: 10% Pb over 4.5 m (4.1 m true thickness) in a 45 m thick laminated siltstone unit forming part of a volcano-sedimentary sequence. The base of the siltstone was faulted out against pyritic black shales. The lead mineralisation occurs in the form of fine-grained stratiform galena, locally remobilised into narrow quartz veinlets within the mineralised zone. Within the mineralised zone the bedding intersection angle was 65° to the drillcore axis. Borehole EG2 was drilled vertically at the same location as EG1. Although the hole collared in laminated siltstones, it intersected a major fault at 32 metres, and encountered only minor lead mineralisation. Borehole EG3, located some 280 m west of EG1 and 2, intersected black shales overlying volcanic rocks. Although the black shales were pyritic, their Pb and Zn contents were not anomalous. Borehole EG4, located at Trewith farmhouse, intersected brecciated volcanic rocks overlying black pyritic shales and pyroclastics. These in turn overlie calcareous siltstones and shales. Pyrite occurs as disseminated nodules and veinlets, while minor galena and sphalerite occur in thin veinlets and on joint fractures. Borehole EG5, situated 180 m east-north-east of Trewithick farmhouse, intersected intercalated shales and volcanics. Minor fracture-filling galena and sphalerite are also present. Maximum assay values were 0.37% Pb and 0.29% Zn, between 38.32 and 39.25 m.

In 1982 a further series of holes was drilled at Egloskerry, with most in the Westend Farm area, and a single hole (EG9), located at Trewithick Farm to test a Cobra geochemical anomaly. The follow-up drilling at Westend Farm (boreholes EG6, 7, 8, 10 and 11), identified lead mineralisation in black shales, as well as in the previously identified laminated siltstones. Lead enrichment is associated with enhanced Zn and As values. Maximum levels were encountered in the black shales in EG6, although the mineralisation is mainly concentrated in fracture zones, rather than being stratiform in type. At Egloskerry, the geological environment of the galena occurrence in BH1 was considered to be similar to those at Meggan and Rammelsberg in Germany, but no further work has been carried out to pursue this analogy further.

In 1981-82 Riofinex carried out soil and overburden geochemical surveys over a Lower Carboniferous shale-siltstone sequence near Bridestowe, located about 13 km south-west of Okehampton. Lead and zinc anomalies defined in these investigations were tested by diamond drilling at Burley Wood [249 087] in 1982. Three boreholes were drilled to an aggregate depth of 371 m. Geochemical analysis of groove samples showed low tenor enrichments in Cu, Pb and Zn in the upper (20–40 m) sections of each borehole in black cherts and silicified mudstones. The underlying shales and siltstone sequences showed no significant enrichments in base metals. Visible mineralisation in core was dominantly disseminated pyrite with traces of galena and sphalerite associated with quartz veining.

Early MRP exploration in the Tournaisian-Visean part of the volcano-sedimentary complex in the Teign Valley

(Chesher, 1968) was focused between Dunsford and Chudleigh, north-east of Dartmoor (Beer et al., 1992). This area was previously worked for lead and zinc ores, with associated silver and copper. A programme of geochemical drainage and soil surveys was followed by geophysical surveys and diamond drilling. Chemical analyses were carried out on waters, stream sediments and panned concentrates collected from secondary drainage. The water samples, including effluents from old mine workings, were only rarely anomalous in base metals. However, stream sediment and panned concentrate analyses revealed copper, lead, zinc and arsenic anomalies caused by the Teign Valley lode zone and manganese anomalies which reflected areas of former mining. One cluster of anomalies suggested possible lead-zinc-copper-arsenic-barium mineralisation to the east of the River Teign.

Soil sampling was carried out mainly across interfluve ridges to the west of the river Teign. Interpretation of the soil analyses confirmed the common occurrence of anomalous lead, zinc and copper within the Teign Valley lode zone and indicated that a few parallel mineralised structures may also be present. Some anomalies suggested the presence of disseminated mineralisation within the bedded succession of shales, cherts and tuffs. Induced polarisation (IP) geophysical surveys were carried out over four separate areas containing geochemical anomalies using the dipole-dipole array. Locally, more detailed measurements were made using the gradient array. Anomalies believed to be related to concealed sulphide mineralisation were recorded in all four areas. In the Dunsford area, chargeability anomalies coincident with lead anomalies in soil may be caused by disseminated mineralisation. Near Bridford, anomalies with different characteristics were attributed to disseminated and vein-style mineralisation. The presence of a small high-grade galena vein was suggested by anomalies to the east of the main vein at Wheal Exmouth. Sixteen traverses north-east of Bovey Tracey defined two significant anomalies compatible with the presence of sulphide mineralisation; soil geochemistry indicated significant lead and copper, but only minor zinc, enrichment. Four short inclined diamond drillholes (85–130 m depth) were sited north-east of Bovey Tracey, between Lower and Higher Coombe, to investigate the clusters of geochemical anomalies which IP data suggested were caused by sulphide mineralisation. The mineralisation was found to comprise disseminated and thin, discontinuous strata-bound veinlets of sulphides within shales, cherts and tuffs close to the Lower–Upper Carboniferous boundary. Galena and sphalerite with a little chalcopyrite, arsenopyrite and loellingite are associated with pyrite, quartz and siderite. Chemical analysis of drillcore revealed high Zn values in some sections, one containing 2% Zn over 3 m. Lead values are lower, with a maximum of 0.2% over 1 m; while several 1–3 m lengths containing 0.1% Pb are present. Copper concentrations are variable; the best intersection contained 0.14% over 1 m. Finely disseminated galena and sphalerite had not been reported previously from the Teign Valley and their discovery indicated the potential for this type of deposit within the condensed Lower Carboniferous sequence of south-west England.

Table 2 Areas of commercial mineral exploration supported by MEIGA (numbers refer to Figure 5)

Reference No.	Project name	Company	Target elements
1	Wolfram Study	Consolidated Goldfields Ltd	W
64	St Ives Bay	Marine Mining Corporation	Sn
65	Godolphin Tin	Thyssen GB Ltd	Sn
73	Mulberry	Noranda Kerr Ltd	Sn
86	Hemerdon Mine	Hemerdon Mining & Smelting	W
100	North Molton	British Kynoc Metals Ltd	Cu
106	Elfordleigh	Consolidated Goldfields Ltd	Sn
119	Duchy Peru	Texas Gulf Anglo Exploration Ltd.	Cu
129	Chacewater	Consolidated Goldfields Ltd	Sn
140	Molland	British Kynoch Metals	Cu
159	Castle-an-Dinas	St Piran Exploration	Sn
160	Teign Valley	Black Rock Mineral Ventures Ltd	Cu
161	Killivose	Great Western Ores	Sn
162	Bedford United/Ding Dong	South West Consolidated Minerals Ltd	Sn
163	Trenery's Prospect	Cornwall Tin & Mining Ltd	Sn
164	Silver Valley	South west Consolidated Minerals Ltd	Sn
165	Redmoor	South west Consolidated Minerals Ltd	Sn
177	Killivose Tunnel	Great Western Ores Ltd	Sn
178	Restronguet Creek	Billiton Minerals	Sn
180	Killivose North Branch	Great Western Ores Ltd	Sn
182	Breney/Redmoor	Consolidated Goldfields Ltd	Sn
184	Killivose DDH 136	Great Western Ores Ltd	Sn
185	Trewint and Tregirls	Hemerdon Mining & Smelting Ltd	Sn
187	Hemerdon	Amax Hemerdon Ltd	W, Sn
188	Goonzion Downs	Geevor Tin Mines Plc	Sn

Reference No.	Project name	Company	Target elements
190	Watertight Door	Great Western Ores Ltd	Sn
191	Reeves Lode	South Crofty Ltd	Sn
195	Dolcoath South Lode	South Crofty Ltd	Sn
196	Roskear Complex Lode	South Crofty Ltd	Sn
198	Mulberry	Central Mining Finance Ltd	Sn
199	Devon Great Consols	Cominco UK Ltd	Sn
202	Allen's Shaft	Geevor Tin Mines plc	Sn
203	Dolcoath Branch & Mine	South Crofty Ltd	Sn
208	Wheal Concord	Wheal Concord Ltd	Sn
210	Goss Moor	Billiton (UK) Ltd	Cu, Pb, Zn
211	Withey Brook Marsh	Geevor Tin Mines plc	Sn
212	Haye South	Amax Hemerdon Ltd	Sn
214	Whiddon Down	Amax Hemerdon Ltd	Cu
218	Gonamena	Black Rock Mineral Ventures Ltd	Sn
222	Offshore Tin Alluvials	Billiton (UK) Ltd	Sn
223	Egloskerry	Riofinex	Pb
225	Remote sensing	Billiton (UK) Ltd	Sn
228	Great Wheal Carne	Geevor Tin Mines plc	Sn
232	Tregullan	Central Mining Finance Ltd	Sn
235	Bridestowe	Riofinex	Cu
237	Fraddon Downs	Billiton (UK) Ltd	Sn
245	Treliver 3	Billiton (UK) Ltd	Sn
247	Great Flat Lode West	Great Western Ores Ltd	Sn
251	Kellybray	South West Consolidated Minerals Ltd	Cu
256	Silverhill	South West Consolidated Minerals Ltd	Sn
264	Offshore spectrometric	Geevor Tin Mines plc	Sn

4.2 NORTH CORNWALL

The volcano-sedimentary terrain in the Wadebridge area of north Cornwall was explored for volcanogenic mineralisation by the MRP (Leake et al., 1989). Reconnaissance overburden sampling across the main outcrops of Middle Devonian volcanic rocks clearly showed the position of the contacts between volcanic and sedimentary rocks, either as sharp increases in elements like Ti or in principal component analysis of the geochemical data. Follow-up overburden sampling delineated several types of anomaly, some of which were investigated with ground geophysical surveys. Eight diamond drillholes were collared to test the source of five overburden anomalies. Forty horizons of basic igneous rock were intersected in these holes, some clearly volcanic and others clearly intrusive, varying in inclined thickness from a few cm to over 50 m. Four compositional groups of basic igneous rock were recognised on the basis of relative concentrations of the immobile elements Ti, Y, Zr and Nb. Two varieties of quartz vein were found in loose blocks during the overburden sampling: one type contained boulangerite and galena, and the other arsenopyrite and pyrite. A significant amount of Au (up to 1 ppm) is associated with the arsenopyrite-bearing veins. No veins corresponding exactly to these two varieties were intersected in the drill holes, though quartz veins and veinlets with either manganoan siderite or ankerite are common. Associated with some of these veins and with chloritic veins are pyrite, arsenopyrite, chalcopyrite, sphalerite and galena in varying proportions and minor amounts of tetrahedrite, some of which is richly argentiferous. A second variety of mineralisation, consisting of minor amounts of bournonite, jamesonite and stibnite, is closely associated with intrusive greenstone bodies and their immediate aureoles. A third type of mineralisation comprising stibnite and its secondary alteration products with siderite was also identified in drillcore.

4.3 NORTH DEVON

MRP investigations were carried out over extensive areas in north Devon. Drainage geochemical surveys over Exmoor and the Brendon Hills identified several areas of anomalous metal concentrations (Jones et al., 1987). Some of these anomalies relate to vein-style mineralisation, but others probably reflect a stratiform distribution of ore metals. Barium anomalies were also recognised and indicate previously unrecorded baryte mineralisation.

A distinct aeromagnetic anomaly of amplitude about 60 nT trends west-north-west–east-south-east over the upland areas of Exmoor and approximately follows the boundary between the Ilfracombe Slates and the Morte Slates. A less prominent linear anomaly to the south occurs over the upper part of the Morte Slates, with maximum amplitudes in the west. Detailed soil-geochemical studies over some of the aeromagnetic anomalies identified some minor Zn-Pb anomalies and a general association of Zn in soil with the magnetic anomaly. Preliminary interpretation assumed that the magnetic anomaly comprised components from both deep and shallow sources (Jones et al., 1987). Two boreholes at Honeymead Farm showed that the shallow source was probably pyrrhotite mineralisation in the form of disseminations on the cleavage faces. Pyrite was also present in drillcore occurring as fine disseminations in sandstones, with calcite in tension gashes and minor veins (Appendix 2). Numerous field and borehole magnetic susceptibility data indicated that the volume susceptibility of the core was very low, typically 0.70 x 10^{-3} SI. This would provide an induced magnetisation of less than 0.03 A/m. The aeromagnetic anomaly along three profiles was modelled in terms of south-dipping structures with total magnetisation vectors up to about 0.2 A/m implying significant Natural Remanent Magnetisation (NRM), typically about 5–10 times the induced component (Edmonds et al., 1985). The modelled magnetisation vector had a southerly declination and a steep dip of 40–80° although no measurements of NRM were made on the core samples. The pyrrhotite is either recrystallisation of pyrite to pyrrhotite or to new mineral growth.

Gold has been recorded at the disused Bampfylde and Britannia mines in the North Molton mining district (Cameron and Bland, 1994). The eleven mines near North Molton worked iron and copper veins close to the margin of the Pickwell Down Sandstone and Upcott Slates (Table 3). The veins trend east–west and dip steeply north or south. These deposits may be divided into two broad groups, iron-manganese and copper-iron. The Wheal Charles and East Buckland mines are in a similar stratigraphic position to Bampfylde. Commercial exploration and drilling for stratiform copper at Molland and North Molton was supported by the MEIGA scheme (Table 3).

Table 3 Mines in the North Molton district of Exmoor

Mine	Metals	Formation
Britannia	Ba-Cu-Fe-Au	US
Bampfylde	Cu-Fe-Ag-Au	PDS
Barton	Fe-Mn	PDS
Walscot	Fe-Mn	PDS
Stowford	Fe-Mn	PDS
Crowbarn	Fe-Mn	PDS
New Florence	Fe	PDS
Tabor Hill #	Fe-Cu	PDS
East Buckland #	Cu	US/BS
Wheal Charles #	Cu-Fe-Mn	PDS/US
Uppcott #	Cu-Fe-Pb	US

US Uppcott Slates; PDS Pickwell Down Sandstone; BS Baggy Sandstone
not sampled in MRP survey

The vein gangue consists typically of quartz, iron oxides and carbonates, brecciated rock, baryte and copper sulphides. A broad geochemical zoning has been proposed with iron to the south, copper in the central zone and barium to the north (Rottenbury, 1974). Historic assays from the Bampfylde lode were about 12 g/t Au. Rottenbury (1974) recorded 86 ppm Au from the upper levels of the North Lode and gold grain analysis indicated sizes of 5–200 µm. Some of the gold was embedded within malachite. Bulk samples of dump material were collected from 18 sites although gold was only recorded from the Bampfylde sites (Cameron and Bland, 1994). These authors estimated that about 100 Troy oz of gold were present in the dump material.

Radiometric (K-Ar) ages for clay minerals in the mineralised fractures in the North Molton district are about 300 Ma (Ineson et al., 1977). Dines (1956) considered that these veins represented the outer parts of the hydrothermal system associated with the Cornubian batholith (c. 280 Ma). However, the mineralisation may represent a Permo-Triassic fracture-filling of extension cracks developed after the Variscan event (Rottenbury and Youell, 1974).

Exploration for gold mineralisation was undertaken by the MRP over the Crediton Trough, an area of Permian and Carboniferous rocks, north of Dartmoor (Cameron et al., 1994). The area was selected on the basis of a model of precious metal transport developed to account for the widespread occurrence of alluvial gold in south Devon, which suggested that gold mineralisation might be present in the Permian sequence and at the contact with underlying Carboniferous rocks (Leake et al., 1988; 1990; and 1992). A broad-scale drainage and lithogeochemical survey was carried out in the area between Hatherleigh in the west and the valley of the River Exe in the east, over the outcrop of Permian red-bed sediments, minor alkaline basalts and lamprophyric lavas and the surrounding Carboniferous sediments. The Permian outliers at Hollacombe (near Holsworthy), Peppercombe (near Clovelly), and Holcombe Rogus (south-west of Wellington), together with parts of the Permian outcrop of the Tiverton Basin and west of Cullompton, were also sampled. Drainage surveying confirmed the presence of gold for the first time at numerous localities on the Permian outcrop. Subsequent microchemical mapping of grains demonstrated a number of close similarities with gold from south Devon, strongly suggesting a similar origin.

The analysis of rock samples from the Crediton Trough showed gold to be locally enriched, up to 1.8 ppm in alkaline basalts and up to 42 ppb in samples of Permian sedimentary breccias. Extensive manganese and zinc drainage anomalies at the southern boundary of the Crediton Trough can be related to mineralisation within the Permian and Carboniferous, some of which was worked in the vicinity of Newton St. Cyres. Cinnabar was reported for the first time from this area, and detrital tin, copper and lead anomalies, thought to variously reflect ore minerals or contamination, were also recorded by the drainage survey.

The distribution of gold anomalies in the drainage samples indicates that the source is probably associated with the early Permian sediments, the boundary faults between the Permian and Carboniferous sequences, and structures in the Permian, especially where they are underlain by volcanic rocks. Follow-up geochemical sampling of drainage sediment and overburden was carried out to trace the source of three groups of high-amplitude gold anomalies within the outcrop of the Permian rocks of the Crediton Trough (Leake et al., 1994). They comprised the Deckport and Solland areas at the western end of the Crediton Trough, and the Smallbrook area adjacent to the faulted southern margin of the Permian rocks some 20 km further east.

At Deckport, where the Bow Breccia (Early Permian) is in faulted contact with the Crackington Formation (Late Carboniferous), follow-up sampling indicated strongly that the major source of gold was the Bow Breccia. In the Solland area gold persists in drainage sediment towards the southern, faulted contact of the Bow Breccia with Bude Formation (Late Carboniferous) strata to the south. Overburden sampling across the trace of a fault to the east of Solland, parallel to the Sticklepath-Lustleigh Fault, indicated that the gold was not associated with this fault but occurred in alluvial terrace material derived from further south. At Smallbrook, where the highest-amplitude drainage enrichments in gold had been found, further sampling showed a sharp cut-off for gold just north of the boundary fault with the Crackington Formation. The gold grains from the Small Brook differ from grains from other locations in the Crediton Trough in being finer grained, generally rounded, not enriched in palladium and with fewer and smaller inclusions. Gold was found physically and by analysis in panned overburden pit samples at several sites to the south-east of the Small Brook, particularly in the residual overburden derived from the Newton St Cyres Breccia (Late Permian). The horizontal and vertical distribution of gold in the overburden and weathered bedrock indicate that it is widely dispersed in the Newton St Cyres Breccia in the form of a fossil placer. The source of the gold is possibly the early Permian sequence to the west of Smallbrook. No drilling or additional work was undertaken by the MRP to determine the concentration of gold in the basal Permian rocks or to determine the importance of Permian igneous rocks on the mineralisation.

Following the discovery of gold in the Crediton area by the MRP, Crediton Minerals plc acquired a Mines Royal Licence in 1996 to explore for gold and silver over an area of 500 km^2 over the Crediton Trough. Between 1996 and 1999 the company drilled a total of 21 boreholes for a total of 1191 m in the area around Thorverton Quarry at the eastern end of the Trough. Two stages of mineralisation were identified by this work. The first phase comprises early widespread gold enrichment, with values up to about 300 ppb Au, in Permian alkali basalt. The second phase comprises more localised gold enrichment, up to 7 g/t, related to intense, structurally-controlled carbonate veining.

4.4 SOUTH DEVON

Radiometric and geochemical soil surveys were used in MRP studies near Lutton to trace localised uranium and base-metal mineralisation in Devonian slates and volcanics (Beer et al., 1981). The mineralisation, which has a strike length at surface of less than 200 m, is confined to two narrow structures in a fault zone trending north-west–south-east. Percussion drilling down to the shallow water-table indicated persistence of secondary metalliferous minerals, but core drilling failed to intersect any recognisable well-mineralised structure. It remains uncertain whether a small ore shoot exists below the surface anomalies. Only oxidised, and possibly enriched, mineralisation was sampled. This yielded a little cassiterite, sphalerite, pyrite, pyrrhotite and covellite, abundant hydrated iron and manganese oxides with adsorbed uranium, lead, bismuth, zinc, copper and arsenic, and flakes of secondary uranium and silver minerals.

A considerable amount of exploration for base-metals was undertaken in south Devon by the MRP commencing in the mid-1980s. In the South Hams district a programme of mineral exploration was carried out across the main belts of volcanic rocks with the objective of locating stratabound or stratiform volcanogenic base-metal mineralisation (Leake et al., 1985). Soil samples were collected along 77 reconnaissance traverses between the River Yealm in the west and Totnes in the east. The most extensive and highest amplitude geochemical anomalies identified were: Ba with smaller amounts of other elements in the Burraton area; Ba and other elements in the Higher Ludbrook area and further north-east; Sb in the Ladywell area; As in the extreme west of the area; Cu in association with a diabase body near Weeke; and Zn and Pb around Willing Cross.

Follow-up investigations comprising geophysical surveys and drilling were carried out over the first three of these areas where the anomalies followed the strike of the volcanic and associated rocks. In the Burraton and Higher Ludbrook areas resistivity, IP, very-low-frequency (VLF) and detailed gravity surveys were conducted. Around Burraton resistivity anomalies were generally coincident with soil Ba anomalies, but there was no coincident gravity anomaly. In the Higher Ludbrook area a massive carbonate horizon found by drilling is responsible for a zone of high apparent resistivity and a residual Bouguer anomaly high. IP anomalies suggested that disseminated pyrite-rich mineralisation may be extensive, although the results of EM and resistivity surveys suggest that the massive pyrite intersected in one of the boreholes is of limited lateral extent. Geophysical surveys were also carried out over Ba anomalies around Whetcombe Cross and near Fursdon in an area of diffuse geochemical anomalies. A small-amplitude IP anomaly in the Fursdon area indicates a possible zone of disseminated, pyrite-rich mineralisation.

Three boreholes in the Higher Ludbrook area proved a sequence of massive ankeritic carbonate-quartz rock about 25 m thick, underlain by massive pyrite, up to 7 m thick, resting on highly altered tuffaceous volcanic rocks; the sequence is interpreted to be of exhalative origin. Associated with the carbonate rock are high Zn values, minor baryte and veinlets containing pyrite, tetrahedrite and chalcopyrite. The carbonate rock also contains inclusions of highly altered schistose tuff with more than 5 wt% Ba. In this rock, and also in similar volcanic rocks beneath the pyrite, barium appears to be accommodated chiefly in muscovite. The massive pyrite is lensoid in shape, with minor chalcopyrite. Pyrite also occurs in layers up to 0.25 m thick and as rich disseminations in the upper part of the volcanic rocks beneath the pyrite rock. The tuffaceous volcanics are highly altered basic rocks enriched in potassium. They contain minor amounts of discordant tetrahedrite, chalcopyrite and cobalt-nickel mineralisation.

Three boreholes in the Burraton area intersected a sequence of dominantly argillaceous sedimentary rocks, although a 10 m thick volcanic horizon, similar in appearance and chemistry to the Higher Ludbrook rocks, was also present. Quartzite and baryte occur within a 2 m zone in one borehole, which may be similar to the massive, layered baryte float seen in the vicinity. A single borehole at Ladywell intersected an inverted sequence of volcanic rocks similar to those from the Higher Ludbrook area. No significant antimony mineralisation was encountered and, as a result the source of the high amplitude Sb anomalies identified in soil samples at Ladywell remained unexplained. However, two further boreholes were subsequently drilled to investigate these soil geochemical anomalies (Leake and Norton, 1993). One hole intersected a zone of oxidised rock containing 120 ppm Sb over 6.4 m within a wider zone showing lower amplitude enrichment in antimony (75 ppm over 21 m) and containing minor amounts of bournonite, tetrahedrite and stibnite. This enrichment in antimony may be primary, possibly related to a single episode of volcanicity. There is no evidence of an associated precious metal enrichment, though there is some enrichment in mercury (up to 11 ppm). The second hole was not enriched in antimony but contained minor amounts of base-metal sulphides in association with carbonate veinlets and sections of dark slate, enriched in zinc (up to 1600 ppm Zn over 1 m).

Further exploration over the Middle Devonian rocks between Plymouth and Totnes was carried out using reconnaissance soil traverses to augment the coverage of the volcanic belt and to extend it into adjacent sedimentary rocks prospective for SEDEX style base-metal mineralisation (Leake and Norton, 1993). The combined dataset from this work and the previous phase of investigations comprises 4815 soil samples analysed for a suite of 15 elements including Cu, Pb, Zn, Sb, Ba, Mn, Fe and Co. The data indicate that the area as a whole is highly enriched in antimony and, to a lesser extent, arsenic.

No evidence was found of further stratiform exhalative mineralisation in addition to the massive pyrite and ferruginous carbonate at Higher Ludbrook and the baryte at Lower Burraton. However, four main areas showing evidence of metal-enriched sedimentary rocks were outlined. In three of the areas, high Mn values in soils derived from the sedimentary rocks is accompanied by low amplitude enrichment in Zn and Pb, reaching around 200 ppm Zn and 170 ppm Pb. In the fourth area, adjacent to the separate belt of volcanic rocks north-west of Totnes, the anomaly is more extensive and of higher amplitude (exceeding 700 ppm Zn and 600 ppm Pb). The soil and drillhole data indicate that extensive hydrothermal systems were associated with the alkali basaltic volcanism in the area and that submarine hydrothermal activity took place. Overburden samples indicate that polymetallic mineralisation occurs within a zone about 3 km long in the west of the area. The zone is enriched in As, Pb, Zn, Mn and Cu and is similar to polymetallic mineralisation carrying gold which occurs further south near Marlborough (Leake et al., 1992). Evidence for further polymetallic mineralisation is present in the north-east of the area, but this differs geochemically from the other areas in having a higher proportion of Zn to Pb and in the presence of anomalous concentrations of Sn. Proximity to the Dartmoor granite suggests that this anomalous zone could be related to the contact aureole of the granite.

Reconnaissance drainage surveys over extensive areas of Devon and Cornwall conducted by the MRP between 1970 and 1976 indicated potential for the discovery of gold mineralisation in several areas (Jones, 1981). In view of these results and observations of gold grains reported during surveys for base-metals over the volcanic rocks between the valleys of the Yealm and the Dart (Leake et al., 1985), further surveys specifically for gold were conducted over wide areas elsewhere in the South Hams district (Leake et al., 1988, 1990 and 1992). The gold anomalies identified were followed up at selected localities by overburden sampling, geophysical surveys and drilling. In addition to the recovery of numerous gold grains by panning in the field, mineralogical examination and microchemical analysis of mineral grains separated in the laboratory led to the discovery of the rare mineral potarite (Pd + Hg) and the recognition of several types of iron oxide, cassiterite and some secondary base-metal minerals. Gold grains derived from overburden display a wide range of compositional variation. Many have relatively silver-rich rims on a silver-poor core which commonly contains a few percent palladium. Other grains are pure gold to the detection limit of the analytical procedure employed.

Gold in panned-concentrate drainage samples is widely distributed over the area south of a line between Plymouth and Brixham, with Au values greater than 0.5 ppm at 44 out of 450 sites (Leake et al., 1992). Anomalies are present over the Lower Devonian sequence and the Start Complex but are less common over the Middle Devonian. There is no simple pathfinder for Au, and the factors influencing its concentration are complex. Many of the gold grains are very intricate in shape, with projections which could not survive if transported more than short distances from source. The gold grains show great variety and complexity in their internal compositional characteristics: one type of grain contains variable concentrations of palladium, often showing intricate growth zonation; while in other areas the gold is enriched in silver. Follow-up overburden sampling showed that gold is present in head and weathered bedrock, as well as in near-surface overburden. Four boreholes drilled near Holbeton at Brownstone Farm [2597 0495] to test the source of an east–west zone of anomalous gold in overburden intersected black slate, pyritiferous in part, and widespread lensoid vein quartz, often with minor carbonate. Samples from a 5 m-wide zone of oxidation, alteration, brecciation and carbonate veining contained minor enrichment of Au, reaching a maximum of 380 ppb.

Two types of mineralisation are thought to be responsible for the gold anomalies in drainage and soil in the South Hams district. The first comprises polymetallic mineralisation associated with hydrothermal alteration, predating the main deformation of the rocks. The second phase, which accounts for most of the gold grains in drainage samples, involves saline oxidising solutions carrying precious metals circulated within and beneath the Permo-Triassic red-bed sequence which had been deposited on the eroded Devonian surface. Deposition of gold occurred where conditions became more reducing, particularly in Devonian rocks by reaction with pyritiferous slates. The gold may have been sourced from either the underlying Devonian strata or, more likely given the wide areal distribution of gold in drainage sediments in south Devon, it was derived from the formerly overlying Permian succession.

Detailed investigations to follow up gold anomalies identified in the reconnaissance survey of south Devon were also carried out south of Modbury. Extensive overburden sampling and ground geophysical surveys were conducted in the vicinity of Whympstone [266 050] and subsequently drilling was carried out to investigate the sources of three gold geochemical anomalies in panned overburden (Leake et al., 1988). Six boreholes, with an aggregate depth of 390 m, intersected a sequence comprising dominantly felsic volcanic rocks that have undergone low grade metamorphism and varying degrees of shearing, metasomatism and hydrothermal alteration. Subordinate sheared felsite, basic volcanics and quartzose metasediments were also intersected. Geochemical analysis for 18 elements was carried out on more than 500 drillcore samples: minor enrichments in copper, lead and zinc were present with sporadic high values of antimony. Gold was determined in approximately half of the drillcore samples, but most values were below the analytical detection limit (10 ppb), with only two values exceeding 100 ppb Au. Minor sulphide mineralisation comprising mainly pyrite with minor chalcopyrite and rare pyrrhotite is widespread in the volcanic rocks. Most occurs as disseminated grains formed prior to deformation. Early pyrite also occurs with either quartz, quartz + calcite, or chlorite + quartz in pre-tectonic veins. Pyrite also occurs in veins with either calcite or quartz that post-date the main deformation.

4.5 MAIN TARGETS FOR STRATIFORM BASE-METAL DEPOSITS

The substantial body of information derived from previous exploration provides good evidence of the potential for stratiform base metal deposits in south-west England. The principal indications of prospectivity are:

- high-grade stratiform sulphide mineralisation at Egloskerry, near Launceston.
- magnetic anomalies in the central part of the region to the north of, and between, the Bodmin and Dartmoor granites. These anomalies are attributed to stratiform pyrite mineralisation subsequently recrystallised as pyrrhotite. These have been explored at Wilsey Down, Sourton and Bovey Tracy. Comparison of the geological setting of this area with the Iberian Pyrite Belt confirms the prospectivity for stratiform base-metal deposits in this area.
- linear geochemical drainage anomalies for zinc over Exmoor associated with regional magnetic anomalies near the base of the Ilfracombe Beds. The comparable geological setting of Exmoor and the Harz Massif of Germany which hosts the major Rammelsberg deposit provides further evidence of prospectivity in this part of the target region.
- the extensive exhalative mineralisation and disseminated sulphide identified by MRP studies in altered volcanic rocks in south Devon suggest the activity of large, convective hydrothermal cells. The strong similarities in the geological setting and mineralisation in south Devon with the Rhenish basin in Germany, which hosts the major SEDEX deposit at Meggen, indicate prospectivity for submarine exhalative mineralisation.

5 Mineral deposit models and exploration parameters

A mineral deposit model can be defined as 'systematically arranged information describing the essential attributes (properties) of a class of mineral deposits' (Cox and Singer, 1986). Deposit models can be divided into two end members: empirical or descriptive models based on observational data; and generic or conceptual models, based on theoretical concepts. Deposit models may include geological, tectonic and structural features, geochemical, geophysical and mineralogical characteristics, ore controls, deposit morphology, grade and tonnage profiles and environmental characteristics.

Deposit models synthesise large amounts of geological data and provide an effective means of classification and communication within the scientific and technological sectors at large. Deposit models are also valuable exploration tools for the identification of new targets and for providing a general guide to the size and grade of a potential target type. Deposit signatures or 'fingerprints' can be established and used as a basis for the identification of exploration targets.

The utility of deposit models in exploration is enhanced if essential features, which show the closest spatial association with mineralisation, can be recognised and separated from non-essential accessory features. The area-selection criteria can be scale-dependent. For example, large-scale features are useful to identify geological environments favourable for mineralisation, whereas smaller-scale features indicate controls on the location of individual deposits. However, at all scales deposit models have their drawbacks and their non-critical use can lead to erroneous judgements. They may emphasise local, parochial features, or may be based on inadequate observations or understanding. The best models should stress the important and essential characteristics and be based upon the study of many deposits. They must be continually re-evaluated and refined to accommodate new knowledge and understanding of the processes responsible for their genesis.

In this study established models for stratiform base-metal sulphide deposits have been used in conjunction with available multivariate geoscientific data to evaluate the potential in south-west England for the occurrence of mineralisation of this type. These deposits include a wide variety of concordant massive sulphide ores that were formed by the discharge of hydrothermal fluids onto the seafloor. They are found in a range of geological settings and include a diverse array of variants. However the majority of deposits can be classified into one of two main groups:

1. volcanogenic massive sulphide (VMS) deposits which are massive sulphides associated with volcanic activity (Figure 6). They have also been termed by various authors *volcanic-hosted, volcanic-associated,* and *volcanophile massive sulphides*. VMS deposits include those hosted by volcanic rocks (VHMS) and others hosted by sedimentary rocks (SHMS).
2. sedimentary exhalative (SEDEX) deposits which are generally larger stratiform bodies hosted by sedimentary rocks (Figure 7). They have also been referred to as *sediment-hosted* and *shale-hosted* deposits. SEDEX deposits have certain similarities with SHMS deposits that are more directly related to volcanic activity.

Major examples of both deposit classes are found in mainland Europe in geological settings comparable with south-west England. The main analogues for SHMS deposits associated with volcanic rocks are found in the Iberian Pyrite Belt (IPB) of Spain and Portugal, while the stratiform sediment-hosted polymetallic sulphide deposit at Rammelsberg in the Harz Massif in Germany provides a model for similar deposits in the Middle-Upper Devonian rocks in the Rhenohercynian zone of the UK.

5.1 VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS (VMS)

VMS deposits are important producers of copper, lead and zinc, with lesser amounts of gold and silver. Typically they contain 1–10 million tonnes of ore with combined Zn-Pb-Cu content between 2 and 10%, with the largest deposits containing in excess of 100 million tones of ore.

VMS deposits occur in rocks of all ages, ranging from about 3500 Ma in the Pilbara craton of Western Australia to the modern sulphide deposits of the East Pacific Rise. They occur in a range of tectonic settings characterised by the presence of submarine volcanic rocks. They are found at both convergent and divergent plate margins, associated with intra-plate oceanic islands and in Archaean greenstone belts. Important VMS deposits occur in the Iberian Pyrite Belt in Spain and Portugal, the Bathurst district in New Brunswick, Canada, the Abitibi Belt of Canada, the Norwegian Caledonides, the classic Hokuroko district of Japan and the Tasman geosyncline in Australia. Many extensive reviews of VMS deposits have been published including: Klau and Large, 1980; Franklin et al., 1981; Lydon, 1984 and 1988; and Franklin, 1993.

VMS deposits typically comprise a concordant lens of massive sulphide, containing at least 60% sulphide, which is underlain by a discordant stockwork or stringer zone of vein-style mineralisation enclosed within a pipe of hydrothermally altered rock. A deposit may comprise several individual massive sulphide lenses and their associated stockwork zones. Mineralisation tends to occur at a single stratigraphic interval, within which several individual deposits may be developed. The location of these is dictated by topographic features on the ocean floor at the time of formation and substrate structures such as syn-volcanic faults and regional-scale fractures. Commonly deposits are spatially associated with felsic volcanic rocks,

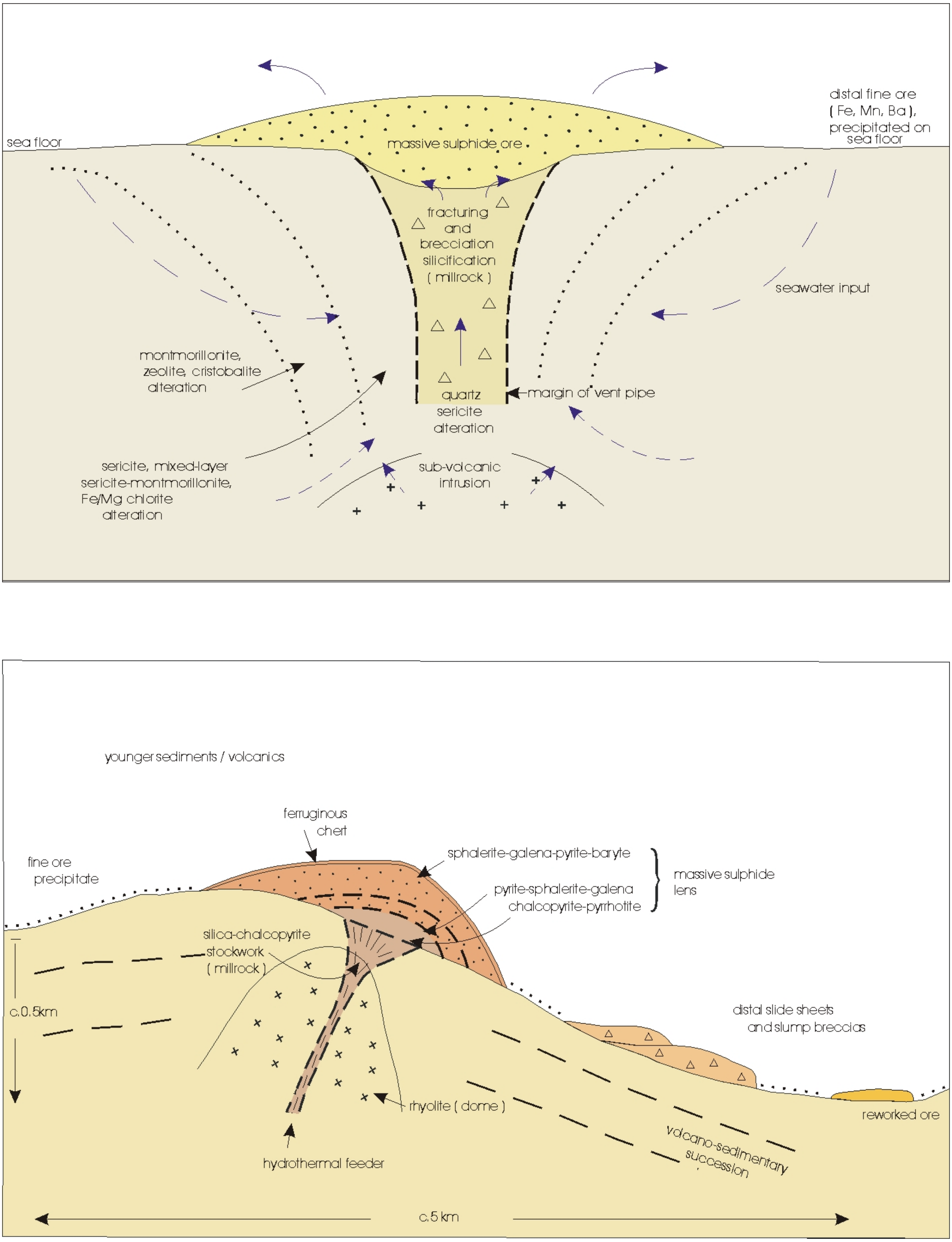

Figure 6 Conceptual models for volcanogenic massive sulphide (VMS) deposits (based on Franklin, 1993 and Lydon, 1988)

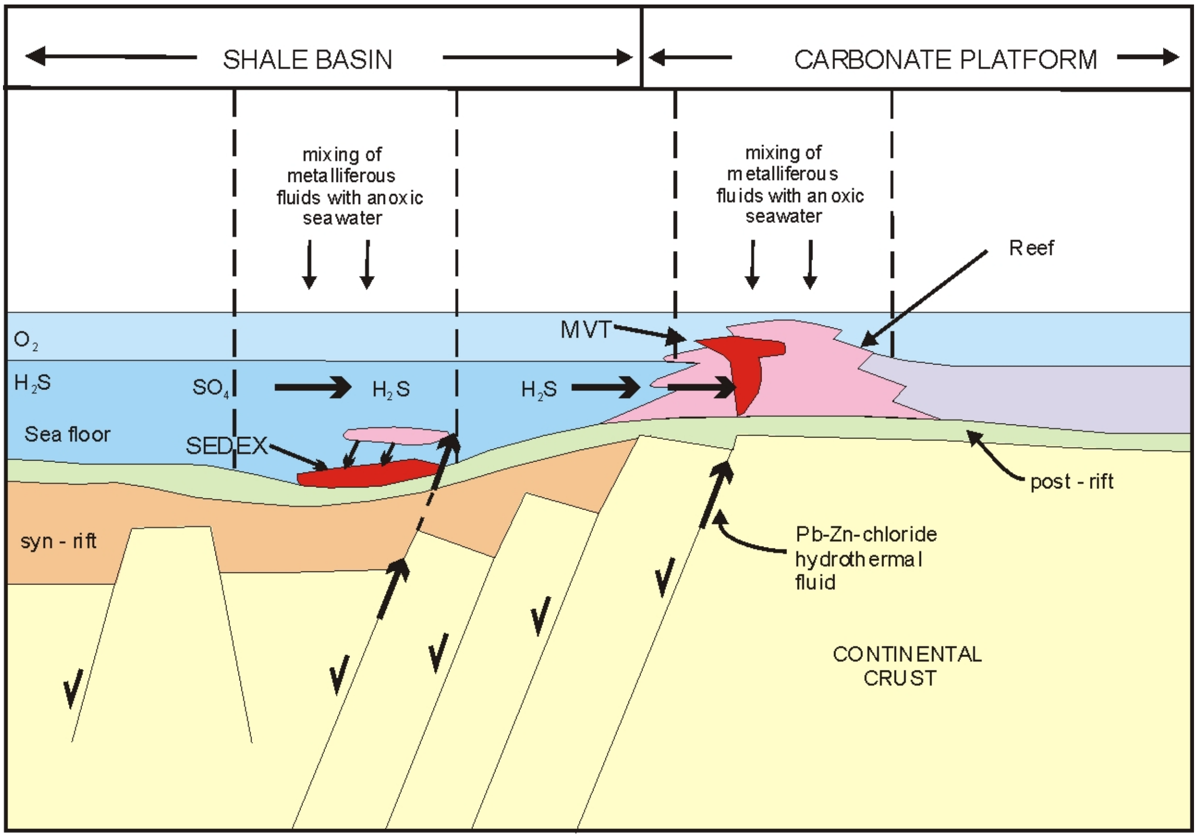

Figure 7 Conceptual model for sedimentary exhalative (SEDEX) deposits (from Goodfellow et al., 1993)

particularly rhyolite domes or fragmental deposits (breccia units), even in successions dominated by mafic volcanics.

Mineralisation typically occurs in a volcano-sedimentary succession which includes bimodal piles of rhyolite-basalt lavas, tuffs and breccias with varying quantities of interbedded clastic sediments, commonly fine-grained (mudstones) ocean-floor deposits. Footwall sequences typically comprise calc-alkalic felsic porphyritic ash-flow tuff, rhyolite domes and flows and felsic epiclastic rocks, sometimes with basalts near the base. The stratigraphy may be dominated by volcanic rocks (e.g. in the Hokuroko district of Japan) and complicated by deposition in submarine calderas and syn-tectonic faulting, producing units of very variable extent and thickness. Strong alteration often accompanies these deposits and may locally severely modify the host rock lithologies to the extent that their original composition and textures are almost totally obscured (e.g. Parys Mountain, Wales).

Ores typically occur in well-zoned, massive bodies that vary in morphology from steep-sided cone-shaped to tabular sheet-like bodies underlain stratigraphically by stringer ore. A generalised and widely applicable zonation is (i) discordant stockwork or veins of pyrite, chalcopyrite and quartz; (ii) chalcopyrite-pyrite zone; (iii) pyrite-sphalerite-galena; (iv) sphalerite-galena-pyrite baryte. The ore zones form a characteristic mushroom-shaped architecture in which the Cu/Zn ratio decreases upwards and outwards. Massive, rubbly and brecciated textures predominate towards the centre of the deposit and clastic sulphide rocks, often containing spectacular sedimentary structures arising from slumping, are common at the periphery. Mechanically-transported breccia ore is also characteristic of some deposits (e.g. Buchans, Newfoundland). The upper contact of the orebodies is usually sharp but the lower is usually gradational into the stringer zone. In sediment-dominated successions orebodies tend to be more tabular and laterally extensive with less prominent zoning. The ore is typically a fine-grained intergrowth of the principal sulphides (pyrite, sphalerite, galena and chalcopyrite). Baryte is common and a range of other minerals such as arsenopyrite, pyrrhotite, sulphosalts, cassiterite, stannite, haematite and magnetite may be present in individual deposits. Gangue minerals are quartz, carbonates, gypsum and chlorite.

Hydrothermal alteration of the host rocks is often intense and well zoned, with a sericitic halo around a chloritic core. The chloritic zone is typically enriched in Fe and Mg and depleted in Si, Na, K and Ca, reflecting the destruction of feldspar, while the sericitic zone is enriched in K. Strong silicification is common around the upper part of the stringer zone in the core of several deposits. Local variations are common within this generalised framework. Four zones have been defined around the classic Kuroko deposits (Figure 6): (i) outer montmorillonite, zeolite and cristobalite, (ii) sericite, mixed layer sericite montmorillonite, iron-magnesium chlorite and minor feldspar, (iii) sericite-mixed layer clays, and (iv) quartz and sericite in the core. In some cases chemical signatures (e.g. sodium depletion) related to alteration may be detected more than a kilometre from the deposit, including stratigraphically below the mineralised horizon.

VMS deposits may be classified in terms of their tectonic environment, the lithologies of the host rocks and the chemistry of the ores. Hutchinson (1973) suggested a scheme based on major ore-element content that included copper (Cu), zinc-copper (Zn-Cu) and zinc-lead-copper (Zn-Pb-Cu) types. Subsequently, Lydon (1988) eliminated the copper-only group suggesting that this type should be included within the Cu-Zn group. A number of other geological features, such as the dominant regional footwall lithology, the gangue mineralogy, Au/Ag ratios and sulphur isotope compositions of the ores, vary systematically with the ore-element chemistry thereby lending support to the validity of this classification scheme.

Zinc-copper deposits are characterised by Zn/Zn+Pb ratios greater than 0.95. They occur in two principal geological settings (Franklin, 1993):

1. terranes dominated by volcanic rocks. These include deposits in Archaean/Proterozoic greenstone belts in the Noranda and Matagami Lake districts in Quebec; Phanerozoic ophiolites in Cyprus, Oman, Newfoundland and Norway; and Recent to modern spreading centres and seamounts.
2. terranes dominated by sedimentary rocks. Often referred to as Besshi-type deposits, these occur in arc-related settings which contain mafic volcanic rocks and significant, but variable, proportions of mainly pelitic sedimentary rocks. These terranes are often highly deformed making original relationships unclear. Most examples have been recognized in British Colombia and include the large, low-grade Windy Craggy deposit.

Zinc-copper deposits are commonly associated with extensive semi-conformable regional alteration zones which occur several hundred metres or more below the sulphide deposits (Galley, 1993). In some districts, such as the Iberian Pyrite Belt, these zones may have a strike length of tens of km and be hundreds of metres thick. They are interpreted as products of seawater-rock reactions above high-level intrusions emplaced into the evolving submarine rift.

The zinc-lead-copper class of VMS deposit has bulk Zn/Zn+Pb between 0.70 and 0.80. They occur mainly in arc-related terranes dominated by felsic volcanic rocks in the footwall. They are commonly referred to as Kuroko-type deposits after the deposits of the Green Tuff Belt of Japan. Other important examples occur in Scandinavia and in the Buchans district of Newfoundland. The largest deposits by far occur where thick sedimentary sequences are present in the footwall with the felsic volcanic rocks. Supergiant deposits of this type are found in the Bathurst district of New Brunswick and the Iberian Pyrite Belt of Portugal and Spain. In both districts the deposits occur in thin felsic pyroclastic strata (<3 km) overlying many kilometres of wacke. Felsic sub-volcanic intrusions are present in both districts. The regional semi-conformable alteration underlying Cu-Zn deposits has not been recognized beneath deposits of the Zn-Pb-Cu class.

The hydrothermal exhalative model for the genesis of VMS deposits has long been established but recent studies of modern sea-floor vent systems from which massive sulphides are currently forming have helped to provide improved insight into their origins. Some outstanding problems, remain, however, especially with regard to the nature of the parent hydrothermal system, particularly those responsible for the largest VMS deposits.

The current consensus is that the fluids in the venting hydrothermal system come from cold, descending seawater that reacts with the heated crust as it passes through it, losing Mg, Sr and Ca, and leaching metals from it as higher temperatures (c. 350°C) are reached. Some contribution from magmatic waters may be involved in at least some systems, and it is possible that modified seawater may enter high level magma chambers. The buoyant, heated metal- and silica-rich fluids then rise to the surface through fracture zones produced by tectonic activity to complete the convection cycle. As the fluid rises it cools and reacts with the wall rocks causing silicification. Copper is preferentially (with respect to lead and zinc) precipitated prior to venting, forming the stringer zones. On sea floor venting, the fluids cool rapidly. Anhydrite, derived entirely from ambient seawater, is the first mineral to precipitate and forms structures which are infilled and replaced by precipitating metal sulphides. Individual vents and chimneys have short lives and the sulphide-rich mound builds as they collapse and/or are overgrown. Zonation develops continually by overgrowth and replacement at the surface and within the mound, while tectonic activity will trigger slump deposits. Baryte forms regardless of source rock, but its presence appears to be dependent on the discharge temperature, with low temperature discharges being rich in baryte and low in metals. Therefore systems that were abruptly terminated while venting high temperature fluids would not have formed significant baryte accumulations.

The uppermost strata of a deposit appear to have diverse origins but they probably have an important role in sealing the deposit. In modern oceans particulate sulphides from vents are commonly rapidly dispersed and oxidised unless protected by sedimentation or volcanic strata. Some ferruginous caps are probably the result of syn-depositional oxidation, while a ferruginous-siliceous zone may arise from low temperature discharges. Baryte and manganese oxide layers could only form if the bottom waters were oxidising, while if the bottom water is reducing then sulphide fallout could form distal concentrations of significance for exploration. Ancient deposits suggest that preservation is enhanced by sheltering in sea floor depressions or by the flanks of rhyolitic domes.

5.2 IBERIAN PYRITE BELT (IPB) MASSIVE SULPHIDE DEPOSITS

Because of the stratigraphical and tectonic correlation between south-west England and southern Iberia it is pertinent to examine the VMS deposits of the Iberian Pyrite Belt of southern Spain and Portugal in more detail. The Iberian Pyrite Belt (IPB) contains many giant and super-giant (>100 Mt ore) massive sulphide deposits hosted in Upper Devonian volcanic and sedimentary rocks. Total ore reserves exceed 1500 Mt in 8 super-giant deposits and many smaller occurrences. Rio Tinto is the largest deposit in the IPB with an original total tonnage exceeding 500 Mt of massive sulphide ores (Williams et al., 1975). A review and synthesis of the main features of the Iberian type of volcano-sedimentary massive sulphide deposits has been presented by Leitel et al. (1998) and Sáez et al. (1999).

Mining in the IPB has a long history dating back to pre-Roman times. Early production was mainly gold, silver and copper. In the last century over 80 mines were active, producing mainly sulphur and copper, together with lesser amounts of gold, silver, lead and zinc, with a total production of over 300 Mt of polymetallic ores. Tin is also exploited at the Neves Corvo deposit in Portugal. In addition numerous manganese deposits related to chert and jasper horizons occur at about the same stratigraphic level as the sulphide deposits.

The IPB is part of the South Portuguese Zone of the Hercynian Iberian Massif interpreted as a tectonostratigraphic terrane sutured to the Iberian Massif during Variscan times (Quesada, 1991). The IPB succession can be divided into three units (Figure 8a):

1. The Devonian pre-volcanic phyllite-quartzite (PQ) group of monotonous shales and sandstones with an increasing proportion of sandstones in the upper part of the sequence of Upper Famennian age.
2. The volcano-sedimentary complex (VSC) comprises a series of three felsic and two mafic volcanic episodes. Felsic volcanic rocks are commonly pyroclastic and may be subaerial or shallow-marine facies. The mafic rocks are either submarine or sub-volcanic in origin.
3. The post-volcanic Lower Carboniferous Culm Group (CG) comprises turbiditic sediments filling a subsiding basin.

The initiation of the IPB VSC sequence appears to be related to the break up of the Devonian platform and the localised development of volcanic activity at margins to the sub-basins. The structure of the IPB is typical of a thin-skinned foreland thrust and fold belt; asymmetric folds verge to the south-west and at least three stages of deformation can be recognised.

Most deposits are Zn-Pb-Cu type, with typical ore grades of Zn 2%, Pb 1% and Cu 0.5%. Locally copper grades exceed 1%. Most deposits have relatively low gold contents, typically about 1–1.5 ppm, with silver contents mostly in the range 20–60 ppm. Supergene enrichment of gold is locally significant, especially in the Riotinto district where gold remains an important product. The IPB can be divided into sectors on the basis of deposit occurrence in relation to volcanic episode. This might reflect a general relationship to second-order basins developed along east–west fault systems. Secondary structural control is provided by the prominent north-east–south-west fault system which also relates to manganese mineralisation and to foci of volcanic activity. North-east-trending faults may also have controlled third-order basins related directly to massive sulphide deposition. These faults appear to have been active in the Carboniferous.

The IPB deposits occur as stratiform bodies of lenticular or blanket morphology underlain by cross-cutting stringer and stockwork zones (Figure 8b). Several massive sulphide bodies may be present, especially in the larger orebodies. This may be due to repetition of the mineralisation at a number of stratigraphic levels or to tectonic superposition. In the largest deposits focused stockwork zones of conical shape may reach more than 700 m in height. Pyrite is the most abundant mineral, while sphalerite, galena, chalcopyrite, tetrahedrite, arsenopyrite and pyrrhotite are also common. Stannite, cassiterite, magnetite and electrum are widespread accessory or trace phases. Bismuth and cobalt minerals occur in the stockwork zones and at the base of the massive sulphides. These are mainly cobalt sulpharsenides (e.g. cobaltite) and bismuth sulphides (e.g. bismuthinite).

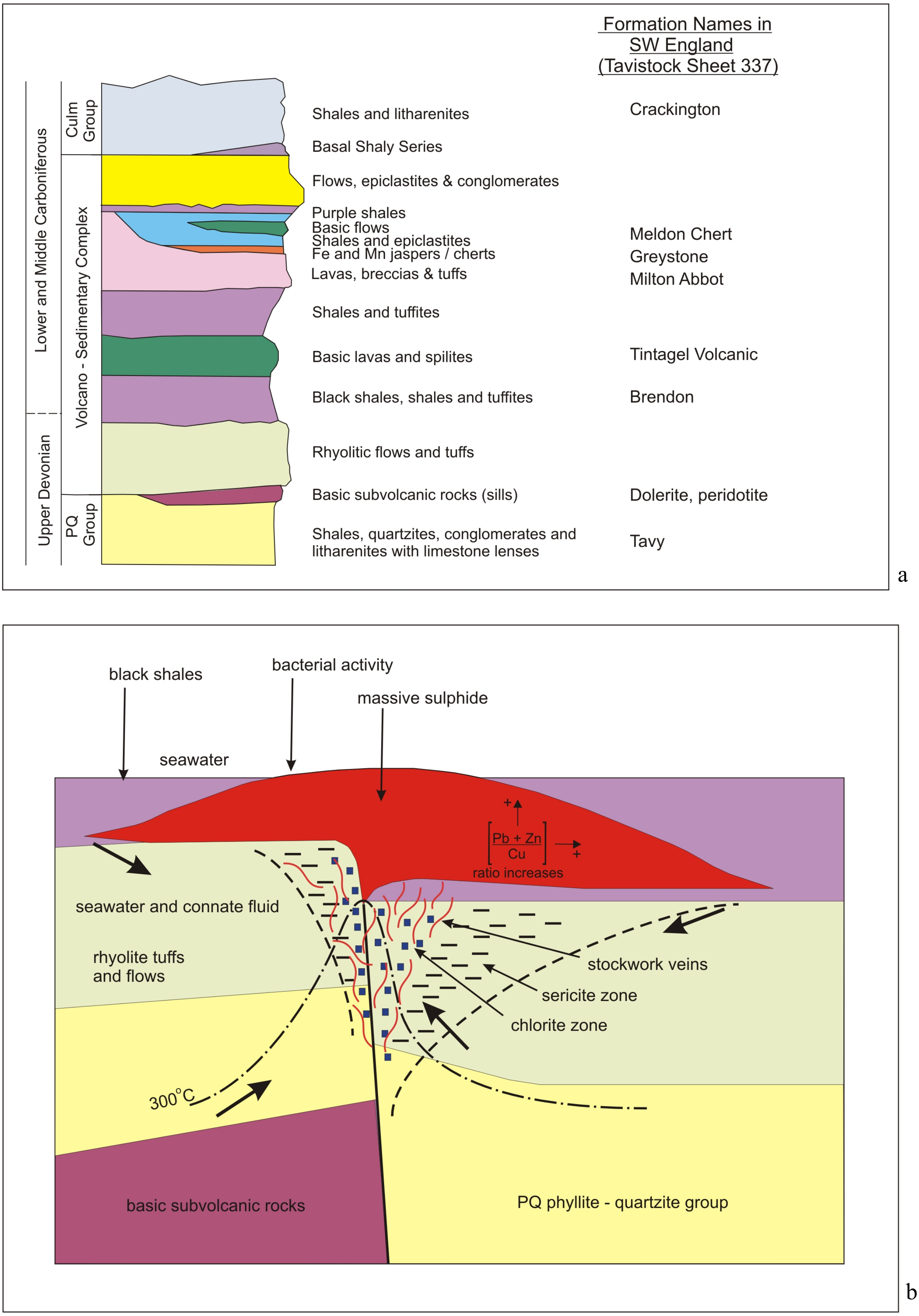

Figure 8 Summary of the geological sequence in the Iberian Pyrite Belt (a) and a schematic model (b) for a massive sulphide deposit. (based on Sáez et al., 1999)

Ore-element zoning typical of VMS deposits is not common in the IPB. The normal copper-rich central-lower zone with a barren pyrite intermediate zone and a marginal and upper zinc-lead zone is present only in a few large deposits.

The sulphide deposits are stratigraphically associated with detrital and volcaniclastic horizons overlying the felsic volcanic episodes. They are directly related to black shale horizons that range from 5 m to more than 200 m thick. These shales are products of low sedimentation rates so that, although the massive sulphide deposits may be spatially associated with volcanic rocks, there is not necessarily a genetic relationship between the two. Similarly genetic relationships to siliceous rocks are unclear. The sulphide deposits and cherts may be synchronous lateral equivalents. Elsewhere they are separated from the sulphides by volcanic rocks or locally they overlie the deposits. The recognition of distal facies in the deposit ore is debatable. Sáez et al. (1999) suggest that most of the massive sulphide was emplaced close to the hydrothermal feeder zone and that there is little convincing evidence for a distal facies produced by sulphide transport.

Regional-scale hydrothermal alteration affects most of the volcanic rocks in the IPB. Propylitic assemblages dominated by chlorite, carbonate, epidote, albite and actinolite are developed in mafic rocks, while in the felsic volcanic rocks albite, chlorite, sericite and silica are the most common alteration products. On a local scale, footwall alteration in the vicinity of the ore deposit typically comprises an inner chlorite zone and an outer sericite zone. Locally significant variations related to mineralisation in whole-rock chemistry and in the composition of individual mineral phases have been documented and may serve as guides to the location of mineralisation.

An origin for the IPB deposits involving convective circulation of seawater and seafloor venting of metal-rich hydrothermal fluids creates some problems when it comes to explaining the huge quantity of massive sulphides present. Sáez et al. (1999) proposed a model derived from Lydon (1988). This involved the existence of an external sulphide crust which impeded dispersion of low density and salinity fluids; internal circulation below that crust and cyclic collapse of the structure. Textural and isotopic evidence indicate an important role for bacteriogenic activity at some stages of ore deposition. Sulphide deposition by replacement processes in unconsolidated black shales is regarded as an important process in the IPB. This, together with the size of the deposits and the participation of basinal fluids, is different from typical VHMS deposits. Sáez et al. concluded that the IPB massive sulphide deposits have characteristics intermediate between the VHMS and SHMS types.

5.3 EXPLORATION PARAMETERS FOR VMS DEPOSITS

Geochemical exploration signatures related directly to the mineralisation and accompanying alteration are common where the mineralised system reaches the surface. In these cases combined anomalies for Ba, Cu, Pb and Zn in stream sediment and heavy mineral concentrates are commonly recorded, though the relatively fine-grained nature of the mineralisation and its presence in resistant siliceous rocks may compromise the signature. In areas with acid groundwater the presence of abundant Fe from the breakdown of pyrite and other sulphides may generate large stream sediment anomalies when secondary hydrous oxides precipitate. High levels of K and depletions of Ca- and Na-related to alteration may also be detectable. Zonation in these and other elements (Si, Mn, Mg) is frequently well developed close to and within a deposit and may provide useful exploration guides. Likewise, mineralogical variations, such as those produced by chlorite and sericite alteration zones, can indicate whereabouts in the overall deposit architecture.

VMS deposits frequently provide strong geophysical exploration signatures and several methods have played an important role in the discovery of individual deposits. Many deposits have low electrical resistivities and produce ground and airborne electromagnetic anomalies. Some deposits however, usually iron-poor and zinc-rich or highly silicified, may be missed by these methods. IP and resistivity can also provide useful data while, particularly in deposits containing pyrrhotite, magnetic surveys can effectively complement other methods. Drill hole electromagnetic methods and detailed gravity surveys can be effective within prospects. Potassic alteration zones may generate radiometric anomalies while silicified zones may result in complementary lows. At the regional scale, methods generating features related to fractures, volcanic centres or specific lithologies defining the mineralised stratigraphic interval, for example pyritic horizons or carbonaceous mudstones, can be very effective.

Strauss et al. (1977) assessed the exploration history and best practice for the IPB deposit type. Gravity surveying has become the standard geophysical technique for exploration in the IPB especially in marginal zones covered by Miocene and younger deposits. Regional geochemical surveys have limited value in the IPB because of the extensive contamination produced by mining activity over prolonged periods.

Key exploration parameters for deposits in the IPB include:

1. extrusive spilitic rocks aligned on productive lineaments defined by acid volcanic rocks; sub-volcanic intermediate–mafic rocks are more distal to the lineaments.
2. sulphide deposits form within 1000 m of local acid volcanic centres, marked by coarse massive pyroclastic rocks and tuff-breccias.
3. spilitic rocks occur locally, within a few hundred metres of the sulphide deposits.
4. extrusive spilitic rocks are the only mafic volcanic rocks located close to, or within, the deposits. They are therefore good indicators of prospectivity.
5. extensive sub-volcanic intrusive rocks indicate barren ground
6. manganese-chert-jasper associations are later than, or lateral to, sulphide deposits.
7. purple shales pass laterally into black shales close to the sulphide deposits.
8. Fe-rich jaspers close to (<200 m) sulphide deposits may carry up to 5% pyrite. Jaspers in sterile ground do not contain pyrite.

9. deposits occur at the boundary of massive volcanic piles and shaly tuffaceous sediments usually in thrust-bound overturned tight isoclinal folds which show rapid, major changes in axial plunge
10. massive pyrite orebodies commonly have marked resistivity and density contrasts with their host rocks. These give rise to significant anomalies which can be detected by detailed surveys over prospective targets.

Positive exploration criteria for IPB type deposits include essential general parameters and more specific local features which all contribute to favourability. These are summarised in Table 4 where their presence in the south-west England study area is also indicated.

Table 4 Exploration criteria for IPB deposits in relation to south-west England

Criteria	Type	Value	
Bimodal felsic-mafic volcanic rocks	E	h	¦
Devonian-Carboniferous VSC	E	h	¦
Sub-volcanic sill complex	E	h	¦
Black shale horizons	E	h	¦
Spilitic lavas	E	h	¦
Co Bi geochemical anomalies	C	l	¦
Hydrothermal alteration (chloritisation)	C	l	?
Active north-east early Carboniferous faults	C	l	?
Volcanic centres - massive pyroclastic rocks and tuff-breccias	C	m	?
Volcanic lineaments	C	h	?
Jaspers containing visible (5%) pyrite	C	m	?
Isoclinal synclines adjacent to thrusts	C	m	?
Residual gravity anomalies	C	h	¦
IP or resistivity anomalies	C	h	¦

E essential, C characteristic
Value or significance: h high, m medium, l low
¦ Present in project region
? Occurrence not known

Essential parameters (E) identify the terrane while characteristics (C) of the deposits determine favourability within this terrane. In SW England many of the essential parameters are present although the extent and distribution of many of the characteristics is poorly known.

New methods for application in exploration for buried deposits in the IPB have been developed under the EC-funded BRITE-EURAM programme (Leistel et al., 1999). This study centred on the development and testing of new field geophysical and geochemical methods, improved analytical capabilities and improved geological knowledge to facilitate the identification of criteria for target identification and prospect evaluation.

5.4 SEDIMENTARY EXHALATIVE DEPOSITS (SEDEX)

Sedimentary exhalative (SEDEX) base-metal sulphide deposits contain the largest proportion of lead and zinc resources of any class of deposit. They provide more than 25% of global zinc and lead production and are typically an order of magnitude larger than VMS deposits. The median tonnage for this type of deposit is 15 Mt, with 10% greater than 130 Mt (Briskey, 1986). Median grades are 5.6% Zn, 2.85% Pb and 30g/t Ag. They also provide minor quantities of by-product copper. Important examples include the Sullivan deposit in British Columbia, McArthur River and Mount Isa in Australia and the Meggen and Rammelsberg deposits in Germany. The key features of SEDEX deposits have been summarised by Goodfellow et al. (1993).

These deposits occur in anoxic basinal sediments capping syn-rift sequences in failed intracontinental rifts or in fault-bounded grabens on rifted continental margins. They commonly have a close spatial and temporal relationship with mafic volcanic rocks which vary from tholeiitic to alkaline in composition. Felsic volcanic rocks are not common. The host facies are typical of anoxic, starved-basin environments, including carbonaceous cherts, shales, siltstones and coarser clastic rocks, breccias and carbonates. The depositional environment is interpreted as restricted second- and third-order basins within linear marine, fault-controlled trough and basins. Water depth varies from deep marine to shallow water restricted shelf conditions. The majority of SEDEX deposits occur in Middle Proterozoic and Devonian–Lower Carboniferous strata. The Proterozoic deposits are generally significantly larger than those of Phanerozoic age.

SEDEX deposits formed within half-grabens or depressions in which the hydrothermal vents were typically located along extensional faults. They comprise one or more sheet-like or lenticular tabular bodies of stratiform sulphides. They range from centimetres to tens of metres in thickness, often as part of a sedimentary sequence hundreds of metres thick. They have a large horizontal extent and may persist laterally for tens of kilometres. The ores comprise fine-grained sulphides which form monomineralic laminae and thin layers up to a few centimetres thick. The principal sulphide minerals are pyrite, pyrrhotite, sphalerite and galena. Baryte is also common, while chalcopyrite is an important constituent of some deposits. Trace amounts of a wide range of other sulphides and sulphosalts are also reported. Stockwork, disseminated and vein mineralisation commonly underlies or occurs adjacent to the stratiform sulphides. These may represent the feeder zone to the stratiform mineralisation or may be related to a later event which either introduced or remobilized metals in the system.

Lateral and vertical zonation may be present in these deposits. Typically Pb is found closest to the vent grading upwards and outwards into more Zn-rich ores. Copper occurs in the underlying feeder zone or close to the exhalative vent. Baryte is concentrated in the upper and outer zones of the deposits.

Hydrothermal alteration in SEDEX deposits is variable in extent and intensity. In the stockwork and disseminated feeder zone low temperature alteration minerals include silica, tourmaline, carbonate, albite and sericite. Celsian (barium feldspar) and barium muscovite have also been reported from some deposits e.g. the Foss baryte deposit, Aberfeldy, Scotland (Coats et al., 1980).

SEDEX deposits accumulated under anoxic H_2S-rich bottom-water conditions. Most of the sulphur in the ores was derived from biogenic reduction of seawater sulphate. The venting ore fluids were near neutral, enriched in zinc, lead, barium and iron, but poor in H_2S. They were discharged at temperatures below 300°C as bottom-hugging brines and bouyant plumes.

5.5 RAMMELSBERG POLYMETALLIC SULPHIDE DEPOSIT

The stratigraphical and tectonic setting of the Devonian sediments on Exmoor may be compared with those of the Harz basin in Germany which hosts the major polymetallic copper-lead-zinc-baryte deposit at Rammelsberg (Table 5). The estimated total tonnage over 1000 years of working at Rammelsberg is about 30 Mt with an average grade of 14% Zn, 6% Pb, 2% Cu, 140 g/t Ag, 1 g/t Au and 20% baryte (Large and Walcher, 1999).

The Rhenohercynian zone of the Variscan terrane includes conformable Devonian-Carboniferous clastic and volcanic rocks folded and thrust northwards over the amalgamated Laurussia terrane (Laurentian-Baltica-Avalonia). The basement rocks are not exposed although the nearby Ecker gneiss may be a remnant of the basement to the Palaeozoic rocks in the Harz Massif. The oldest Lower Devonian (Emsian) rocks are clastic medium- to thickly-bedded micaceous siltstones, sandstones and quartzites. The Middle Devonian is marked by calcareous shales at the base with a monotonous sequence of fine sandstones, siltstones and shales passing upwards into dark grey shales with up to 20% carbonate and minor pyrite.

The deposit is hosted by the Middle Devonian (Eifelian) Wissenbach Shale along a structural line which marks rapid changes in thickness of the dark shales and is the focus of mafic volcanic rocks which now occur in the thicker part of the unit. The lateral equivalent of the ore horizon, containing euhedral grains and framboidal aggregates of pyrite and with enhanced levels of Zn and Pb, has been recognised up to 7 km from the Rammelsberg deposit.

Table 5 Simplified stratigraphy, lithology and mineralisation for the Harz-Rhenish Massif

Age	Mineralisation	Thickness (m)	Lithology
Namurian		>1500	Well bedded greywacke with shales
Visean		20	Thin bedded cherts and black shale
Tournaisian		30	Dark grey pyritic shale
Famennian		300	Shales, increasingly calcareous upwards
Frasnian		1	Dark limestone
	Lahn-Dill Fe	200	Streaky shales with occasional limestone, tholeiitic lavas and tuffs
Givetian	Meggen Zn-Ba	400	Grey shales with occasional limestone, dolerite sills
Eifelian	Rammelsberg Zn-Pb	60	Dark grey shales
		30	Dark grey shales with limestones
		400	Light grey sandy shales
		120	Dark grey calcareous shales
		30	Sandstone and shales
Emsian		>500	Quartzitic sandstone with thin shales

The Rammelsberg orebodies comprise stratiform massive sulphides strongly deformed into tight isoclinal synclines, commonly with tectonic contacts. The Old Orebody has a strike length of 600 m, extends to 300 m depth and is 12 m thick. The larger New Orebody has a vertical extent of 500 m with a thickness up to 40 m and had an estimated tonnage of about 20 Mt grading 6% Pb, 14% Zn and 1% Cu. The overlying Grey Orebody consists of fine-grained baryte with included sphalerite and galena (4% Zn+Pb+Cu) in beds up to 6 m thick. A different style of mineralisation, referred to as the ‘Kniest’, occurs in the stratigraphic footwall of the main orebodies. The Kniest consists of cross-cutting veins, disseminations and lenses of chalcopyrite, pyrite, galena and sphalerite, with quartz, ankeritic calcite and chlorite. This mineralisation was low grade with about 3% Zn, 1.4% Pb and 1.3% Cu. In addition to the major ore elements, the mineralisation at Rammelsberg is characterised by high values of Sb, As, Co, Bi and Sn.

The main ore minerals are sphalerite, pyrite and baryte, with lesser galena and chalcopyrite. Primary textures are not well preserved due to recrystallisation and deformation but include bedding lamination, slumping and load casts. Sulphur $d^{34}S$ isotope values range from -15 to +20 per mil for pyrite, but are more homogeneous for sphalerite and galena and show a general increase upwards through the ore deposit. Most of the baryte S has $d^{34}S$ values of 20–30 per mil, although those for the Grey Orebody are significantly lower. Two sources of S are proposed: a hydrothermal component and a biogenic component from bacterial reduction of seawater sulphate.

There is a general vertical zonation in the distribution of Cu, Zn, Pb and Ba, but this is complicated by local variations in individual ore horizons. In addition, minor veinlets and disseminations of sulphide occur in Lower Devonian sandstones and shales about 300 m stratigraphically below the massive sulphide mineralisation. Hydrothermal alteration around the sulphide ores is weak and comprises minor increases in silica and carbonate contents and in the Fe/Mg ratios of chlorites in shales as the mineralisation is approached.

The age and sequence of mineralisation at Rammelsberg has been debated for a long time. The region may have been subject to two phases of mineralisation related to the syngenetic massive sulphides and synorogenic vein mineralisation. Alternatively, both massive and cross cutting mineralisation may be part of the same phase with early hydrothermal activity associated with the Kniest silicification. An exhalative origin for the massive sulphides is generally accepted, but the importance of replacement processes in the formation of the underlying cross-cutting mineralisation is unclear. A general model involving the expulsion of hydrothermal fluids derived from the underlying Lower Devonian syn-rift clastic sequence along major steep faults during post-rift extension is consistent with processes envisaged for the genesis of this class of deposits by various authors e.g. Lydon et al., 1985; Large, 1988.

Key exploration criteria for the mineralisation in the Harz massif are listed in Table 6. The presence of these features in North Devon is also shown in the same table.

Table 6 Exploration criteria for SEDEX deposits in Middle Devonian shales and slates in relation to south-west England

Criteria	Type	
Rhenohercynian zone	E	¦
Middle Devonian post-rift shale sequence	E	¦
Marginal structures to rifted basin	E	
Diabase sills in trough facies	E	
Low energy sedimentology	E	¦
Debris flow and sediment deformation	C	
Cross-cutting mineralisation with alteration	C	
Steep isoclinal folds	C	
Zn, Pb, Ba regional geochemical anomalies	C	
Sb, As, Co, Bi geochemical anomalies	C	
Associated minor Zn-Pb vein system	C	¦

E are considered essential, C characteristic

¦ indicates a parameter is represented in North Devon

Stratiform base-metal sulphide mineralisation is widespread in the Variscan of western and central Europe. Another major deposit which was mined for a long period is located at Meggen in the Rhenish massif in Germany (Krebs, 1981). Like Rammelsberg, this deposit occurs in the post-rift stage of basin evolution. The stratiform mineralisation comprises a bed 3.5–8 m thick with lateral continuity over a strike length of 6 km occurring in the Upper Givetian to Lower Frasnian (Middle to Upper Devonian transition). The ores at Meggen comprise fine-grained massive pyrite, marcasite, sphalerite, galena and baryte. Total tonnage was 50 Mt at 8% Zn and 1% Pb. In the southern Rhenish Massif the Lahn-Dill stratiform siliceous hematite-magnetite-siderite deposit is hosted in a sequence of basic tuffs volcanics and sediments close to the Givetian-Frasnian transition. Other important massive sulphide mineralisation occurs in Middle to Upper Devonian rocks of the Moravo-Silesian district of the north-east Czech Republic (Pouba, 1986).

6 Prospectivity methods

As discussed in the preceding section generic or empirical mineral deposit models can be used to identify the exploration criteria for a particular type of mineralisation. These criteria form the basis of any analysis of a region for exploration potential. The simplest form of prospectivity analysis would involve appraisal of the region for the presence or absence of the identified criteria. Often this analysis would be subjective, depending on the importance assigned to particular criteria and on the availability of data to assess the criteria. In some cases crucial geological or geochemical data might be absent or incomplete. In other areas there may be several phases of data collection, possibly collected for other deposit types, and the exploration geologist has to decide which of the data are suitable for inclusion in the prospectivity appraisal.

Prospectivity appraisal using digital data and GIS-based software is designed for either a data-driven analysis of the data relationships or a knowledge-based analysis using exploration expertise. Data-driven analysis aims to relate all specified data to known occurrences of the particular deposit type within the region and, by association, highlight those data relationships which closely mimic the patterns at the known occurrences. A knowledge-based system, which can be applied to regions with few or no recorded mineral occurrences, uses the expertise of the exploration geologist to determine the relative significance of the exploration data and then search for patterns which reflect the total effect of such significance. In practice, this involves selecting which of the available data layers to use in the analysis and the relative weight and pattern of influence to assign to each of them.

For this study a knowledge-based prospectivity system using a Binary Weights of Evidence (BWE) to integrate multivariate data has been used. The parameters for the relative weight of influence, zone of influence and style of influence define the model and the system calculates and plots a pixel-based prospectivity grid from the information provided. The usefulness of the prospectivity grid relies on assessment of the importance of the data to the signature of the mineral deposit model.

Various classes of multivariate geoscience data are frequently available in digital form for inclusion in the prospectivity analysis. These include several types of data, such as points, grids, vectors, polygons or sets. In addition, relationships between datasets can give rise to other features, or *event* occurrences, which can be included as separate data layers. Common examples of event occurrences are intersections e.g. the intersection of two faults or a fault with a particular geological horizon.

Most prospectivity analyses will use only a limited number of data layers, depending on the relevance of available data. Each data layer consists essentially of data attributes related by a series of [x,y] values. For point and vector data the [x,y] pairs define the occurrence pixels for those data. For polygon data the [x,y] pairs define an area within which are a set of occurrence pixels and a vector which defines the margin of this set. Event data provide [x,y] occurrences which define the intersection of two data layers. All occurrence pixels can be used to contribute to the prospectivity appraisal according to the significance defined in a table of index parameters for each data layer.

The exploration criteria are defined on the basis of generic and empirical mineral deposit models built from a knowledge of the target deposits world-wide, modified by specific features of any known local mineralisation in the area being assessed. Multivariate data are analysed using these criteria to define the relative weight for occurrences of any particular data layer. Combination of the data layer weight arrays produces a prospectivity map which shows relative favourability for the occurrence of the target deposit type. The degree of confidence and value that can be attached to the prospectivity maps depends on the availability, quality and relevance of the data, together with the reliability of the exploration model. The methodology used in this study is summarised in Table 7.

Table 7 Summary of the main stages in knowledge-based prospectivity analysis

1	Selection of target mineralisation and area for prospectivity analysis
2	Review deposit model(s) to determine key exploration indicators
3	Assessment of capability of available data to provide the key indicators
4	Data processing, interpretation and analysis to extract key indicators
5	Assignment of weightings, zones and styles of influence to key indicators
6	Calculation of prospectivity using Binary Weights of Evidence model

6.1 BINARY WEIGHTS OF EVIDENCE MODEL

In the simplest form this displays a set of information which has a binary code representing present (1) or absent (0). More commonly, the model is used to produce binary weights of evidence (BWE) maps to incorporate the effects of numerous populations. For example, if 5 populations were plotted together, each with a weight of 1.0, then the maximum prospectivity score would be 5 and the minimum 0. By normalising the score to the sum of the weights a binary weights of evidence map in the range 0.0–1.0 can be generated.

The resolution of the prospectivity model is determined by the pixel size for analysis and is independent of the plot area or any of the plot option parameters. However if the analysis includes gridded data the effects of the pixel size in relation to the grid mesh size need to be considered. Similarly the contribution of any vector to prospectivity is based on the [x,y] pairs for the line so that 'simple' vectors defined by a few widely space points might not give the expected contribution to the prospectivity map.

6.2 PROSPECTIVITY PARAMETERS

For each active data layer in a model, the analysis is based on a table of index parameters which define the zone of influence, the style of influence (exponent and peak distance) and the weight of influence for any data layer. Definition of the zone of influence, the style of influence and weight for each layer of evidence is based on generic and empirical models of the target mineralisation and the specific knowledge of the region.

In this study prospectivity has been assessed across the region for a grid of mesh size 0.25 km. This is the minimum realistic mesh size for gridding the regional magnetic and gravity data and approximately the same order of magnitude as the size of typical deposits. Favourable parameters within the available data have been weighted on a scale of 0-1 and assessed for the likely style and zone of influence. The prospectivity maps are generated by combination of the contributions from the selected data layers using a Binary Weights of Evidence model.

6.2.1 Zone of influence (buffer zone)

The zone of influence (buffer zone) allows the user to specify the zone of contribution for an individual data layer or for several options. For example, the user may wish to emphasise the significance of the intersection of two vectors, say faults and lineaments, or the significance of say gold occurrences in bedrock. For a buffer zone value of zero, only the pixel (target pixel) which contains the data element (vector intersection or data point) would contribute to the prospectivity model. For a zone value of 1 the adjacent 8 pixels are also included in the proximity window and scored into the prospectivity model. A zone of influence value of 3 will mean that each data element affects a window of 7x7 pixels centred on the target pixel into the analysis. The entire zone of influence so defined may not necessarily contribute to the prospectivity. This depends on how the style of influence (distance exponent, peak distance) is defined.

6.2.2 Style of influence

Linked to the concept of a zone of influence or buffer zone is the distance effect within the zone. The significance of any target data element is assumed to be constant or to decrease or increase away from the occurrence pixel according to a simple cosine distance law. The user can define the nature of this distance relationship during definition of the table of index parameters. The style of influence assumes the value f in the relationship:

$$\mathbf{f} = \cos [\ |(\mathbf{n}-\mathbf{x})|\ \mathbf{a}\ ]$$

where **n** is the distance from the target pixel in pixel widths, **x** is the peak distance (see below), and **a** is the distance exponent and **f** is always greater or equal to 0.

Suitable values of the distance exponent (**a**) are in the range 0.0–3.0. For example, for a zone of influence of 10 pixels and a distance exponent of 2.5, the relative weight at a pixel distance of 5 would be 0.56 of the maximum weight; at a distance of 6 pixels it would be 0.03 and beyond this it would be zero. Similarly, a zone of influence of 10 and a distance exponent of 2.2 would mean that the actual zone of influence ($f > 0$) would only extend to 7 pixels away from the target pixel.

In some instances the influence of the data layer might not be a maximum at the occurrence point. For example, 'halo' effects might be important at specified distances from data occurrences. A simple shifting of the zone of maximum weight away from the target pixel can be achieved by use of the peak distance (**x**) parameter. A peak distance of 0 (pixels) will mean maximum relative weights occur at the target pixel. A peak distance of 5 will mean maximum weights occur at a radius of 5 pixels from the data events and decrease at greater and lesser distances. For the present study 'halo' effects were not considered appropriate and all peak distance parameters were zero.

6.2.3 Weight of influence

The weight of influence (w) is defined in the table of index parameters by any real value. It is the maximum value of the function describing the effect within the zone of influence. For Boolean and Binary weights of evidence prospectivity maps, any positive values can be used. For a peak distance of zero, the maximum weight for any data layer will only be scored in the target pixel. The apparent weight, w_a, for any pixel within the zone of influence is given by product of the weight and distance function (f) described above.

$$\mathbf{w_a = w\ .\ f}$$

For simple Boolean models individual data layer weights are either 0 or 1. For this study the defined weights for data layers are always in the range 0.0–1.00. The sum of weights, essential for normalisation of the prospectivity map, is defined by the sum of weights for each plotted data layer. Each data layer is treated therefore as a level of evidence. Consequently, if data layers contain non-unique data, i.e. duplicate data points, or overlapping polygons then these will be scored twice in the prospectivity analysis, although the sum of weights will not reflect this. This can mean that some BWE models will have final prospectivity scores at or above 1.00. To compensate for this, if the non-normalised prospectivity grid contains elements greater than the sum of weights, then the maximum prospectivity score is used to normalise the BWE map before plotting.

7 Data and exploration criteria

7.1 GEOLOGY

The study region covers more than twenty 1:50 000 geological map sheets (Figure 2). Many of these were originally surveyed in the period 1870–1900 but have since been revised (Table 8).

The UK 1:50 000 geological maps are currently being digitised and edge-matched to provide a national coverage of attributed linework. The attributes will initially comprise a rock Lexicon code and a rock lithology. At the time of writing this programme is not complete, so this study uses 1:250 000 digital geology as the basis for all analysis. The region is covered by the following 1:250 000 scale geological maps: Lands End 50N-06W; Portland 50N-04W; Lundy 51N-06W and Bristol Channel 51N-04W.

In south-west England the Upper Devonian and Lower Carboniferous sequence is equivalent to that present in the Iberian Pyrite Belt (Figure 8a). Recent mapping in the present study area has identified numerous formations separated by tectonic boundaries. By analogy with the IPB, chert and black shale horizons identified in many of these formations are important target lithologies for massive sulphide deposits. A summary of the main formations mapped in the Upper Devonian–Lower Carboniferous of south-west England is presented in Table 9.

Table 8 1:50 000 scale geological maps in the region

Map Sheet	Date of last revision
277 Ilfracombe	1977
278 Minehead	1997
292 Bideford, Lundy	1977
293 Barnstaple	1982
308 Bude	1980
309 Chumleigh	1966
310 Tiverton	1974
322 Boscastle	1969
323 Holsworthy	1974
324 Okehampton	1969
325 Exeter	1995
336 Camelford	1994
337 Tavistock	1993
338 Dartmoor Forest	1995
339 Newton Abbot	1997
347 Bodmin	1982
348 Plymouth	1998
349 Ivybridge	1974
350 Torquay	1976
355 Kingsbridge, Start	2001

Table 9 Summary sequence of the Upper Devonian and Lower Carboniferous strata in west Devon (based on 1:50 000 sheets 336 Camelford, 337 Tavistock and 348 Plymouth)

Age	Formation names	Lithologies
Namurian	Crackington Bealsmill ■	Basinal distal turbidites and sandstones with subordinate grey and black shales.
Upper Visean	Firebeacon Chert ■ Meldon Chert ■ Newton Chert ■	Thick bedded grey cherts, with black shales and limestones.
Visean	Trambley Cove ■ Barras Nose ■	Laminated grey and black shales and slates with thin tuff beds.
Tournaisian	Greystone, Meldon Shale ■ St Mellion Cotehele Sandstone ■	Dark grey siltstone and slate with tuffs, pillow lavas and black shales, thin limestones and massive sandstones.
Tournaisian-Famennian	Brendon	Interbedded sandstone and siltstone
	Buckator	with volcanic rocks.
	Petherwith	Grey green laminated slates, thin nodular bioclastic limestones.
	South Brentor	Dark and black shales
	Yeolmbridge ■	
Upper Fammenian	Burraton Slate Overwood Slate	Grey to black micaceous slate and siltstone, occasional nodular and lenticular limestones.
	Stourscombe Bealbury	Green and blue-green shales and siltstones and purple shales.
Fammenian	Lezant Slate Tavy Tredorn Slate Woolgarden Slate	Green and grey banded slates and laminated mudstones with rare thin sandstones.
Eifelian-Fammenian	Saltash	Grey cleaved siltstone and mudstone with sporadic thin limestone.
	Torpoint	Brown-purple mudstone with green-yellow siltstone. Local tuffs, basalts and hyaloclastites.
Eifelian-Frasnian	Plymouth Limestone	Stromatoporoid boundstone units and crinoidal grainstone. Locally thinly bedded fine grained limestone and thin bedded wackestone. Minor tuffs, basalts and hyaloclastites.
■ indicates presence of black shales within the formation		

The Upper Devonian–Lower Carboniferous sequence in North Devon has similarities with that of the Harz Massif of Germany which contains the major stratiform base-metal deposit at Rammelsberg. In North Devon, outcrops of Dinantian strata occupy limited areas within second-order folds at the northern margin of the Culm synclinorium. Much of the ground to the north in Exmoor and the Brendon Hills is underlain by Upper Devonian sandstones and slates. In the Harz Massif, the ore horizon in the Rammelsberg deposit occurs in dark grey shales of Eifelian age. The Eifelian Hangman Grits in Devon are more arenaceous than the Harz Eifelian sequence. The Hangman Grits are overlain by the Ilfracombe Slates which are primarily grey slates with minor sandstone and a few discontinuous limestones in the Morte Slates and Kentisbury slates.

Table 10 Summary sequence of the Upper Devonian and Lower Carboniferous strata of North Devon

Age	Formation	Thickness (m)	Lithology
Tournaisian-Visean	Codden Hill Chert ■	250	Grey and black shales locally siliceous with cherts and grey limestones.
Fammenian	Pilton Shales	500	Shales with sandstones, siltstones and thin limestones.
	Baggy Sandstones	450	Massive cross-bedded sandstones, siltstones and thin limestones.
	Uppcott Slates	250	Yellow green and purple slates with occasional fine cross-bedded sandstones and thin limestones.
	Pickwell Down Sandstones	1200	Red and brown cross-bedded, rippled sandstones with shales, basic tuffs near base.
Frasnian	Morte Slates	1500	Smooth grey and green slates with thin limestones near base and basic tuffs. Strong southward-dipping cleavage.
Givetian	Ilfracombe Slates Kentisbury Combe Martin Lester Wild Pear	650	Slates with sandstones and thin limestones.
Eifelian	Hangman Grits	1000	Grey and purple sandstone with subordinate slates and beds of pebbly sandstone.
Emsian	Lynton Slates	>100 m	Slates.
■ indicates presence of black shales within the formation			

7.2 STRUCTURE

Faults derived from the 1:250 000 Series geological maps are shown in Figure 3. There are many more structures shown on the 1:50 000 maps but these were not available for this report. For example, recent mapping in the Plymouth district (BGS, 1998) indicates an important set of north-west-trending faults showing evidence of dextral movement (Portnadler, Portwrinkle, Cawsand) and east-south-east-trending faults (Ludcott) which dissect the nappe structures.

The region is transected by a dominant north-north-west-trending fault set the most important of which is the Sticklepath Fault which transects the north-eastern part of the Dartmoor granite. Other components of this fault set, largely inferred from the mapped geological boundaries, truncate much of the geology in the region between Dartmoor and Bodmin Moor. The identification of a small Tertiary basin at Lamerton to the north of Tavistock also indicated the importance of the north-north-west dextral fault system (Rollin, 1988).

Regional analysis of geophysical data suggest that a set of north-north-east-trending structures may also affect much of south-west England. These can be seen as lineaments in images of the gravity and magnetic data for the UK and surrounding countries (BGS 1997, 1998). These structures might be related to the genesis of IPB deposits but the nature of this relationship is not known.

Nappe-and-thrust structures are important in the IPB, with many of the deposits occurring within thrust-bound, overturned isoclinal folds. Detailed fold axis data are not available for south-west England and have not been used in this work.

7.3 GEOPHYSICS

7.3.1 Rock properties

Measured values for rock density and magnetic susceptibility are available for numerous sites in south-west England and a summary is presented in Table11.

In south-west England it is known that the pyrrhotite mineralisation in the Meldon Chert Formation and in albite dolerites north of the granites has significant NRM (Cornwell, 1967). At some sites the NRM appears to have a southward and upward vector approximately in the direction of the pole [declination 188°, inclination -13°] for the Exeter lavas (ca. 280 Ma) so that remagnetisation of pyrrhotite at the time of intrusion of the Dartmoor granite seems the most likely cause of the NRM. At other sites the NRM vectors are not easily grouped and the NRM often shows a strong anisotropy associated with the bedding or cleavage direction. The NRM vectors for the Clicker Tor and Polyphant ultrabasic rocks have a mean vector direction [declination 185°, inclination +52°], more typical of Upper Devonian and Lower Carboniferous poles (Cornwell, 1967).

Table 11 Summary of measured rock density and magnetic susceptibility data for south-west England (based on BGS records)

Formation	n	N	Ds	Dd	Dg	P %	k
Permian sandstone	2	2	2.35	2.13	2.74	23	0.10
Permian breccia	8	4	2.47	2.32	2.75	15	0.08
Permian basalt	6	2	2.41	2.28	2.62	13	0.08
Namurian (Culm)	50	32	2.69	2.66	2.75	3	4.78
Bude Formation	3	1	2.53	2.42	2.71	11	0.18
Crackington Formation	52	13	2.65	2.61	2.73	4	1.00
Tintagel Volcanic	43	9	2.67	2.57	2.84	10	16.58
Tournaisian-Visean	10	3	2.56	2.45	2.76	11	0.31
Famennian	28	6	2.69	2.62	2.82	7	0.58
Epidiorite	12	3	2.92	2.90	2.96	2	0.80
Dartmoor granite	20	8	2.59	2.55	2.67	4	0.21
Dolerite	5	2	2.86	2.85	2.88	1	
Lamprophyre minette	7	2	2.42	2.28	2.63	14	0.36
Meldon aplite	1	1	2.58	2.55	2.63	3	0.14
Meldon pyrrhotite hornfels		1					169.0
Meldon dolerite		1					2.94
Sourton dolerite		1					0.68
Smeardon dolerite		1					0.74

n, number of samples; N, number of sites; Ds, saturated density; Dd, dry density; Dg, grain density; P, effective porosity %; k, magnetic susceptibility 10^{-3} SI units

7.3.2 Aeromagnetic data

The regional magnetic data for the study region were collected by the Hunting Group for the Geological Survey during 1957 and 1958. The data were acquired in analogue form along flight lines orientated north-south at a spacing of approximately 400 m and a flying height of 500 feet (152 m) above terrain. These surveys had no tie lines so that the data have been adjusted by a micro-levelling technique.

The aeromagnetic data have been converted to digital format, referenced to a new International Geomagnetic Reference Field for the UK and published as a shaded relief map for the UK (BGS, 1998).

The magnetic data for the region have been interpolated onto a square grid of mesh size 0.25 km using a minimum tension algorithm and are displayed as a shaded-relief image illuminated from the north (Figure 9). Residual magnetic anomalies have been obtained by generating a regional field by analytic upward continuation of the observed magnetic anomaly by 2 km. Subtraction of the regional anomaly from the observed field provides a residual anomaly (Figures 10, 11) which aims to represent the higher frequency component of the observed data. This residual magnetic anomaly has been used in the quantitative interpretation of the data and in the identification of prospective zones on Exmoor (Figure 11).

The Hunting Group 1957 survey, west of British National Grid line 220 km E, also collected airborne electro-magnetic (EM) data. The airborne EM system used a dual frequency out-of-phase (quadrature) system with a horizontal transmitting loop on the aircraft and a vertical receiver loop towed on a cable. The phase differences between the primary and secondary fields were measured at 400 Hz and 2300 Hz. The depth penetration of this system was probably low, of the order of 20–30 m, and the data were very strongly affected by cultural noise. These data are not in digital form and have not been used in this work.

7.3.3 Gravity data

Gravity observations have been made at Ordnance Survey spot heights and bench marks across the region as part of the national survey by BGS. The Hercynian granites of south-west England all have a relatively low density (c. 2.6 Mgm^{-3}) and are associated with strong negative gravity anomalies (BGS, 1997).

Regional gravity data have a distribution of about one station km^{-2}. Detailed profile and infill gravity surveys have also been carried out at several localities across the region (Table 12) as part of the Mineral Reconnaissance Programme (Tombs, 1980) and to support the BGS mapping programme (Rollin, 1988). Many of the detailed surveys were to explore the form and structure of the concealed margins of the Cornubian granites. These surveys typically provide data at a station distribution of about 3 km^{-2}. However stations and traverses were generally located along public highways and consequently lack the regular distribution favoured for the detection of small deposits.

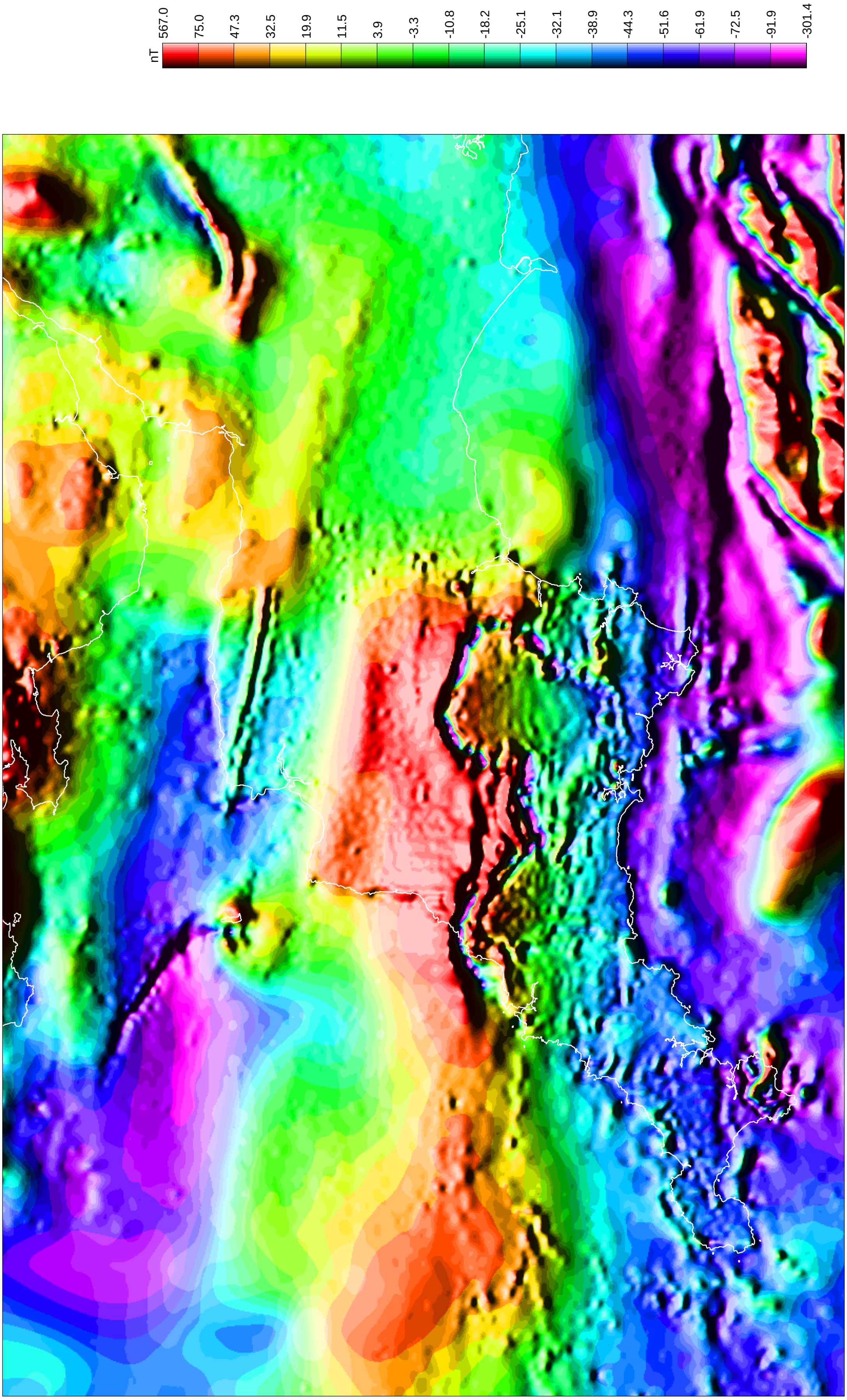

Figure 9 Colour shaded-relief image of regional aeromagnetic anomaly over south-west England

Table 12 Detailed gravity surveys in East Cornwall and Devon

Survey	Number stations	Reference
St Austell #	1669	Beer et al., 1975
SW Dartmoor #	434	Tombs, 1980
Tavistock	1461	Rollin, 1985
Boscastle	3 traverses	McKeown et al., 1973
Okehampton	8 traverses	Edmunds et al., 1968
Crediton	11 traverses	Cornwell et al., 1992
Chillaton #	2 traverses	Rollin, 1985
Brownstone #	2 traverses	Leake et al., 1992
Teign Valley #	3 traverses	Beer et al., 1992
# data collected as part of the Mineral Reconnaissance Programme		

The regional and detailed observed Bouguer gravity data for the region (Figure 12) have been interpolated on to a square grid of mesh size 0.25 km and are displayed as a shaded-relief image illuminated from the north (Figure 13)

Stratiform massive sulphide deposits are commonly associated with a small (typically 1–2 mGal) positive residual gravity anomaly. Pyrite has a density of 4.8–5.1 Mgm^{-3} (Read, 1970) and massive pyrite deposits commonly have density values exceeding 4.5 Mgm^{-3} (Strauss et al., 1977). Consequently some IPB deposits are associated with small high frequency residual gravity anomalies up to 4 mGal. The regional gravity survey of the UK was not designed for detection of such anomalies. Furthermore, although the region has two detailed gravity surveys in the zone of interest the gravity field is still relatively under-sampled in comparison with exploration practice in the IPB. Both the detailed gravity surveys used public highways and tracks to make observations so that station distribution is not uniform. Nevertheless an attempt has been made to identify residual anomalies which might be targets for further exploration. Both of the detailed gravity surveys had originally been interpreted for residual negative anomalies associated with stockwork and cusp structures in the granite roof rather than for small positive features related to massive sulphide mineralisation.

A residual gravity field was derived using a regional field based on arbitrary sampling of the observed data. In this case the regional was calculated from a subset of the regional gravity data (without the detailed surveys) and the sub-sampled data (one station per five observed) were gridded at 1 km, smoothed using a simple 5 point filter and then interpolated to 0.25 km, to match the observed data grid. The residual field is the observed data minus the regional field. The residual gravity anomaly for the central region is shown in Figure 14. There are a few small positive high-frequency residual anomalies near Launceston and south-west of Ivybridge.

7.3.4 Depth solutions

Data inversion and deconvolution are techniques to derive geometrical and/or property information of the source from analysis of the observed data. Most commonly it is used to estimate the depth to source of magnetic and gravity anomalies. For the project area, the digital aeromagnetic data have been interpreted by semi-automatic techniques to provide estimates of the depth to sources. The profile and gridded magnetic data have been interpreted using 2D Euler, Werner and slope methods, while the grid magnetic data have also been interpreted using the analytic signal method.

Data from the north–south aeromagnetic flight lines have been analysed profile-by-profile to model the location and depth of likely sources At least two types of source are indicated: the high frequency (reversed polarity) anomalies across the 'pyrrhotite belt' are superimposed on a low-frequency anomaly which is characteristic of a deep basement block which rises to a margin close to a line from Great Torrington to Tiverton. This basement anomaly is clearly evident in the shaded relief images of the aeromagnetic data (Figure 10) and in composite plots of the deconvolution of profile data across the region. Selected examples are illustrated: profile 220 (Figure 15) crosses the anomalies on the north side of Bodmin Moor; profile 280 (Figure 16) crosses the ground between the granites near Tavistock; and profile 320 (Figure 17) crosses the Dartmoor granite and the magnetic anomalies near Okehampton. The magnetic anomaly due to the basement feature is best seen on profiles 220 and 320 where it occurs well to the north of the reversed anomaly.

The 2D depth solutions for anomalies in the 'pyrrhotite belt' are generally shallow, usually within 500 m of OD. Many of the solutions are at, or close to, outcrop. Maps of the 2D solutions for slope analysis and Werner deconvolution show mean depth solutions of 0.54 and 1.0 km below OD respectively (Figures 18, 19). Slope analysis solutions for profiles across the longer wavelength anomaly are significantly deeper, typically about 1–2 km on line 220 (Figure 15) and 3–4 km on line 320 (Figure 17), although it should be noted that the slope method tends to overestimate the depth to source. The conclusion is that the long wavelength anomaly represents a relatively magnetic basement block which was probably active during the Variscan deformation such that thrusts and fold structures might be ramped against and over it. The region at the northern margin of the block and on top of the block are considered as prospective terrane for buried deposits of IPB type.

7.3.5 Analytic Signal

The analytic signal of a potential field is a vector which describes the complex gradient of a the field. The magnitude of the analytic signal of a potential field is calculated from the square root of the sum of the squares of the partial derivatives in x,y,z. In theory, the magnitude of the analytic signal, the parameter used to estimate depth, is unaffected by the direction of the magnetisation vector. Figure 20 shows the calculated total field magnetic anomaly and the calculated magnitude of the analytic signal for a buried rectangular plate with a magnetisation vector declination D= 220° and inclination I= 20°. The figure also illustrates how the magnitude of the analytic signal can be interpreted using a simple function to provide source location and depth. Consequently the analytic signal might provide a rationalisation of the observed field regardless of the uncertainty of the NRM and total magnetisation vector.

Analytic signal magnitude (Figure 21) was calculated for the residual magnetic anomaly. This transformation of

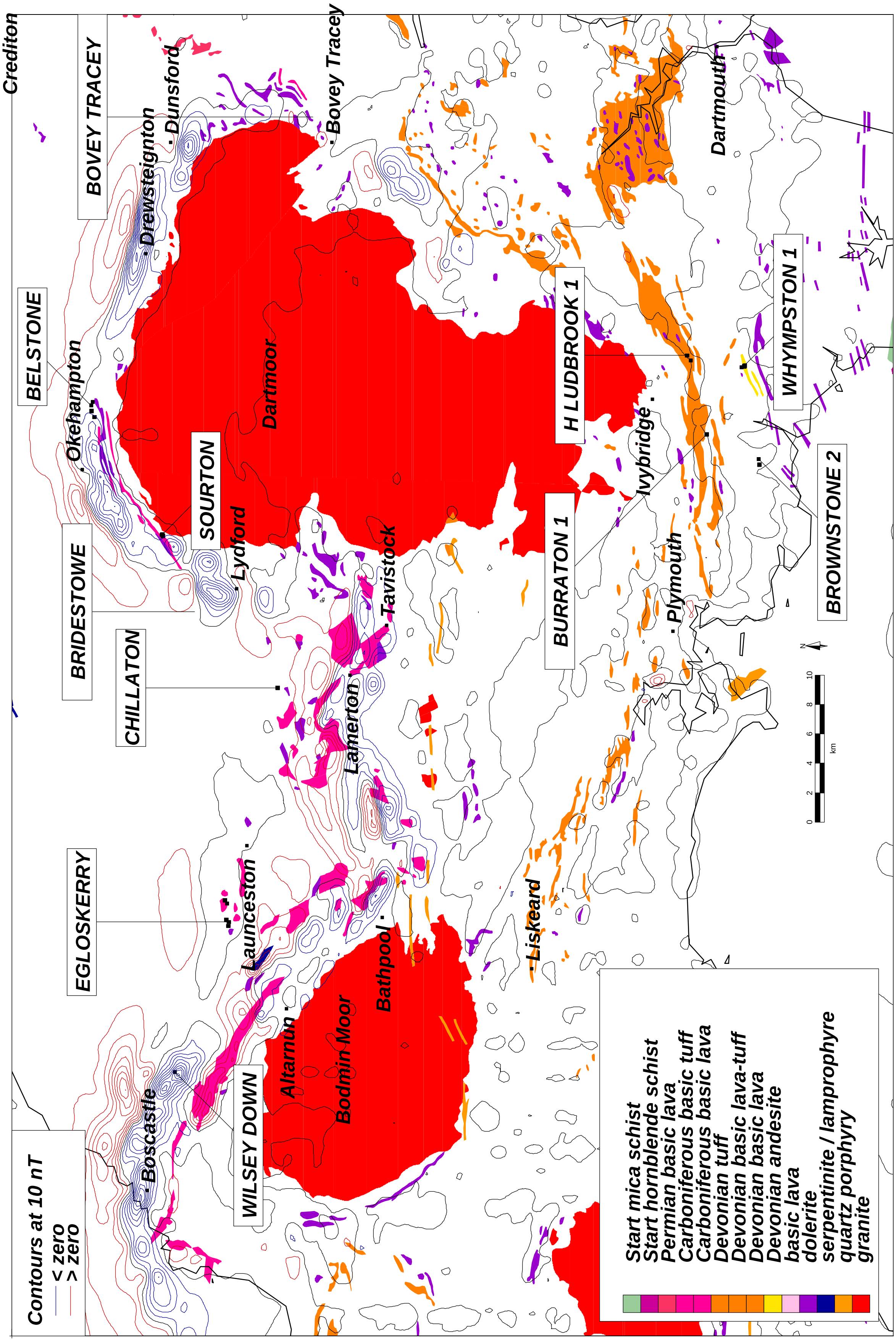

Figure 10 Residual magnetic anomaly in the central region

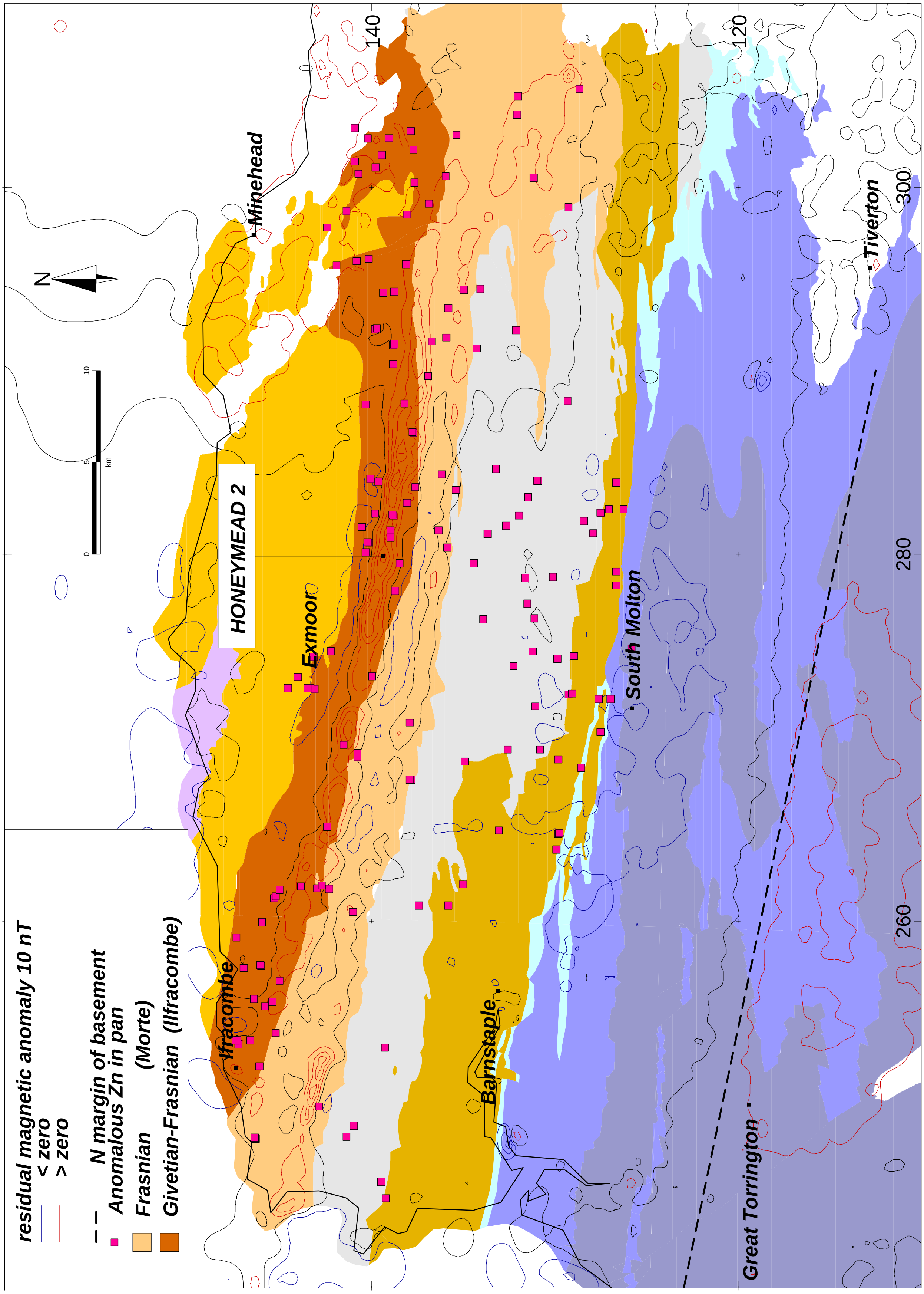

Figure 11 Residual magnetic anomaly in the Exmoor region with sites of anomalous zinc in panned concentrate from Jones et al. (1987)

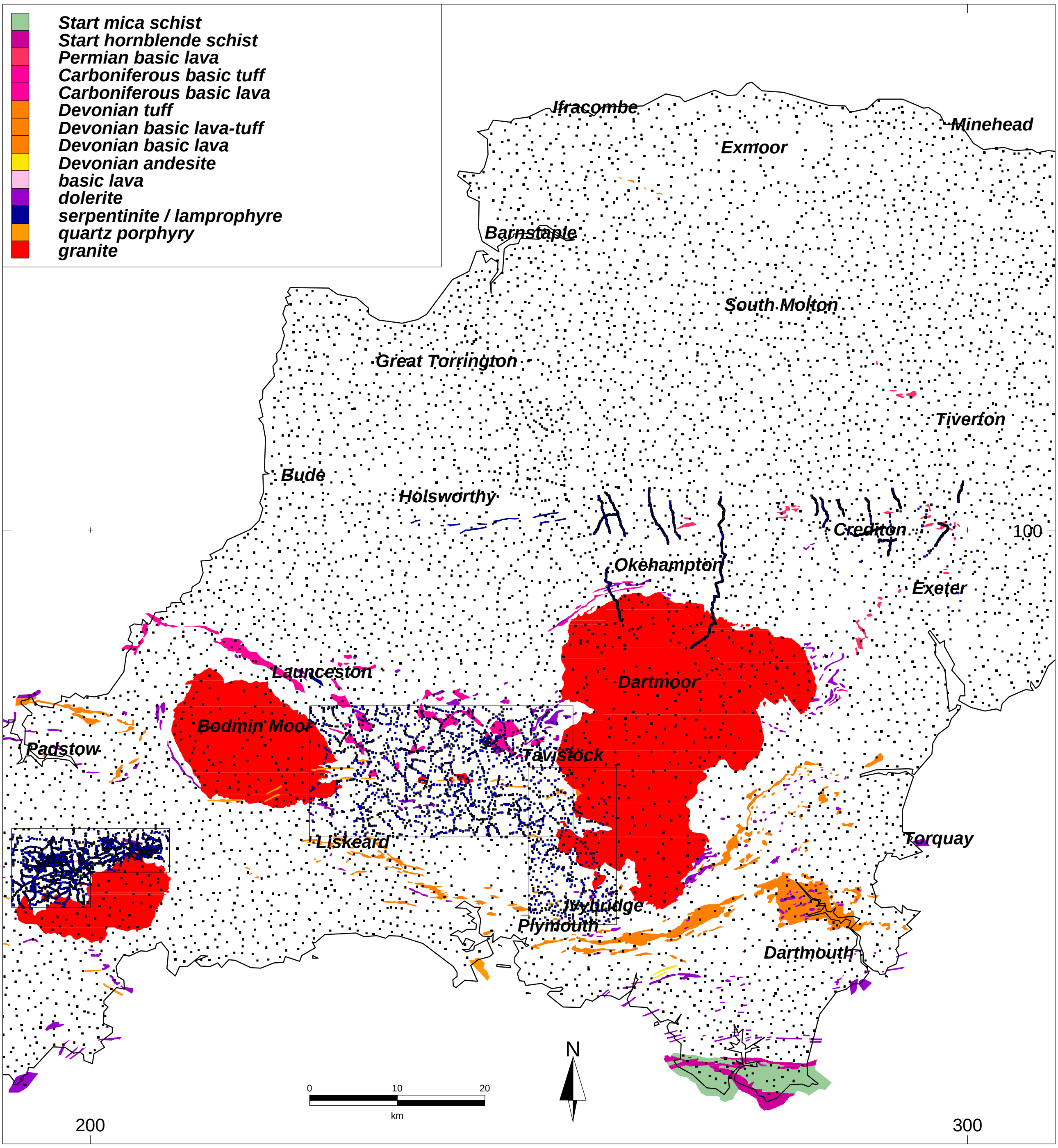

Figure 12 Location of gravity observations

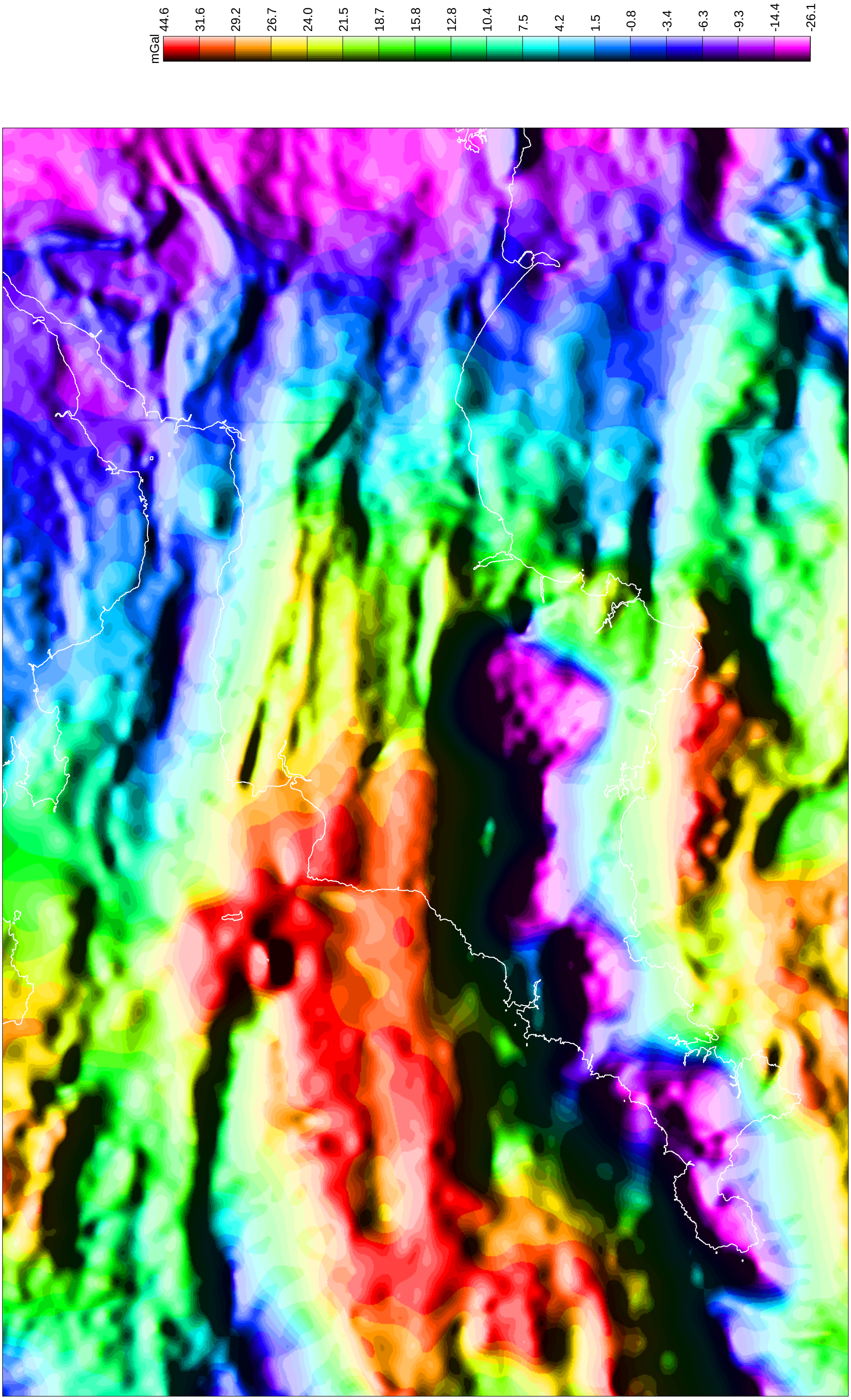

Figure 13 Colour shaded-relief image of the Bouguer gravity anomaly over south-west England

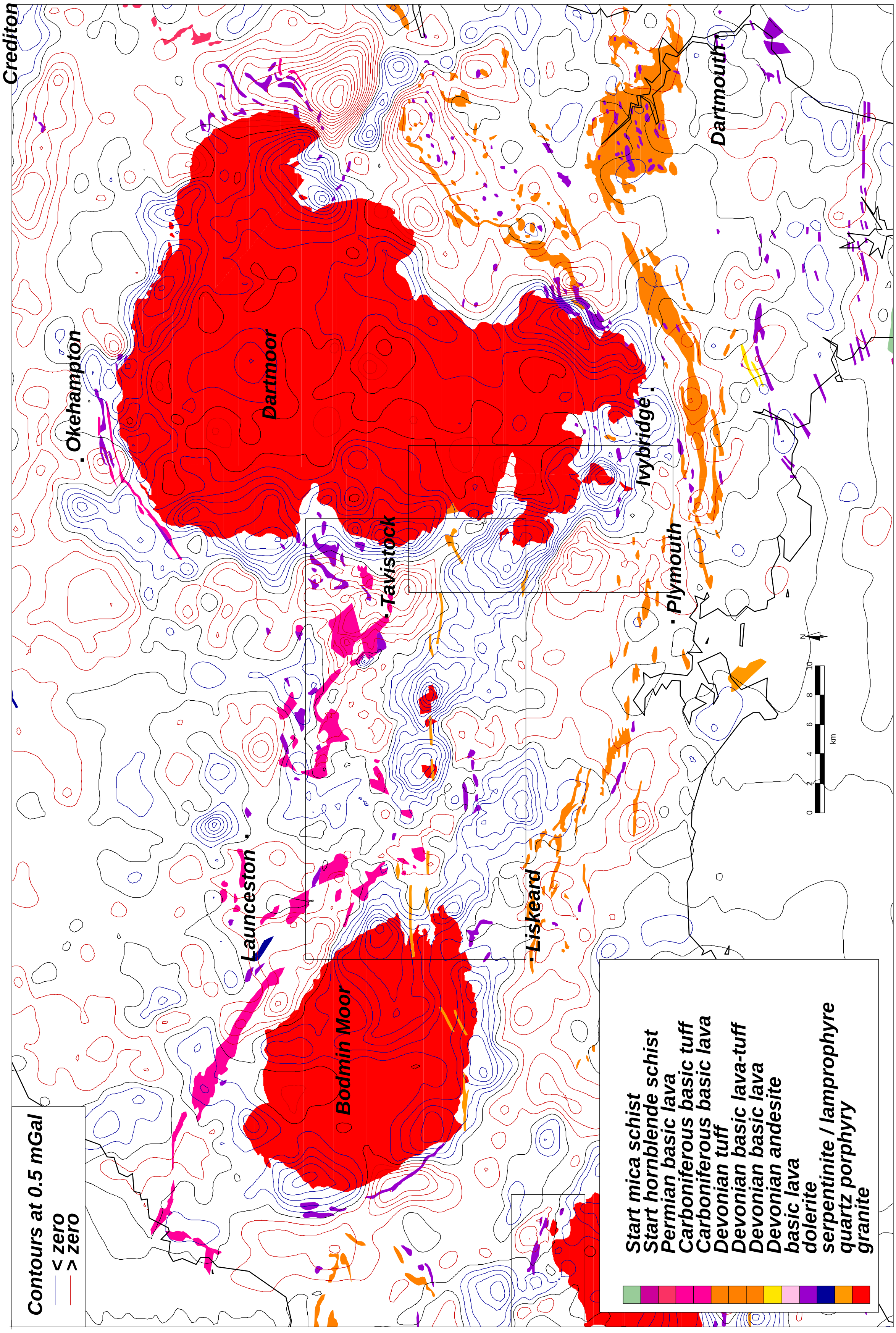

Figure 14 Residual gravity anomaly in the central region

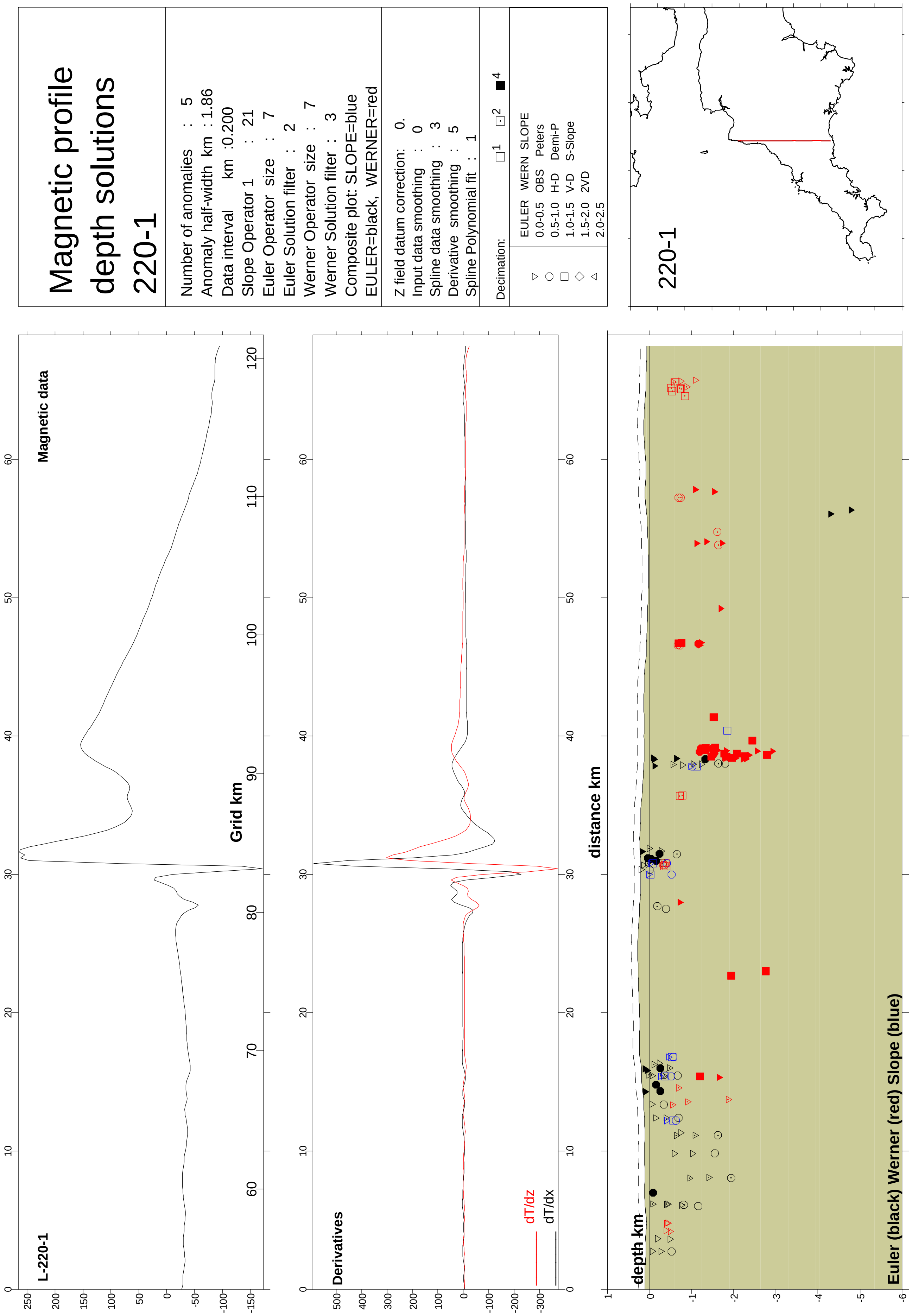

Figure 15 Composite 2D Euler, Werner and Slope solutions for profile 220-1 Bodmin Moor

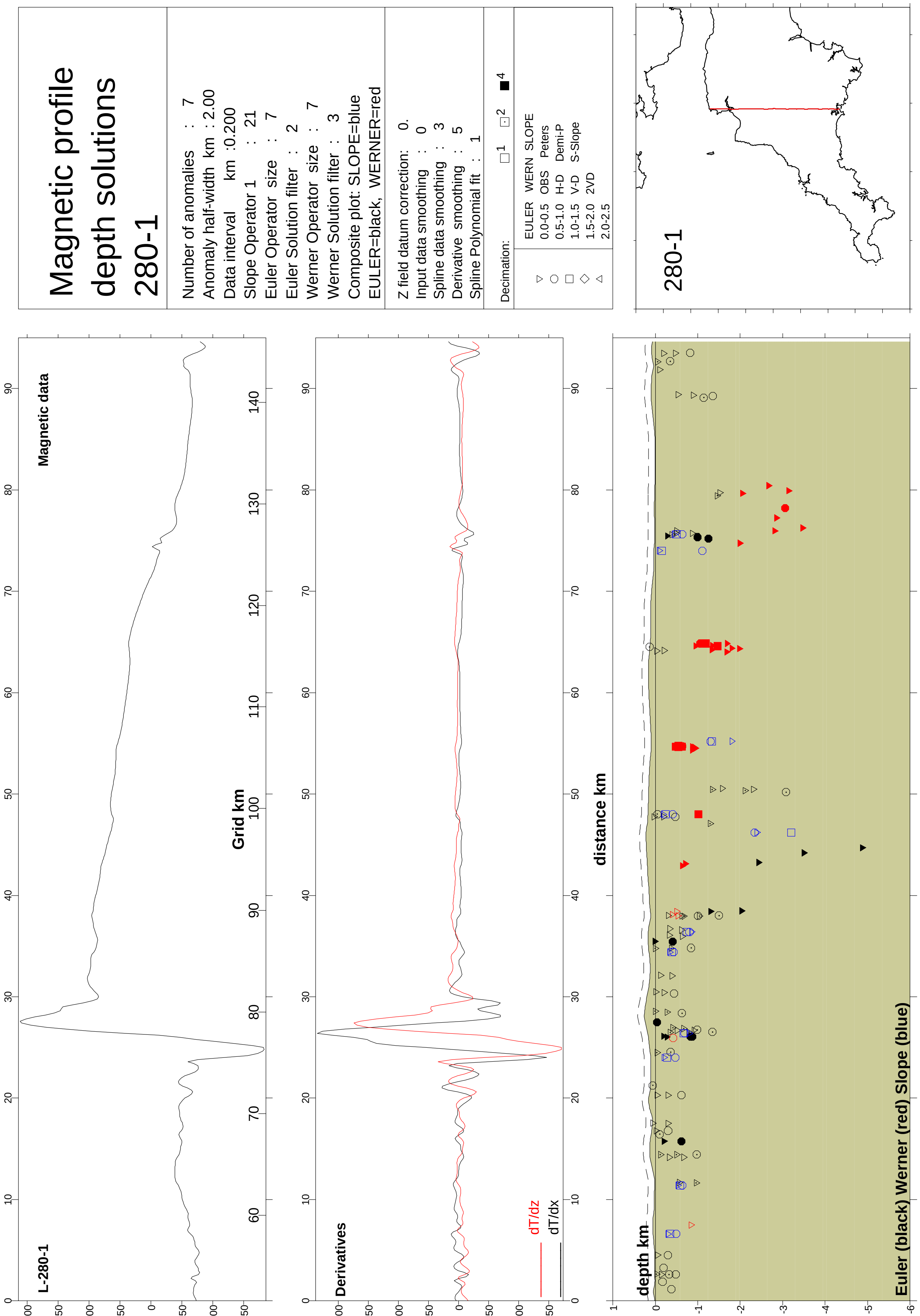

Figure 16 Composite 2D Euler, Werner and Slope solutions for profile 280-1 Tavistock

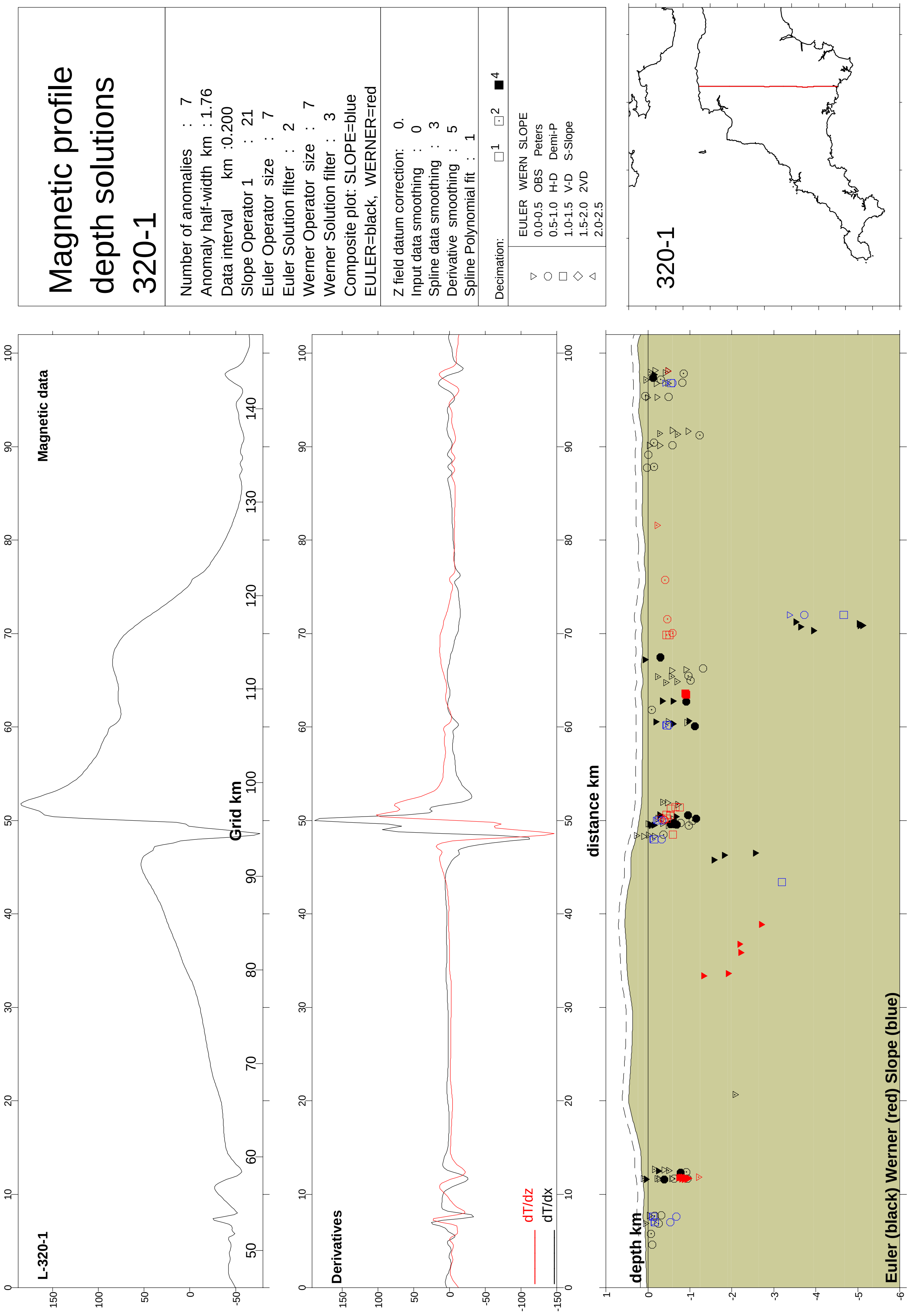

Figure 17 Composite 2D Euler, Werner and Slope solutions for profile 320-1 Dartmoor

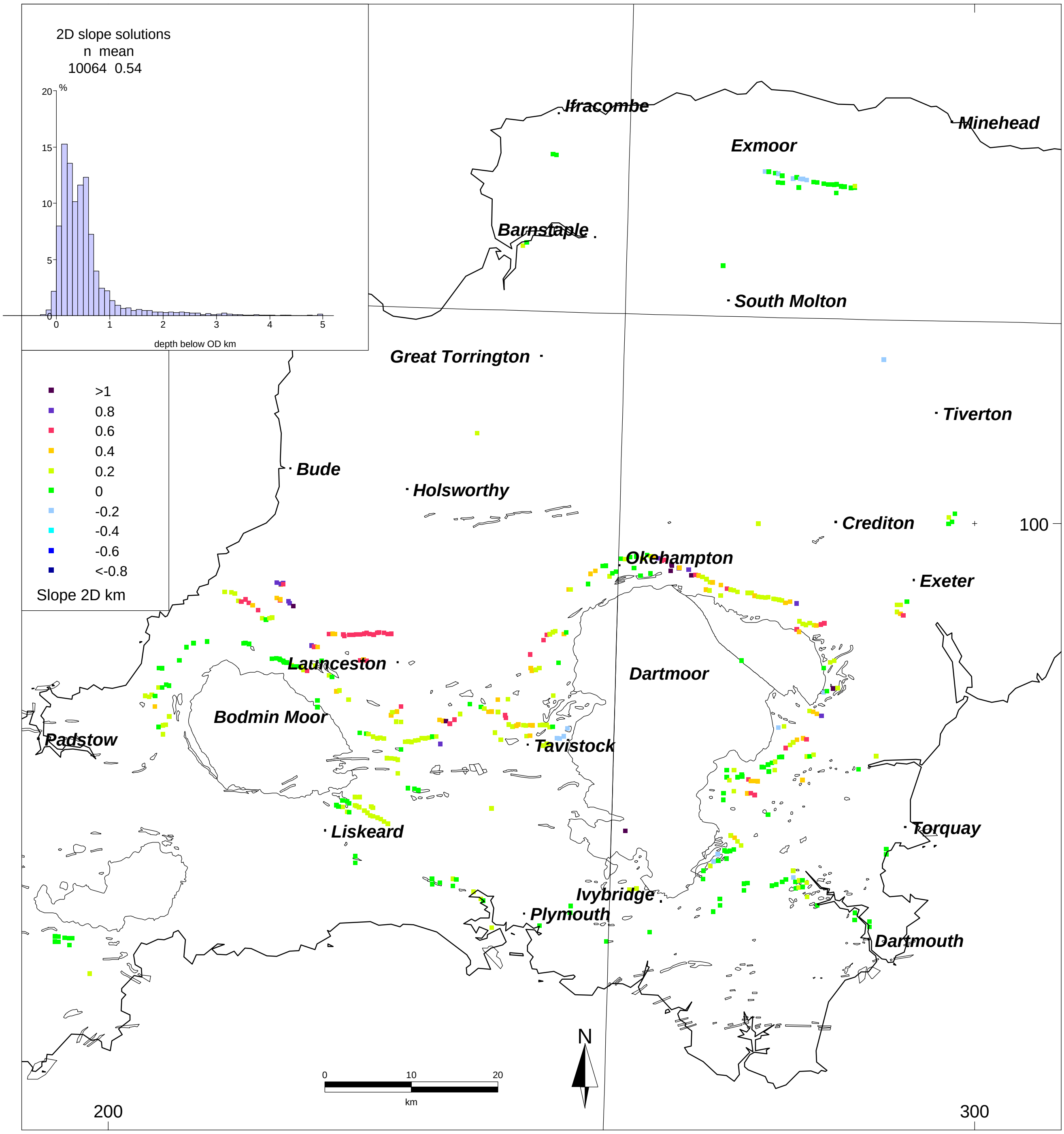

Figure 18 2D Slope solutions from profile data

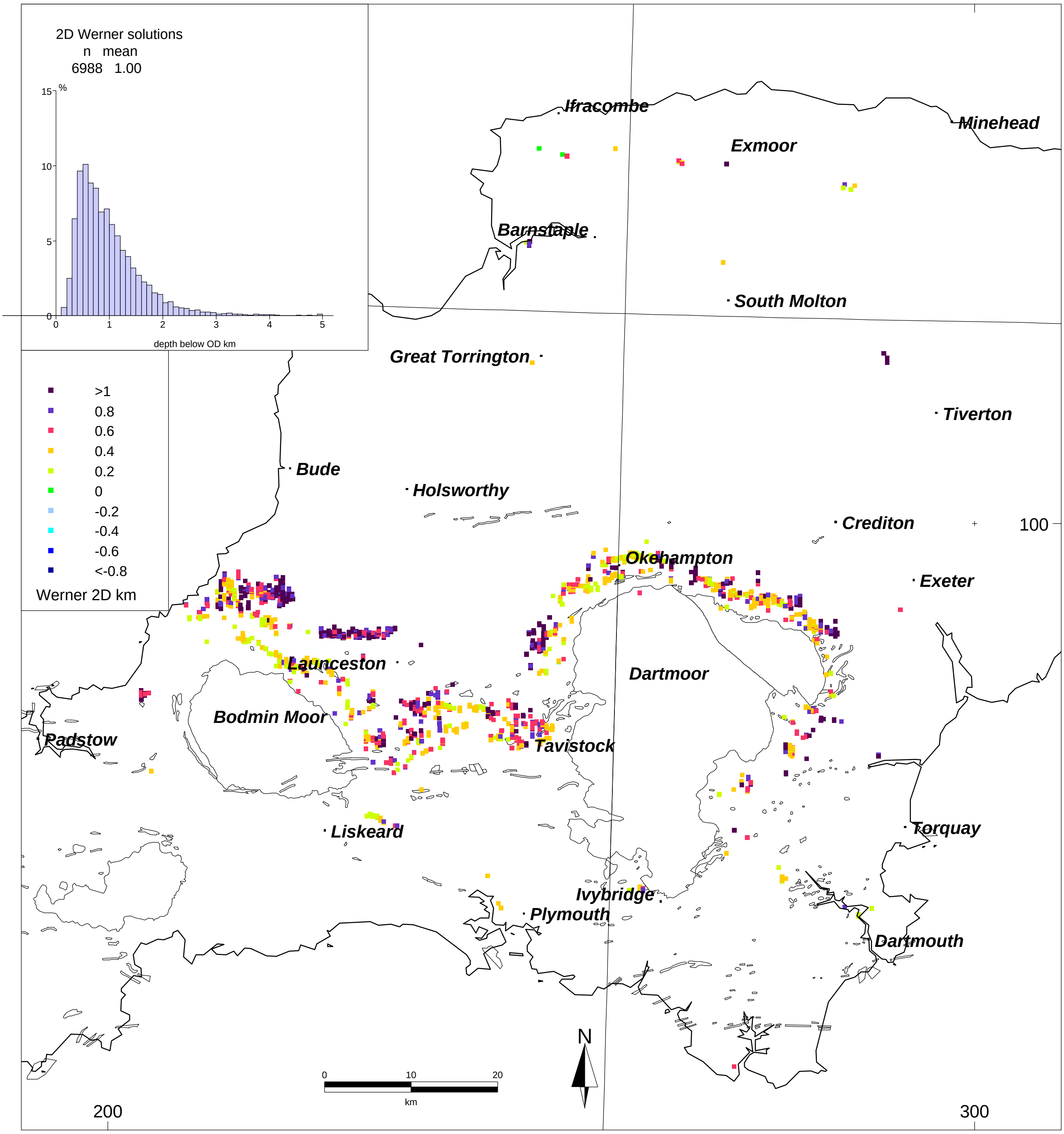

Figure 19 2D Werner solutions from profile data

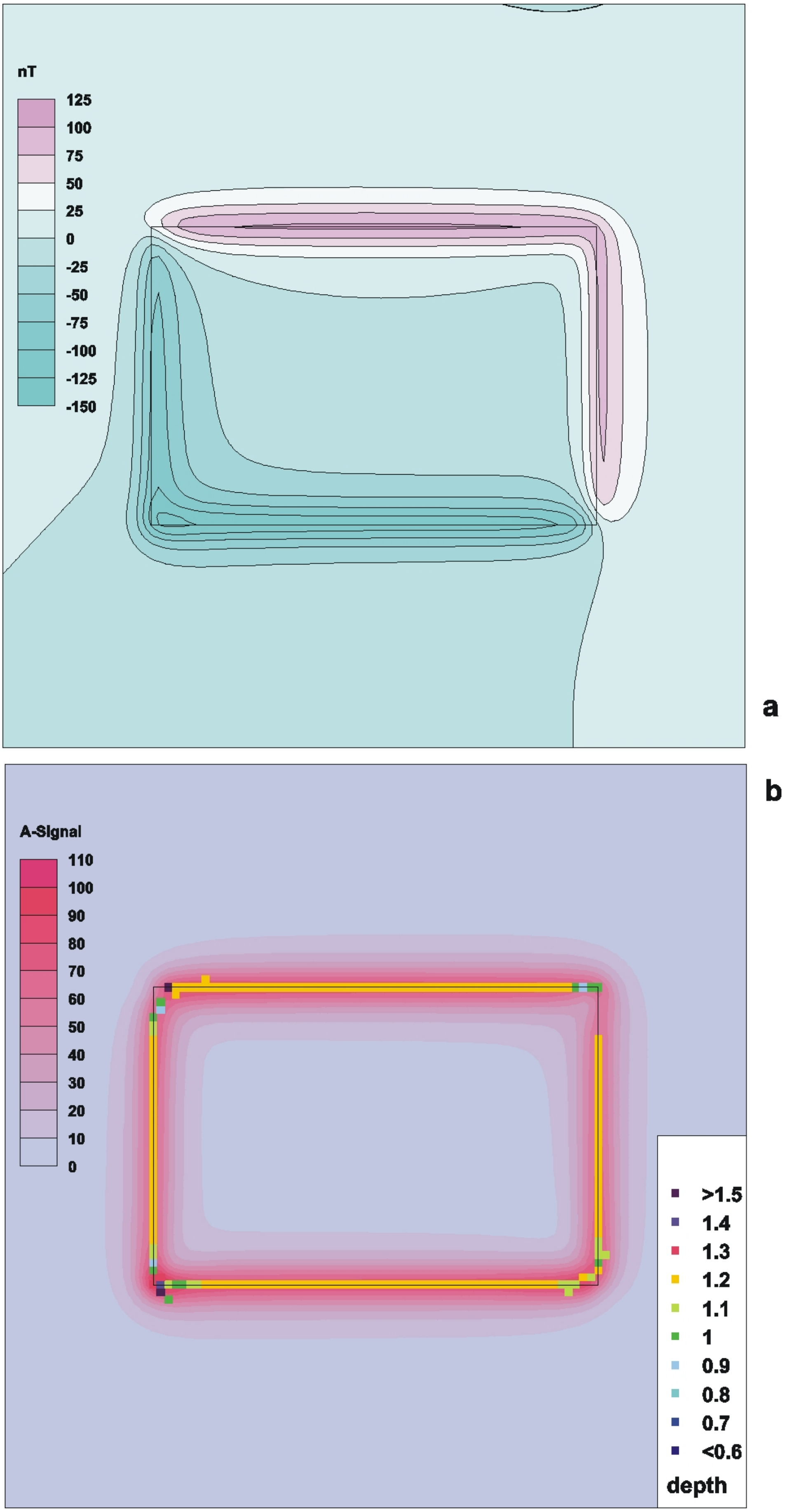

Figure 20 Magnetic anomaly and analytic signal for a thick plate model with a top surface at a depth of 1 km with a magnetisation vector D=220, I=20 (a) Calculated total field anomaly (b) calculated analytic signal magnitude and depth solutions

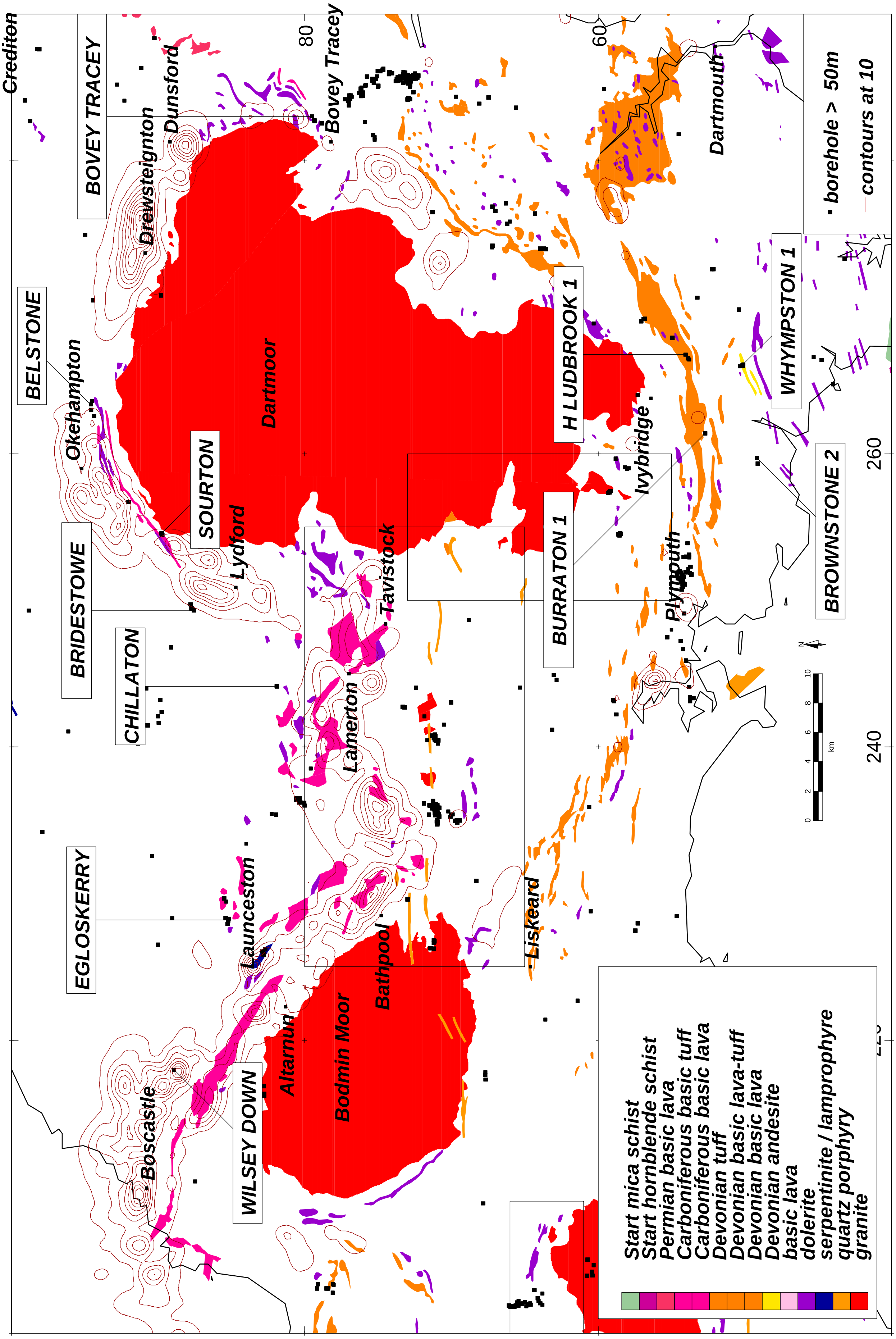

Figure 21 Magnitude of the analytic signal of the residual magnetic anomaly in the central region

the field is expected to indicate the position of the source regardless of the direction of the total magnetisation vector. The location of deep boreholes (>50 m) and the main sites of exploration in the magnetic zone indicate that many of the larger postulated magnetic sources, as identified by the analytic signal, have not been tested by drilling. Only the Wilsey Down borehole is sited on or close to a local maximum in the analytic signal field.

The magnitude of the analytic signal has been used to provide depth-to-source solutions using a simple Laplacian transform (Figure 22). These solutions represent estimates of source depth below a flat topography at a level 150 m below the data observation level (i.e. approximately depth below ground level). The histogram of depth solutions for the 3D analytic signal method gives a mean depth of 0.55 km below ground level.

In the prospectivity analysis the magnitude of the analytic signal of the residual magnetic field has been used to indicate sources for the magnetised zone north of Bodmin Moor and Dartmoor. In addition, 2D Euler deconvolution solutions which lie within the zone of high magnetic gradient (horizontal gradient magnitude >50 nT/km) have been used as estimates of depth to source and incorporated into the prospectivity. It is implicit that these solutions mainly represent magnetic pyrrhotite within the prospective terrane and that this source is also indicative of primary stratiform sulphide deposits. Prospectivity in the Exmoor region has been indicated by residual magnetic anomaly above 15 nT and by the position of the shallow Euler 2D depth solutions.

7.4 GEOCHEMISTRY

7.4.1 Soil and overburden data

The Mineral Reconnaissance Programme collected and analysed many soil and deep overburden samples from south-west England. A total of 10 563 soil and overburden samples (Figure 23) were collected from the project region, mainly from work at Ivybridge (Leake and Norton, 1993), South Devon (Leake et al., 1995), Teign Valley (Beer et al., 1992) and Exmoor (Jones et al., 1990). The principal results of these surveys have been discussed in section 4 of this report. These data have not been used in the prospectivity analysis because of their restricted areal distribution.

7.4.2 Drainage geochemistry

The legacy of past mining activity locally presents a significant problem for the application of stream-sediment geochemistry to exploration in the target region. Nevertheless this problem is much less serious than in the IPB or in west Cornwall where mining has been carried out widely for centuries.

Extensive drainage geochemical surveys were carried out over Devon and east Cornwall by BGS between 1970 and the mid-1990s as part of the DTI-funded Mineral Reconnaissance Programme (Jones, 1981; Jones et al., 1987). The national Geochemical Baseline Survey of the Environment (G-BASE) regional geochemical mapping programme has not yet covered south-west England.

In the study region about 2800 stream-sediment samples (Figure 24) and about 3340 panned-concentrate samples (Figure 25) have been collected by BGS. However, it should be noted that certain elements were not analysed in all projects and consequently these data have restricted areal distributions e.g. Bi was analysed in stream sediments from only 84 sites and Sb from only 23 sites.

The largest single survey was carried out over Exmoor and the Brendon Hills (Jones, 1987). Samples of water, stream sediment and heavy mineral concentrate were collected from more than 700 sites. Subsequently, an additional 100 samples were collected to extend the coverage in areas of specific interest. In this survey stream-sediment samples were analysed for Ag, Ba, Co, Cr, Cu, Fe, Mn, Mo, Nb, Ni, Pb, Sn, U, V, Zn and Zr; and panned-concentrate samples for Ba, Ca, Ce, Cu, Fe, Mn, Ni, Pb, Sb, Sn, Ti and Zn. Those sites on Exmoor with anomalous base-metal concentrations in panned concentrates are listed in Appendix 3.

The stream-sediment geochemical data for the study area are summarised in Table 13. Data for the following elements are available for more than 2500 sites: Ba, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sn, Zn, Zr.

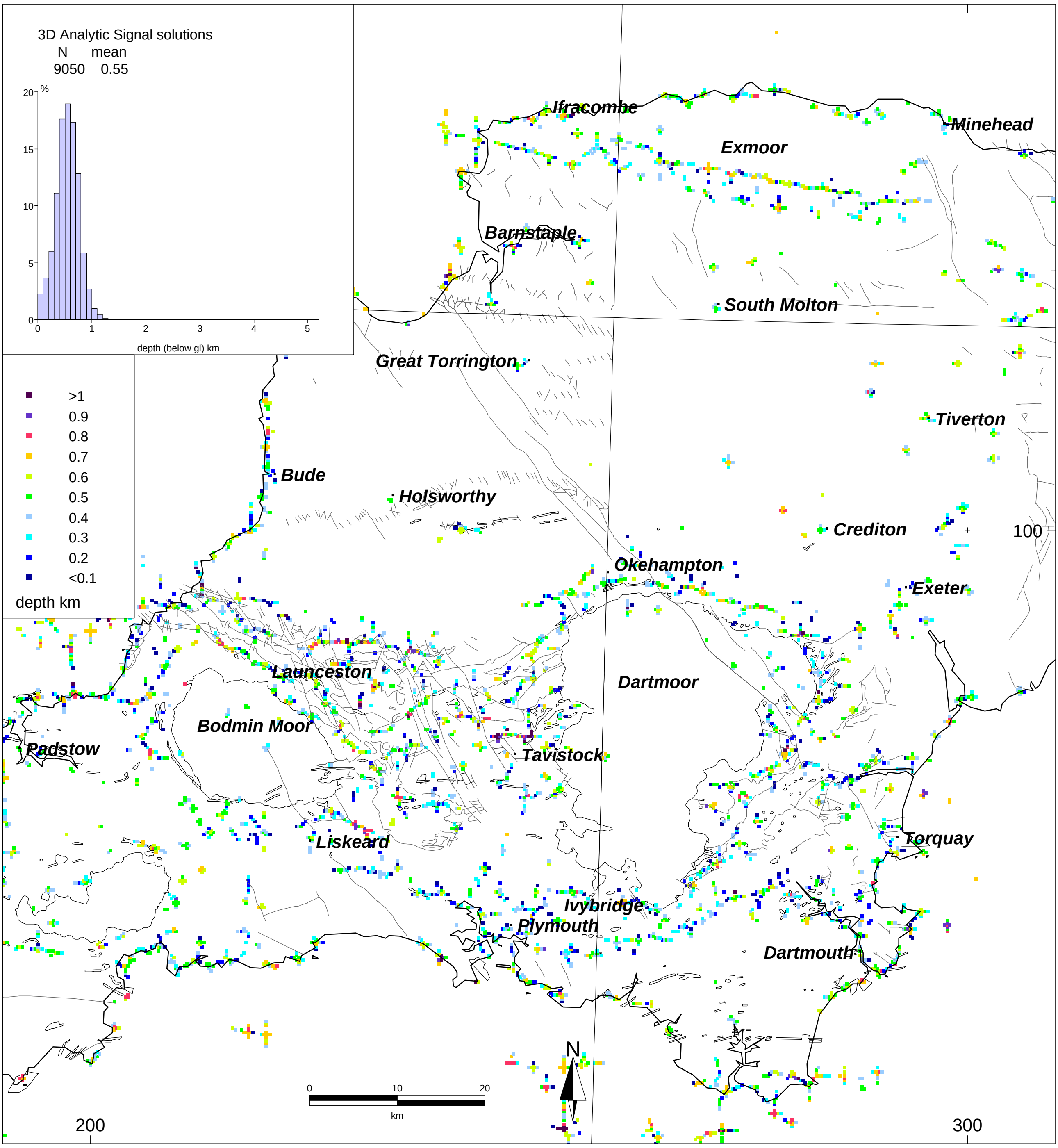

Figure 22 Depth solutions from the analytic signal of the residual magnetic anomaly

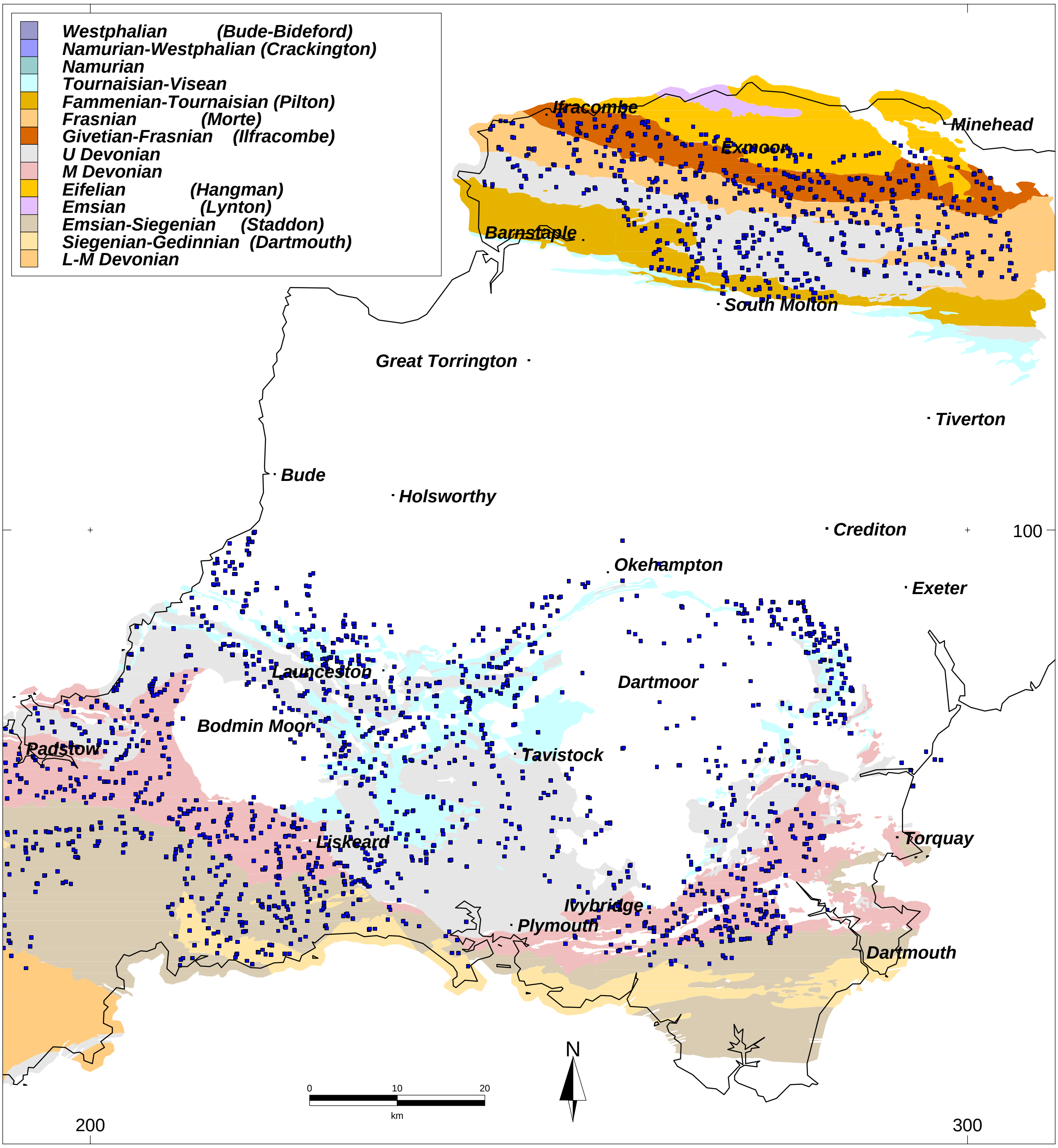

Figure 23 Location of soil and overburden sample sites

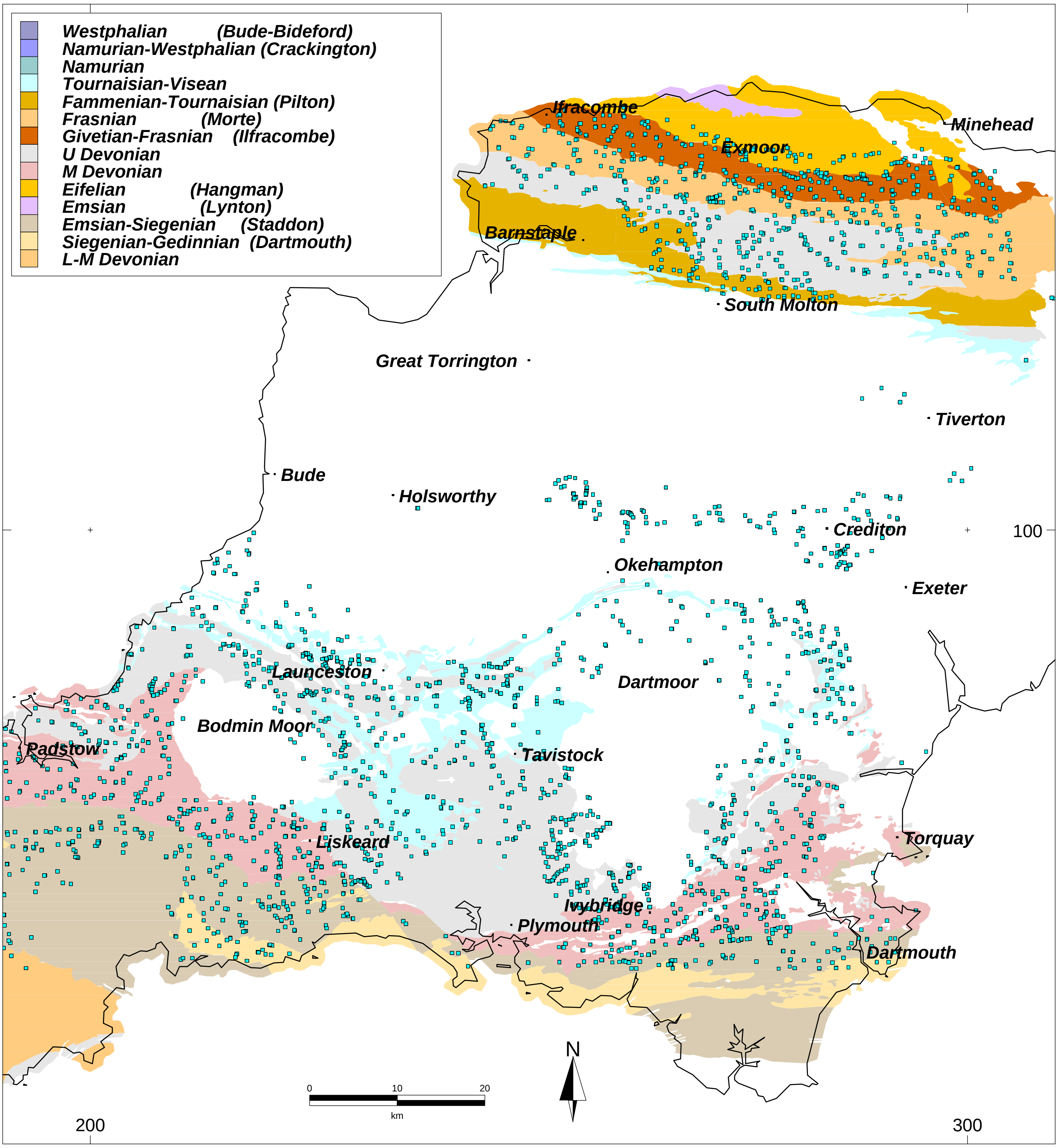

Figure 24 Location of stream-sediment sample sites

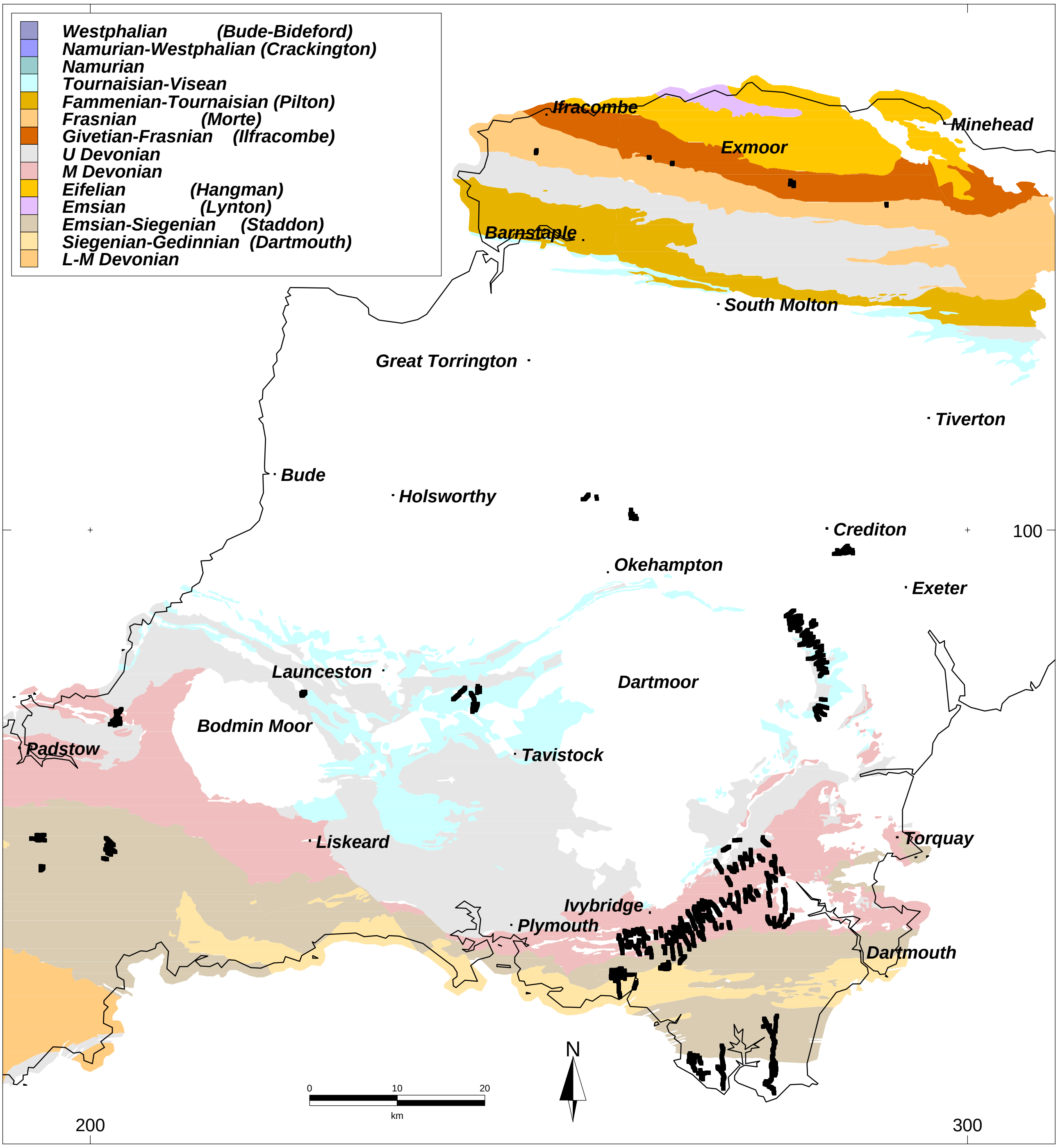

Figure 25 Location of panned-concentrate sample sites

Table 13 Summary statistics for stream-sediment geochemical data from the study area (all values in ppm)

Element	n	minimum	maximum	mean	median	75%	90%	95%
Ag	420	1	30	2	1	1	2	4
As	825	1	30000	192	40	90	140	320
B	630	10	10000	841	180	823	2400	3200
Ba	2752	8	56000	401	327	420	560	697
Be	682	1	130	8	4	8	18	24
Bi	84	1	420	25	6	10	13	75
Co	2674	1	750	26	19	28	42	56
Cr	2639	8	2400	132	114	148	215	245
Cu	2782	2	15000	61	20	30	60	95
Fe	2791	7822	420000	44794	41820	52486	68765	75000
Mn	2790	16	130000	1909	1186	1990	3339	5600
Mo	1083	1	130	2	2	2	4	6
Nb	653	2	240	36	23	56	56	82
Ni	2795	2	420	60	56	75	100	109
Pb	2795	5	11700	93	40	50	90	140
Rb	8	81	196	115	93	137	142	142
Sb	23	4	20	12	10	13	15	20
Sn	2914	1	11663	636	32	279	1800	4200
U	2351	0	2077	5	3	3	5	9
V	2024	7	934	122	110	144	180	240
W	114	1	3500	128	15	40	150	250
Y	1345	4	307	39	30	54	77	95
Zn	2797	10	18600	193	140	190	290	400
Zr	2654	18	10000	390	301	425	605	753

Histograms and log-probability plots of the data indicate multi-modal distributions reflecting the populations from various lithologies, mineralisation and contamination. In order to assess the variation in stream-sediment data related to lithology/stratigraphy, the dataset has been divided according to the main stratigraphical intervals or formations of interest to this study (Table 14). It is evident that for the available data coverage the background (median) values of Pb and Zn are similar in all four groups. In contrast, background values for Cu and Mn in the Lower Carboniferous rocks are much higher than in the other groups. This has been taken into account in the prospectivity analysis by adjustment of the threshold (95% values) values for Cu, Pb and Zn in stream-sediment samples collected over Lower Carboniferous rocks.

Table 14 Summary statistics for stream-sediment geochemical data within the main target formations in the study area (all values in ppm)

	element	n	minimum	maximum	mean	median	75%	90%	95%
Middle Devonian	Cu	947	5	7000	54	20	30	50	100
	Pb	946	10	9500	83	40	60	90	140
	Zn	948	10	18600	193	130	190	280	380
	Mn	943	100	18000	1222	869	1314	2400	3200
Ilfracombe Beds	Cu	194	5	80	20	20	20	25	35
	Pb	195	10	460	48	40	50	70	90
	Zn	195	70	1700	207	160	230	330	400
	Mn	195	192	7729	1550	1093	1508	2880	4652
Morte Slates	Cu	220	5	70	19	20	25	30	35
	Pb	222	10	140	38	30	40	60	70
	Zn	222	50	590	161	150	180	230	280
	Mn	220	389	16697	1473	1127	1534	2578	3453
Lower Carboniferous	Cu	269	5	3380	106	40	60	105	205
	Pb	269	10	3080	118	50	70	120	270
	Zn	269	10	8000	262	160	240	350	640
	Mn	265	232	32000	3733	2400	4200	7837	10000

The geochemical data for panned-concentrate drainage samples are summarised in Table 15. Elements with the greatest availability (>2800 sites) are As, Ba, Ca, Cu, Fe, Mn, Ni, Pb, Sn, Ti and Zn. Other elements were collected for specific project purposes and accordingly have limited areal distributions and are of less value to the present study.

The distributions of selected elements in stream-sediment and panned-concentrate samples in the target region are shown in Figures 26-37. The distributions of these elements over the four main geological targets of this study are described briefly below.

High values of Ba in stream sediments and panned concentrates occur over the outcrop of Devonian rocks south of Dartmoor (Figures 26 and 27). These may relate to stratiform exhalative mineralisation for which evidence was reported by Leake et al. (1985) and Leake and Norton (1993). High tenor anomalies are also found in the vicinity of Chillaton in the central zone, north-west of Tavistock. In this area Leake et al. (1994) identified weak base-metal anomalies in soils associated with known occurrences of stratiform manganese mineralisation. High Ba values also occur at several sites over the Middle Devonian Hangman Grits near Minehead, around Wiveliscombe [298 129] and Dunster [299 143], close to the Permo-Triassic unconformity. These anomalies occur over a strike length of several kilometres in an area without any record of former mining. Anomalous Ba values are also found near an old baryte working at Wooton Courtenay [294 145], downstream from the Florence iron mine near North Molton.

Copper is enriched in stream sediments from Lower Carboniferous rocks in the Teign valley, in the central area between Bodmin Moor and Dartmoor and along the northern margin of the Bodmin Moor granite (Figure 28). The high Cu values in the Teign valley are associated with anomalous levels of Ba, Pb, Zn and Mn which are related to the known occurrences of vein mineralisation in this area. However it should be noted that Beer et al. (1992) reported minor occurrences of disseminated and stratabound base-metal mineralisation in this area.

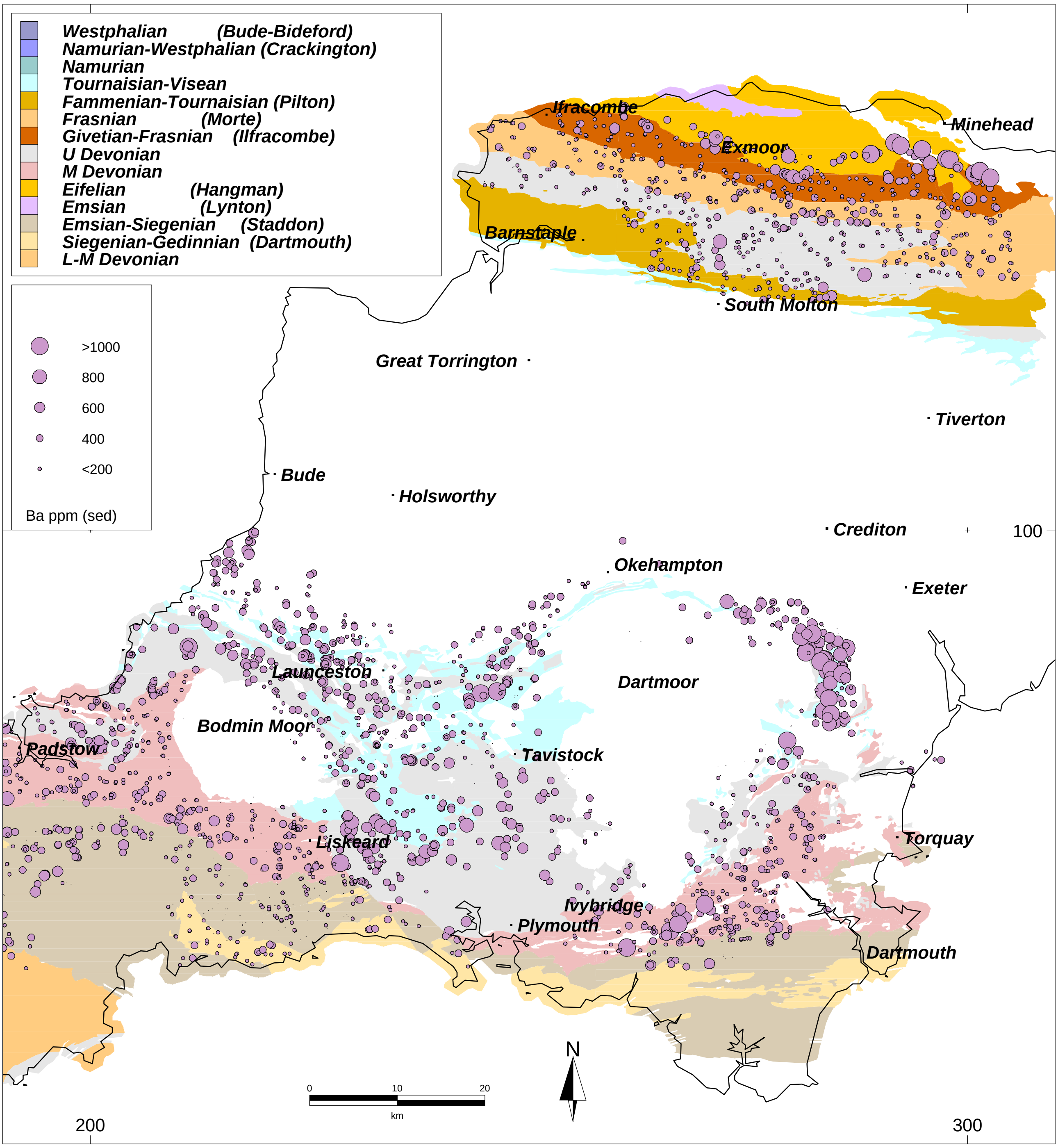

Figure 26 Distribution of Ba in stream-sediment samples

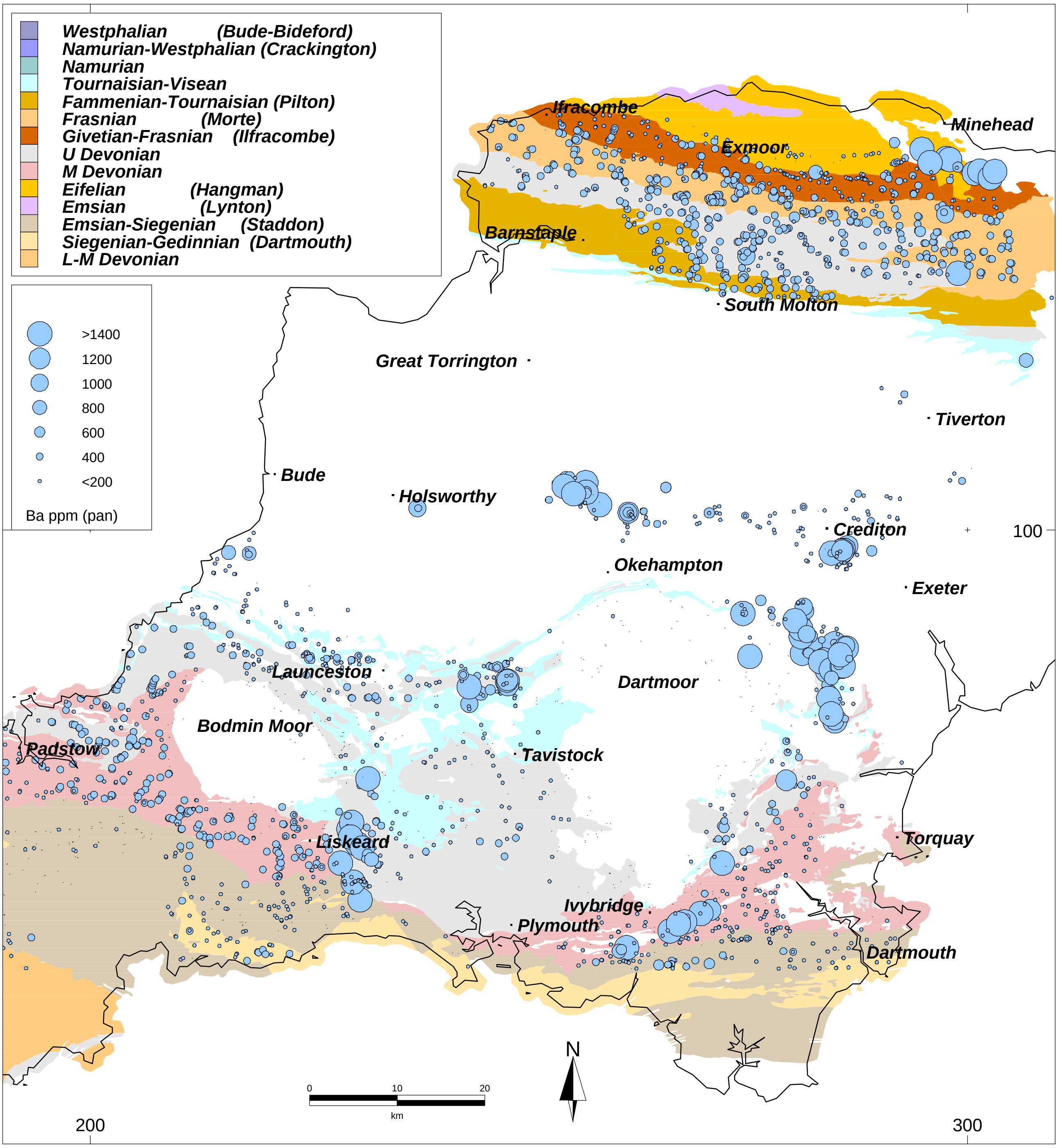

Figure 27 Distribution of Ba in panned-concentrate samples

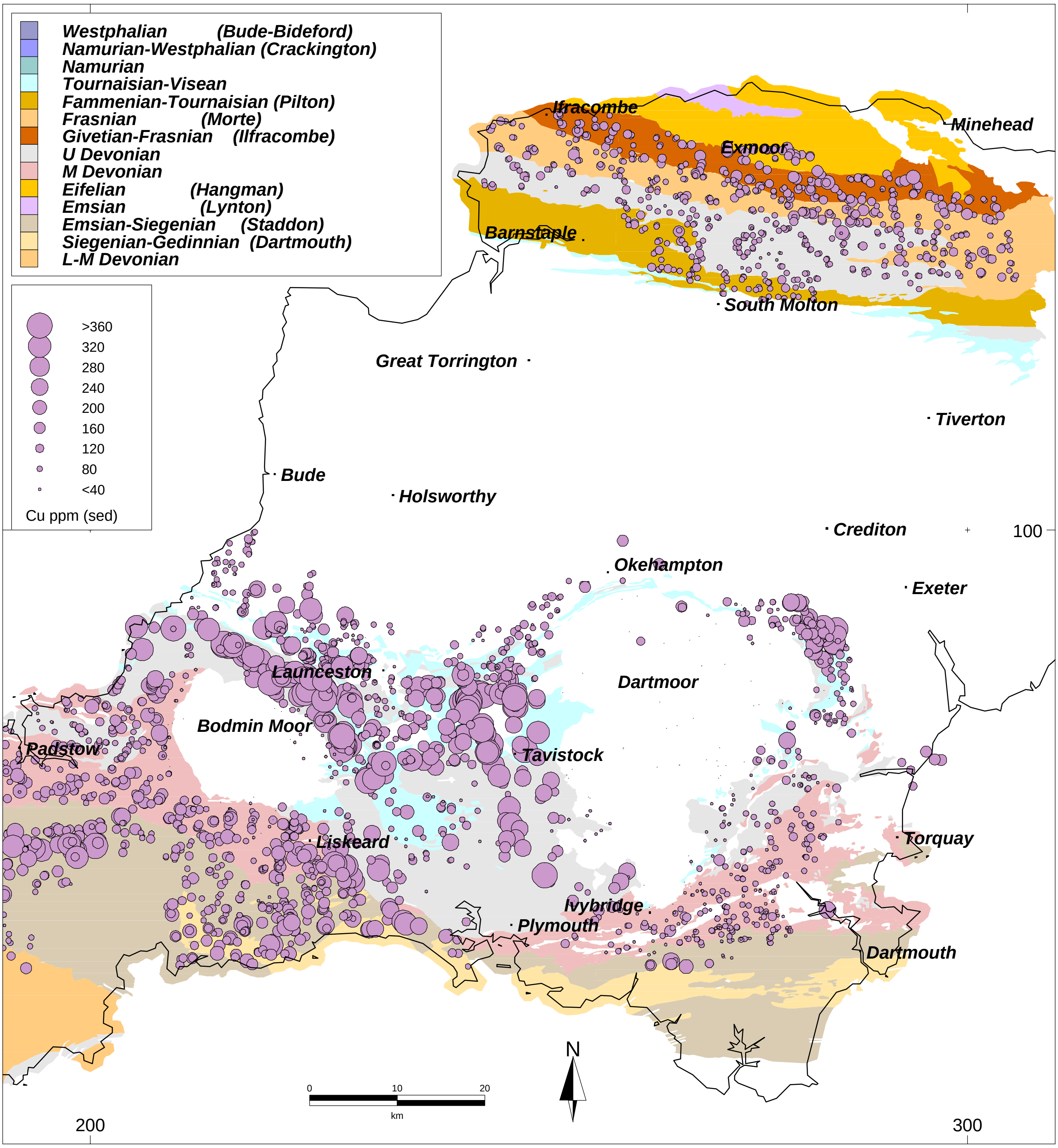

Figure 28 Distribution of Cu in stream-sediment samples

Table 15 Summary statistics for panned-concentrate geochemical data from the study area (all values in ppm)

Element	n	minimum	maximum	mean	median	75%	90%	95%
Ag	604	0	115	8	5	9	15	20
As	3290	1	126000	291	70	140	280	520
Au	69	0	14	1	0	0	1	2
Ba	2819	5	255433	636	312	430	518	591
Bi	217	1	536	10	3	5	15	27
Ca	2833	44	278700	5187	1400	3100	8400	19200
Ce	2476	1	8200	180	65	114	320	670
Co	149	10	390	122	120	160	200	210
Cr	121	58	538	164	150	211	238	260
Cu	3093	1	26500	150	30	55	120	255
Fe	2838	6700	569764	85503	74650	94800	142370	183393
Hg	38	0	2006	69	4	10	45	65
Mn	2828	40	110825	1794	810	1335	2590	4400
Mo	170	1	24	6	5	9	13	15
Nb	185	3	114	14	10	14	22	29
Ni	2978	1	7500	59	51	68	95	120
P	92	44	3317	716	611	873	1004	1047
Pb	3341	1	274000	362	70	130	300	590
Rb	123	32	215	73	69	80	100	110
S	115	106	4761	367	301	377	532	701
Sb	1876	1	5595	24	7	13	25	45
Sn	2945	1	187210	3592	210	1900	9341	21300
Sr	606	5	2818	99	71	102	148	223
Ti	2838	140	236600	6023	4160	5396	9700	16200
U	177	1	53	5	3	5	9	13
V	191	18	551	99	84	109	165	214
W	710	1	143820	1686	55	370	1588	4500
Y	281	7	172	21	18	22	26	47
Zn	3172	15	28400	254	150	214	330	482
Zr	899	10	8573	332	181	299	695	1155

Sporadic high values of Pb occur over Middle Devonian rocks to the south of Dartmoor, to the south-east of Ivybridge, and south-east of Bodmin Moor, around Liskeard (Figures 29 and 30). In the Ivybridge area Leake et al. (1985) reported disseminated sulphide mineralisation in altered Middle Devonian volcanic rocks associated locally with high values of Ba, Cu, Mn and Sb. In the Liskeard area several mines worked lead-silver veins associated with antimony-bearing minerals, bournonite and tetrahedrite. Local Pb anomalies are also found over Upper Devonian–Lower Carboniferous strata on Exmoor. Values over Lower Carboniferous rocks are generally low, with the exception of the Teign valley as noted above.

High concentrations of zinc occur widely on Exmoor (Figures 31 and 32). Sporadic high Zn values occur over the Morte Slates, but the main anomalous zone is close to the base of the Ilfracombe Beds. The anomaly occupies an area in which mining has never been carried out and has a strike length of several kilometres. Sphalerite was also recorded in some panned concentrates from this zone. Jones (1987) also identified widespread Ni enrichment over the Ilfracombe Beds. This could be related to stratiform pyrrhotite-bearing mineralisation which gives rise to the coincident magnetic anomaly. The median Zn content of stream-sediment samples collected over Lower Carboniferous strata is 160 ppm, with high values occurring mainly in the central zone and in the Teign valley. Zinc contents of stream sediments from Middle Devonian rocks on the south side of Dartmoor are generally low.

High Mn values occur over Lower Carboniferous rocks in the Teign valley and in the central zone near Launceston and Tavistock (Figure 33 and 34). Scattered high values are also found in stream sediments and panned concentrates on, and to the south of, Exmoor. The highest levels in concentrates are derived from Upper Devonian strata in the North Molton district where iron-manganese-copper mineralisation was worked or explored at several sites (Cameron and Bland, 1994). Manganese values over Middle Devonian rocks are generally low. The distribution of Co in stream sediments is strongly influenced by hydromorphic effects and hence its distribution pattern is similar to that of Mn.

Most values of Ag in panned concentrates greater than 20 ppm (95th percentile) are found over Carboniferous rocks near Launceston and Tiverton in the central zone

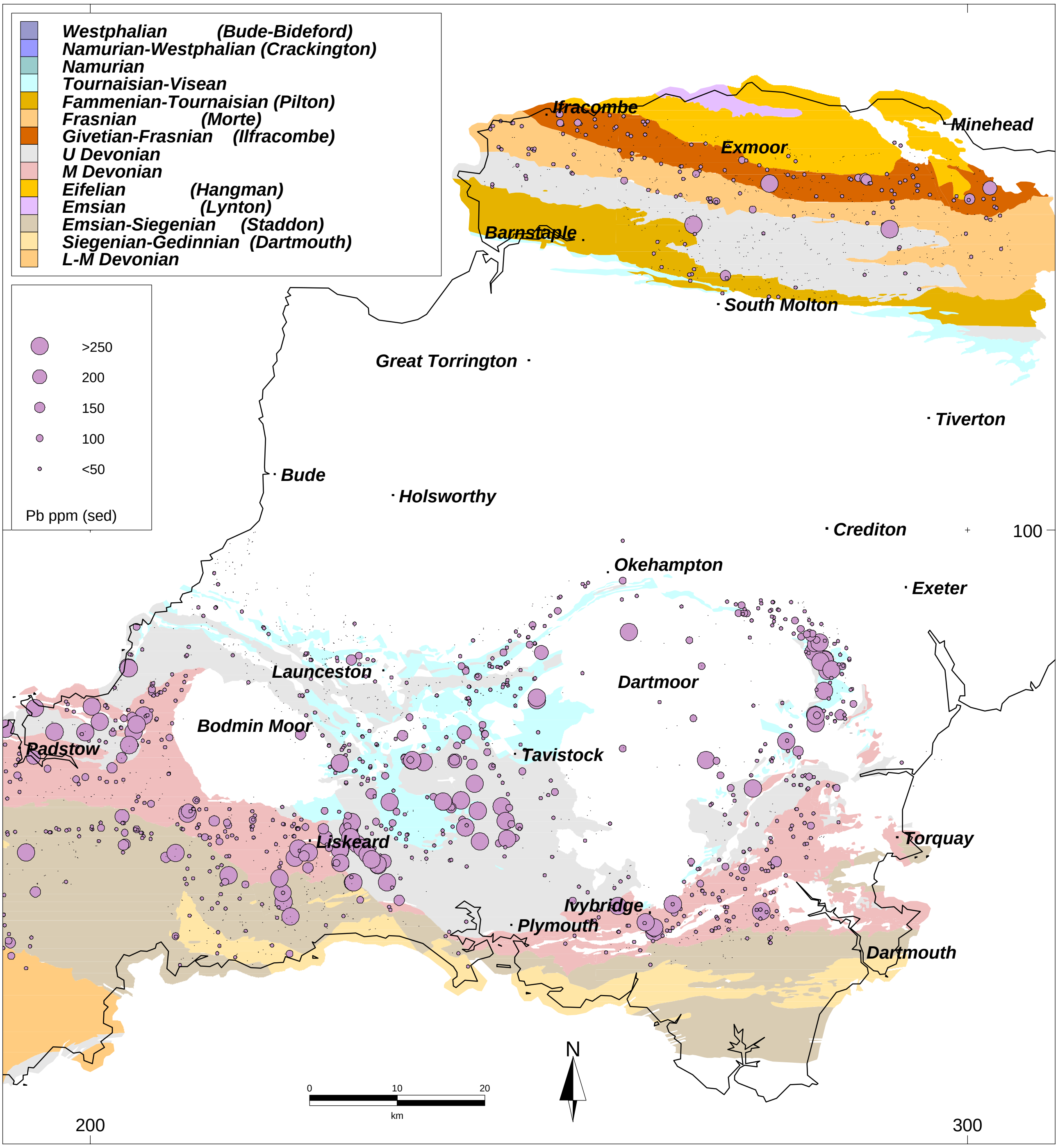

Figure 29 Distribution of Pb in stream-sediment samples

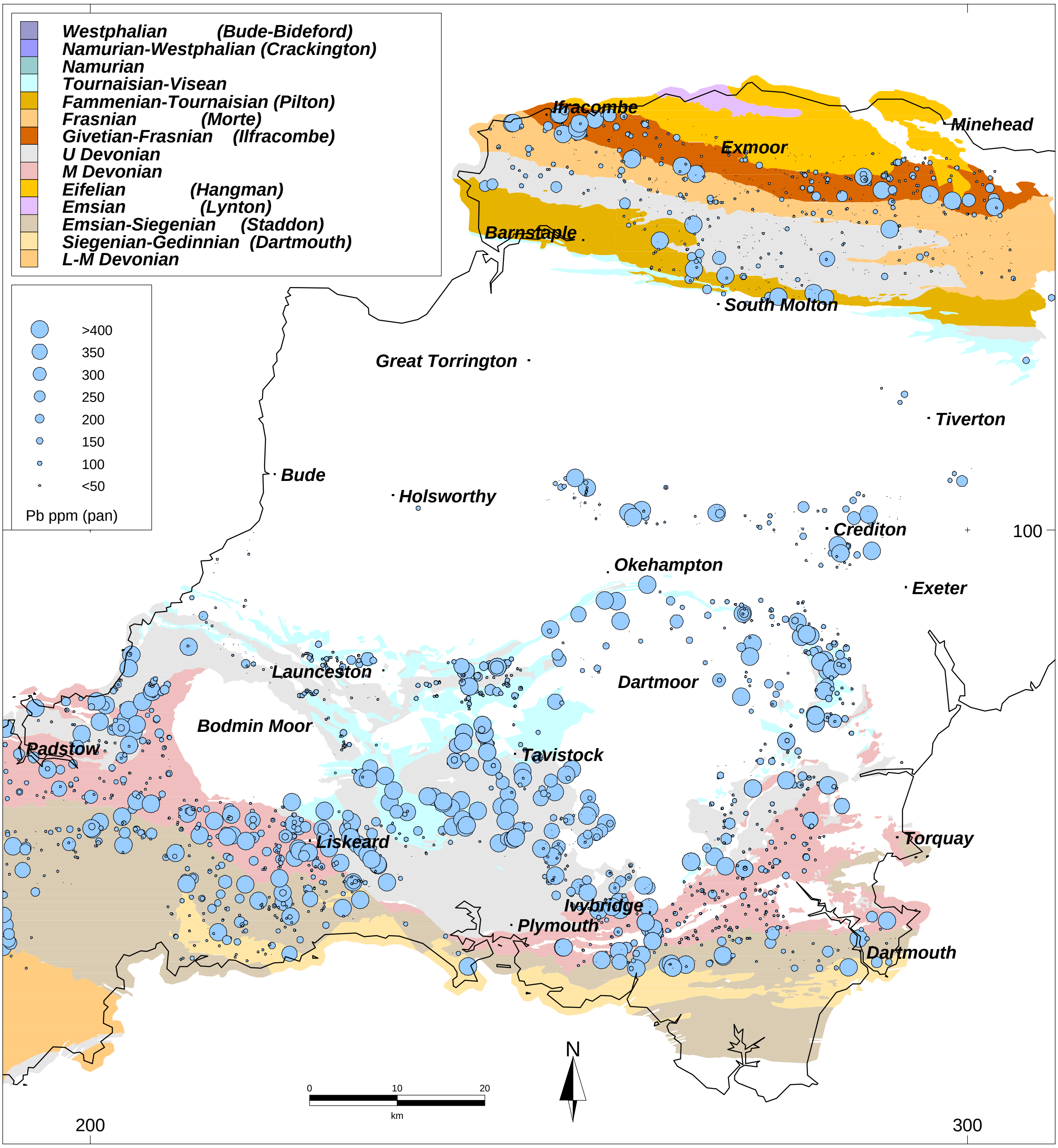

Figure 30 Distribution of Pb in panned-concentrate samples

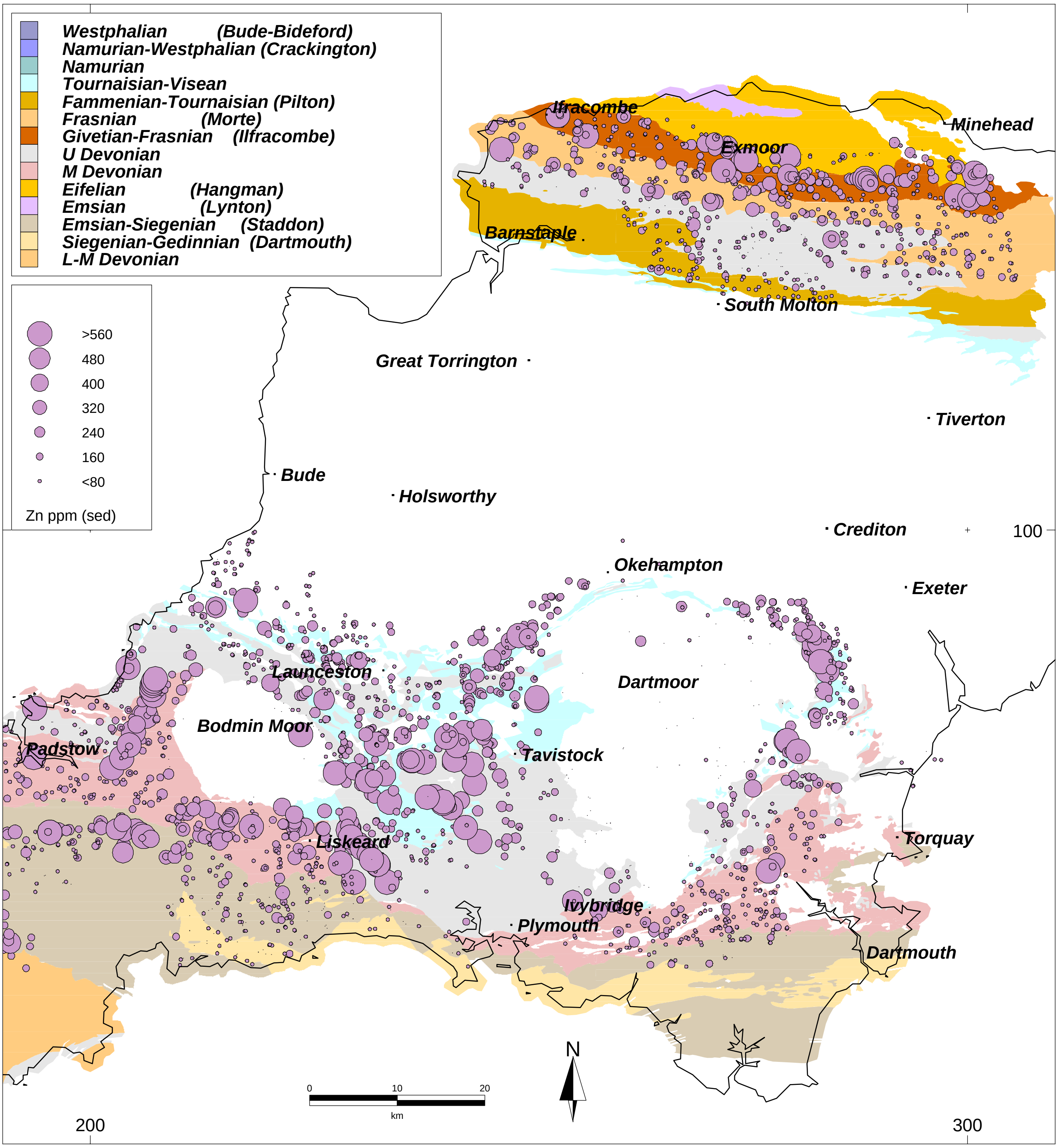

Figure 31 Distribution of Zn in stream-sediment samples

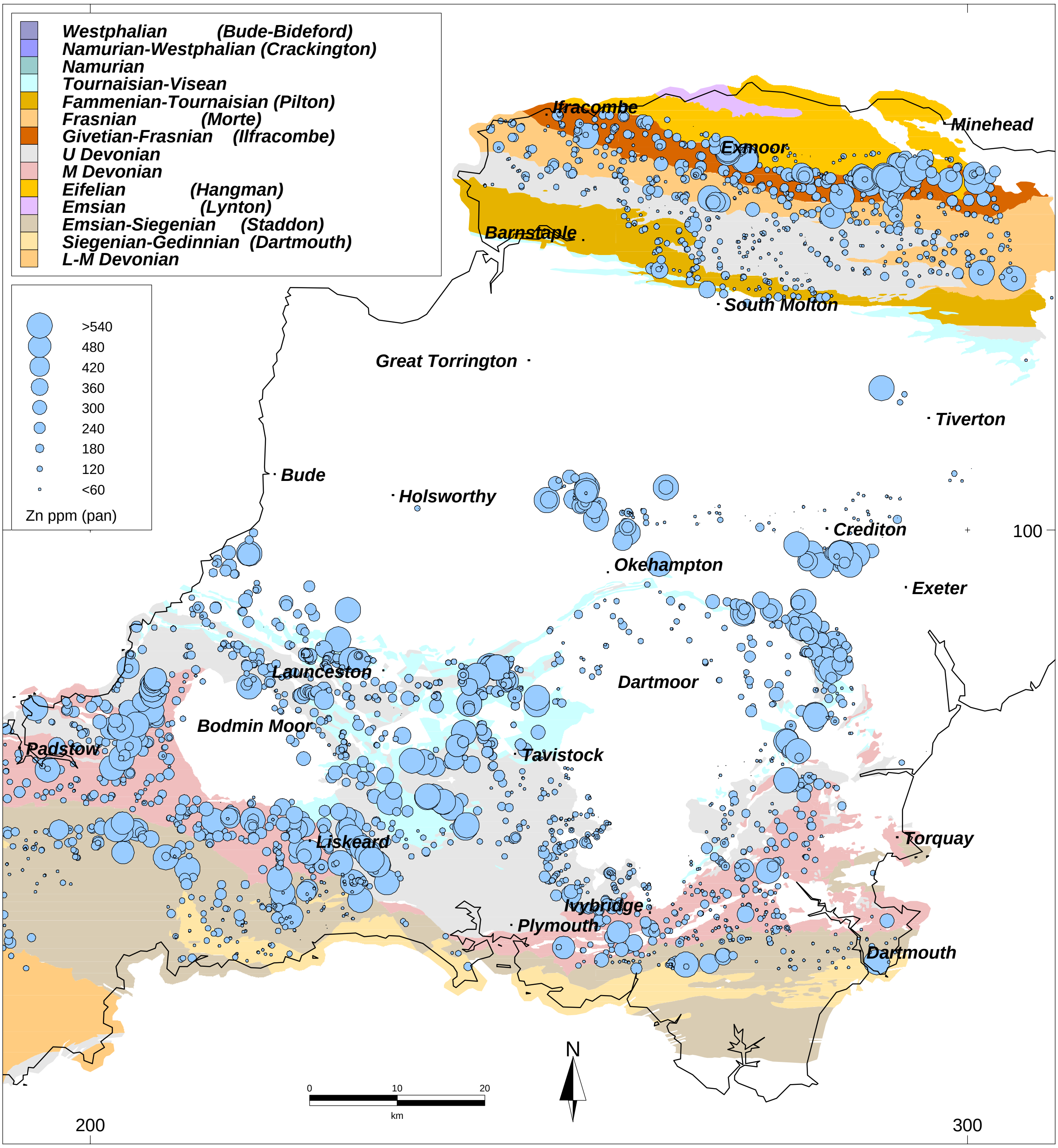

Figure 32 Distribution of Zn in panned-concentrate samples

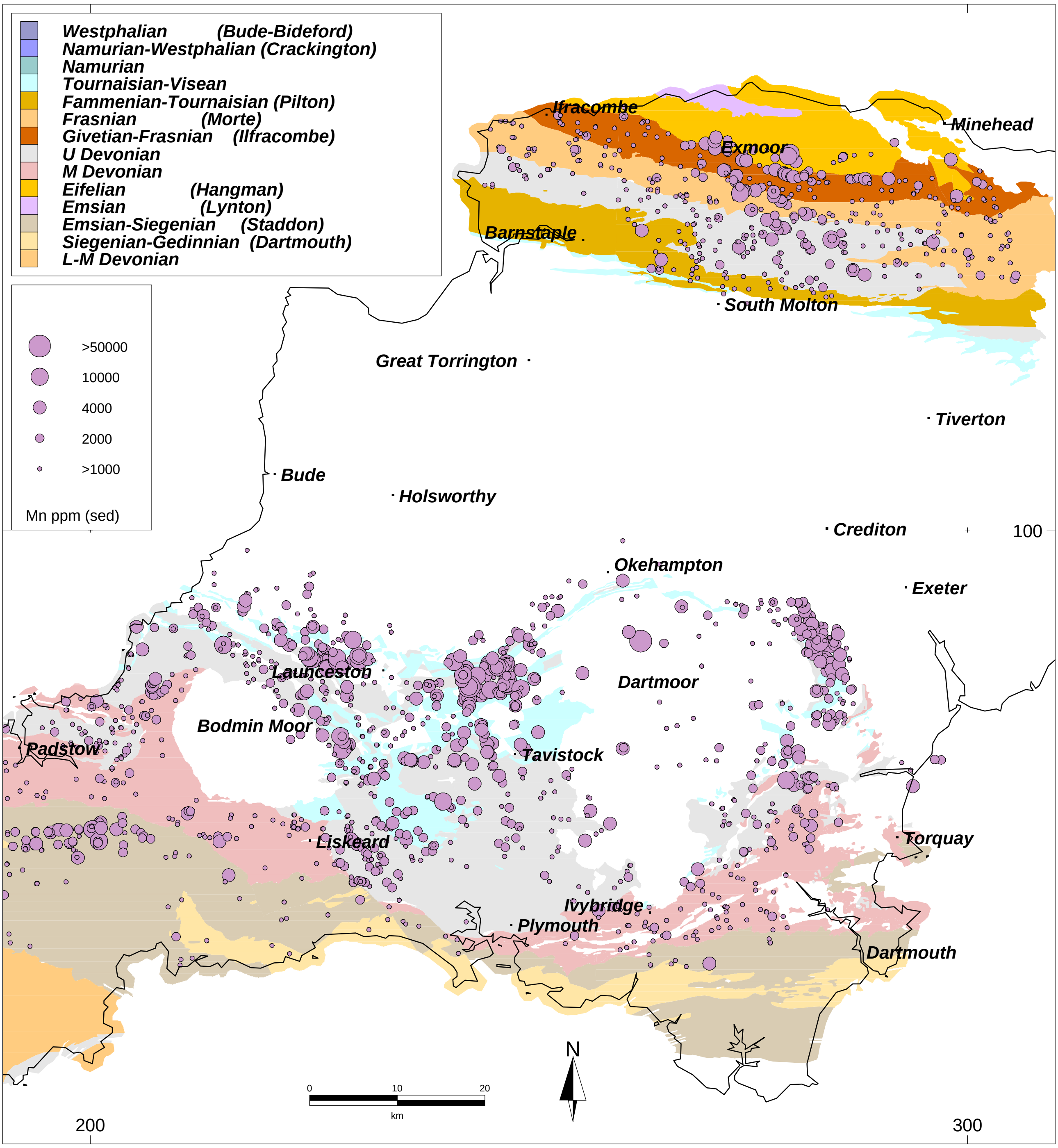

Figure 33 Distribution of Mn in stream-sediment samples

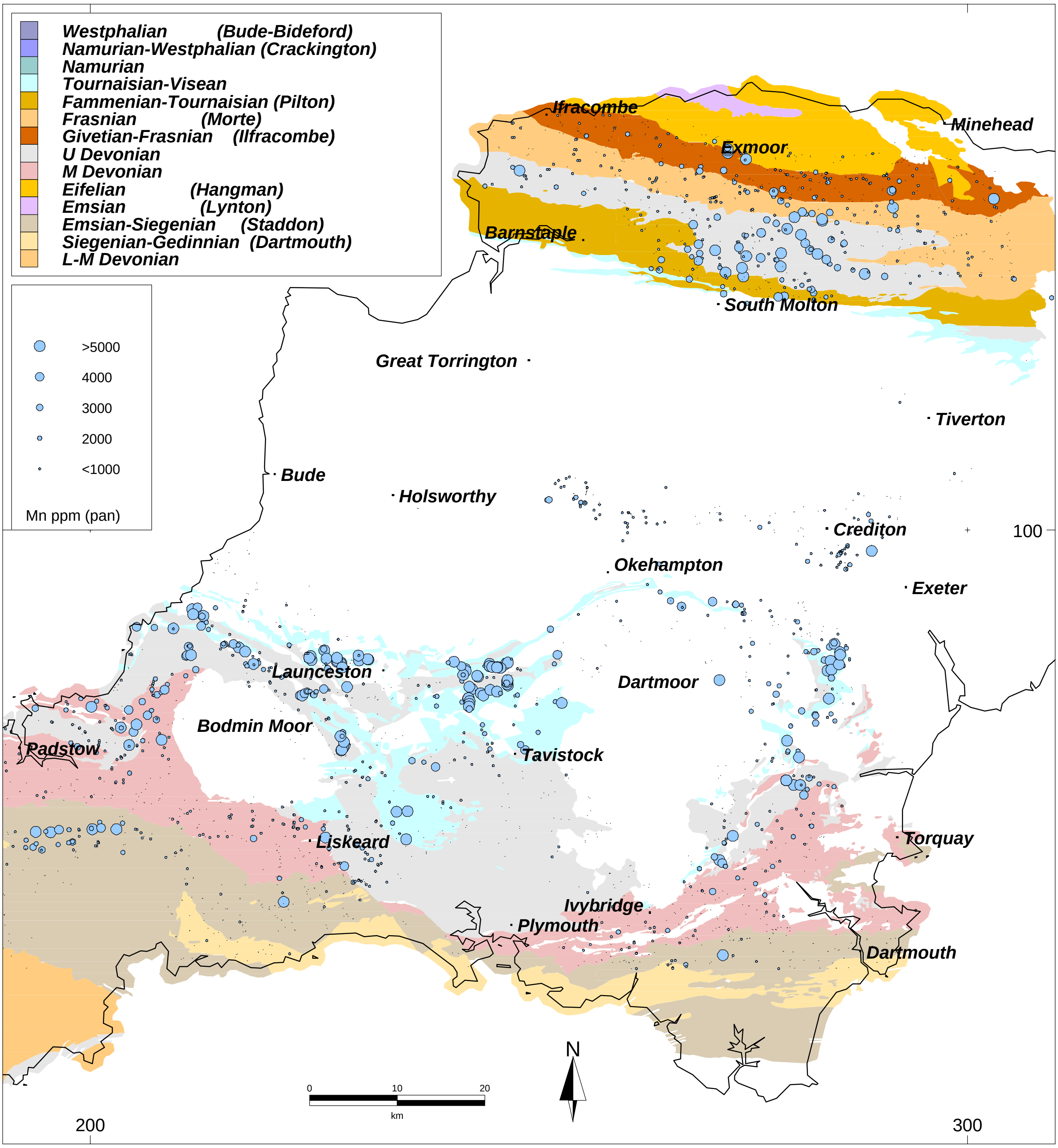

Figure 34 Distribution of Mn in panned-concentrate samples

(Figure 35). Silver data are not available for panned-concentrate samples from Exmoor.

The distribution patterns of As and Sb in panned concentrates are generally similar (Figures 36 and 37), although As data are not available for north Devon. Areas of high values occur around Ivybridge, Liskeard and Padstow associated with Middle Devonian volcanic rocks (Leake et al., 1985, 1989). The anomalies near Padstow, between Wadebridge and Port Isaac, are related to lead- and antimony-rich lodes which previously supported small-scale mining. Disseminated and stratiform sulphide mineralisation with antimony sulphosalts are also noted in Lower Carboniferous black shales and tuffs in this area (Clayton and Spiro, 2000). In north Devon there is a cluster of high Sb values to the south of Exmoor, especially around the villages of Twitchen and Molland. Jones (1987) suggests that these anomalies may relate to undiscovered mineralisation.

7.5 MINERAL OCCURRENCES

The majority of mineral occurrences in south-west England comprise mines and trials on granite-related hydrothermal lodes. Dines (1956) subdivided the south-west England mining district into 14 regions. The present study covers part of six of these regions and includes about 470 mines (Table 16).

Dines (1956) gives details of shafts, adits levels, main ore products and outputs although for many mines these data are incomplete and not verified. Furthermore the accurate locations of the mines are not provided as grid or geographic coordinates. For the purposes of this study the positional information has been taken from Burt et al. (1984, 1987) and from BGS records. For the study region a total of 1209 mines and trials was compiled, although not all records have a reliable British National Grid reference or in some cases a main commodity. In most instances the mine locations with incomplete data are found to be alternative names, or names of individual prospects within a mine or working already recorded. The locations of the known mineral workings are shown in Figure 38. This dataset has formed the basis of the record of mineral occurrences and is listed in Appendix 4.

Table 16 Numbers of mines in the mining districts of the target region

Mining Region (Dines, 1956)	Mines
Wadebridge	40
Liskeard and Bodmin	103
Callington and Tavistock	202
Dartmoor and Teign valley	71
Okehampton	20
Devon and Somerset	32

The majority of the mine workings referred to in Dines (1956) have been identified as lode or vein occurrences, while the others been recorded as stratiform, pod, stockwork and occasionally stratabound or replacement. For this study all mineral occurrences and deposits where stratiform mineralisation is interpreted to occur have been compiled on the basis of recent mapping, historical records, MEIGA data, drilling results and the records presented in Dines (1956) (Table 17). The locations of these sites are shown in Figure 39.

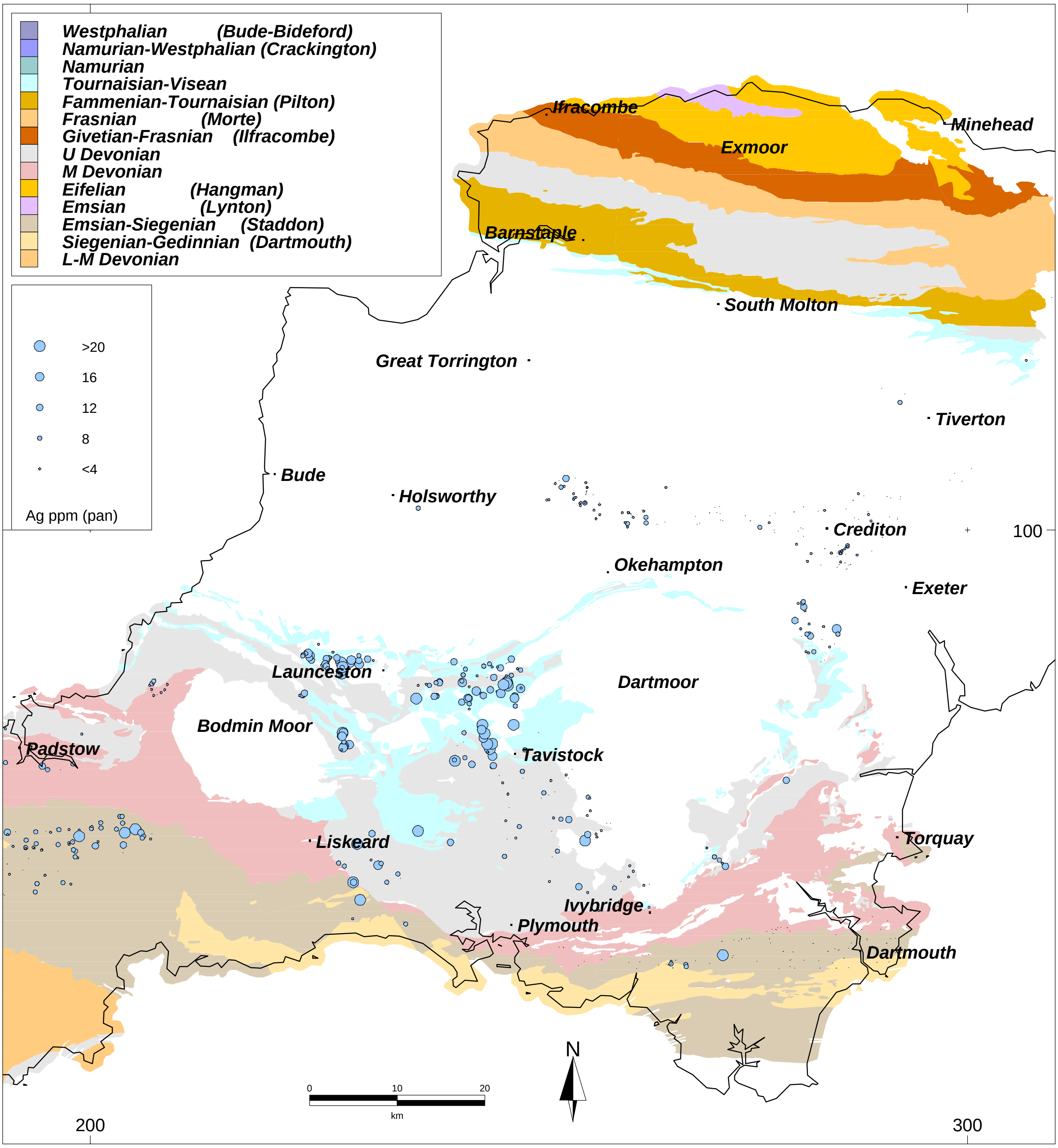

Figure 35 Distribution of Ag in panned-concentrate samples

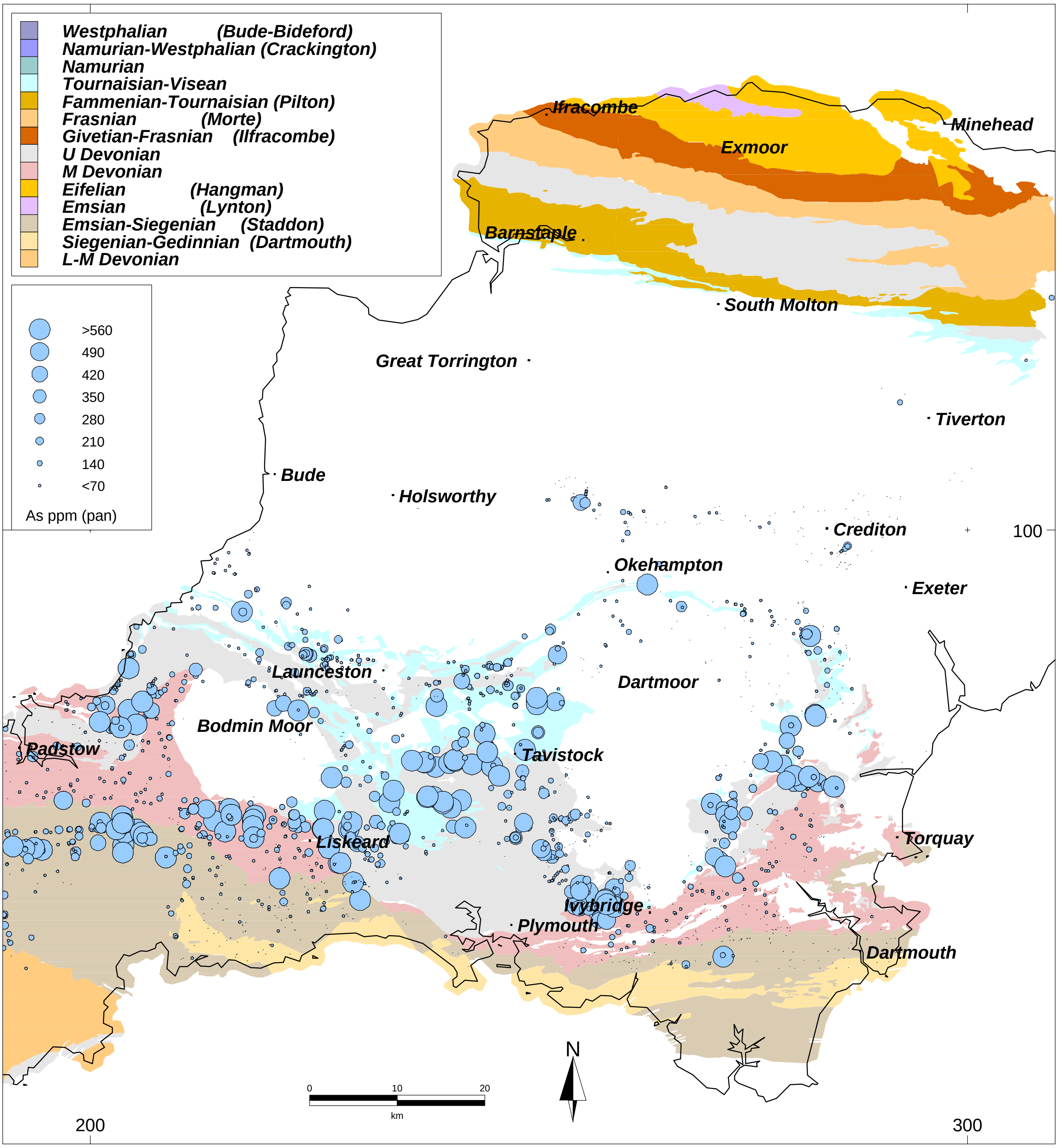

Figure 36 Distribution of As in panned-concentrate samples

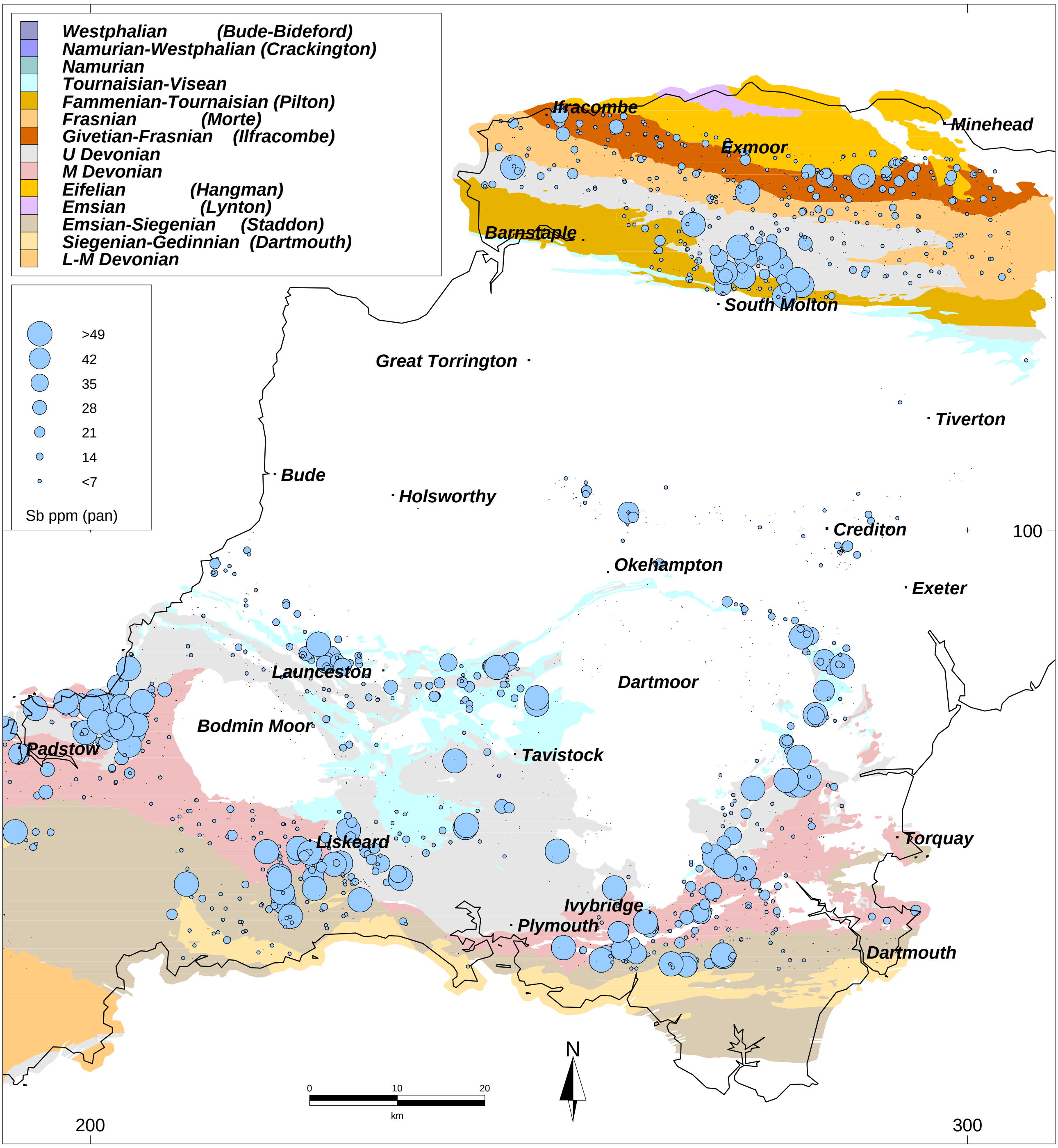

Figure 37 Distribution of Sb in panned-concentrate samples

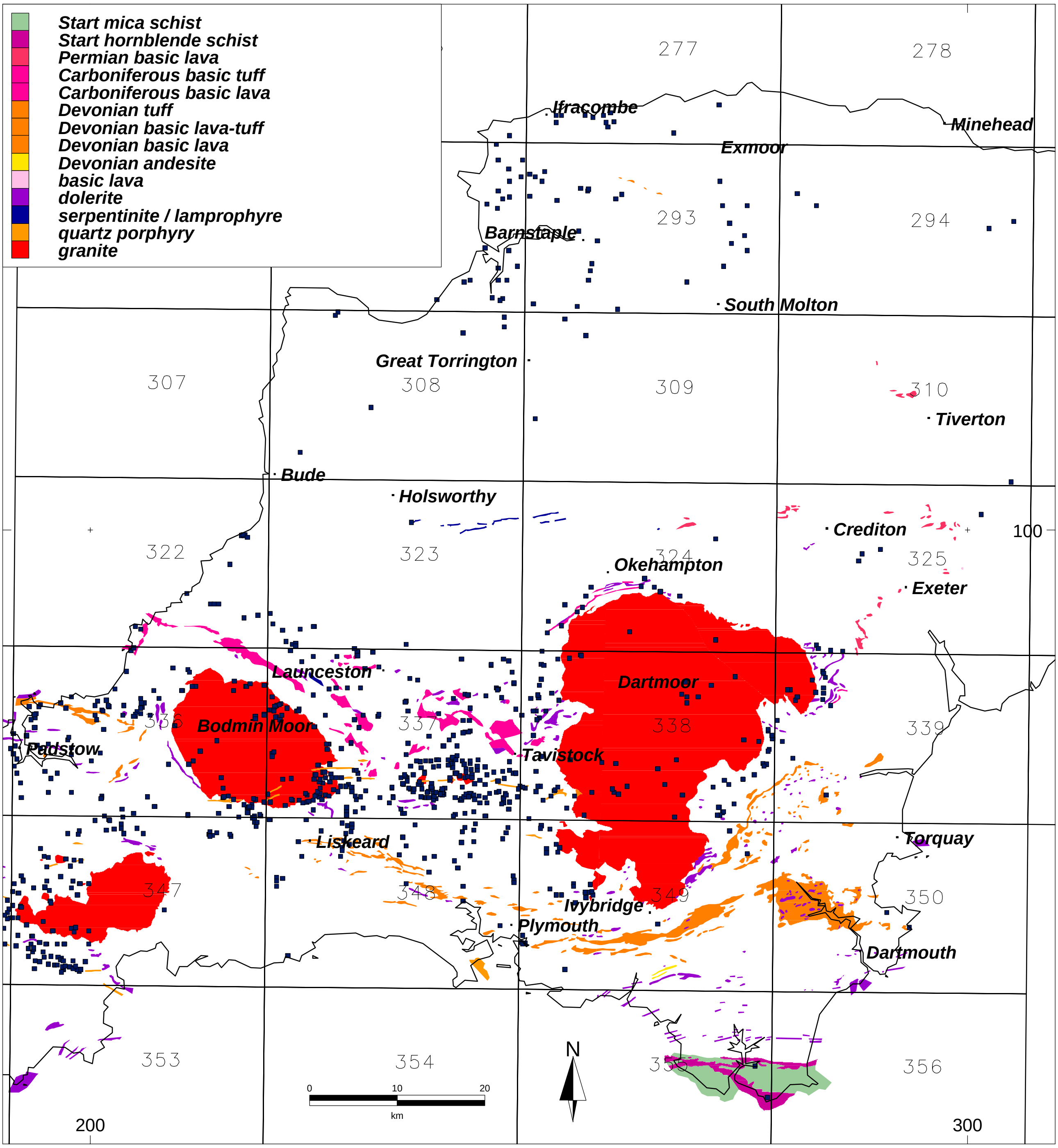

Figure 38 Location of mine workings and trials (shown as squares; listed in Appendix 4)

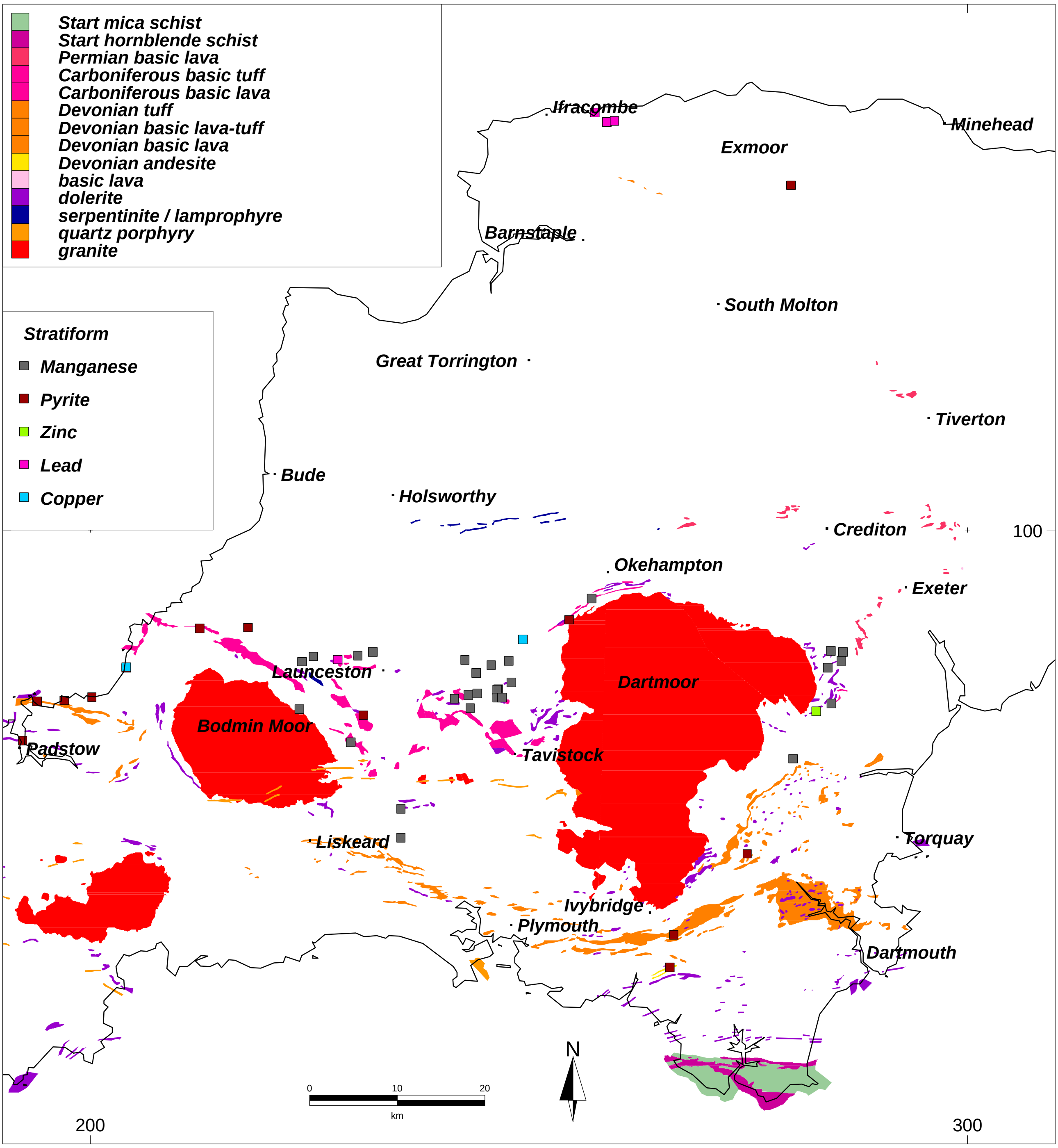

Figure 39 Location of known occurrences of stratiform mineralisation indicating the main metals present

Table 17 Stratiform metal deposits in the target region

Deposit Name	National Grid Easting	National Grid Northing	Stratigraphy	Major ore elements (minor ore elements)	Remarks	Source
Lester Point	25750	14761	IFS	Pb (Zn,Cu)	Sulphides+FeCarb in slate	Edmonds et al., 1985
Combe Martin Mine	25889	14654	IFS	Pb (Zn,Cu)	Sulphides+FeCarb in slate	Edmonds et al., 1985
Knap Down Mine	25975	14667	IFS	Pb (Zn,Cu)	Sulphides+FeCarb in slate	Edmonds et al., 1985
Honeymead No.1 BH	27989	13935	IFS	Fe	Disseminated py+pyh	Jones et al., 1987
Honeymead No.2 BH	27990	13934	IFS	Fe	Disseminated py+pyh	Jones et al., 1987
Buckingham Mine	31741	14026	IFS	Cu (Pb)	Sulphides in limestone	Edmonds, 1985
Currypool Fm BH	32270	13871	IFS	Fe (Cu,Pb)	Minor sulphides in slate	BGS records
Tregardock Beach	20408	8428	BNF	Fe (Cu,Zn)	Minor sulphides in black slate	Selwood, 1998
Tregardock Beach	20408	8440	BNF	Cu (Sb,Ag)	Tetrahedrite in tuff	Selwood, 1998
Halwill Barton BH	21245	8879	BNF	Fe (As,Cu)	Minor sulphides in black slate	McKeown et al., 1973
Wilsey Down BH	21797	8890	FCF	Fe (As,Zn)	Disseminated py+pyh+apy in slate	McKeown et al., 1973
Sourton Tors BHs	25456	8979	MCF	Fe (Cu,As)	Py+pyh+minor Sulphides in slate	Beer and Fenning, 1976
Teign Valley BH G2	28275	7935	CMSH	Zn (Pb,Cu)	Sulphides in shale	Beer et al., 1992
Treburland Mine	22380	7960	SBT	Mn	Stratiform Mn Carb+sil+oxides (skarn)	Dines, 1956
Tremollett Mine	22970	7580	TVF	Mn	Stratiform Mn Carb+sil+oxides (skarn)	Dines, 1956
Halwill	23110	7890	FCF	Fe	Ochre altered stratiform carb/Sulphides	Dines, 1956
Larrick	23110	7890	FCF	Fe	Ochre ?altered stratiform carb/Sulphides	Dines, 1956
Lidcott	22410	8500	BKF	Mn (Pb,Fe)	Stratiform Mn carb+sil+oxides	Dines, 1956
Lewannick	ukn	ukn		Mn	possibly a vein of ankerite	Dines, 1956
Westdownend	22540	8560	FCF	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Truscott	23050	8570	FCF	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
St Stephen	23220	8610	FCF	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Wooladon	ukn	ukn		Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Allerford	24270	8520	FCF	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Lewtrenchard	24570	8460	FCF	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Coryton	24770	8510	FCF	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Sydenham & Lee Wood	24400	8370	FCF	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956

Deposit Name	National Grid Easting	National Grid Northing	Stratigraphy	Major ore elements (minor ore elements)	Remarks	Source
West of England	24800	8265	LYDD	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Lifton	ukn	ukn		Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Greystone Wood	23620	7940		Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Edgecumbe	23970	7910		Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Chillaton & Hogstor	24310	8120	GSTN	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Quither	24410	8140	LYDD	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Bowden Common	24650	8190	GSTN	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Whitstone	24640	8180	GSTN	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Westcott	24640	8090	GSTN	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Monkstone	24690	8090	GSTN	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Ramsdown	24150	8080	GSTN	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Cardwell	24330	7970	GSTN	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Pencrebar	23540	6820	NCH	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Torwood	23539	6492	NCH	Mn	Stratiform Mn carb+sil+oxides	Dines, 1956
Meldon Quarry	25715	9220	MCF	Mn	Stratiform Mn Carb+sil+oxides (skarn)	Edmonds et al., 1968
Scanniclift Copse Mine	28442	8624	TCH	Mn	Stratiform Mn carb+sil+oxides	Edwards and Scrivener 2000
Harehill Plantation	28582	8613	TCH	Mn	Stratiform Mn carb+sil+oxides	Edwards and Scrivener 2000
Ashton Mine	28562	8510	TCH	Mn	Stratiform Mn carb+sil+oxides	Selwood, 1984
Hill Copse Mine	28406	8433	TCH	Mn	Stratiform Mn carb+sil+oxides	Selwood, 1984
Riley Mine	28448	8024	TCH	Mn	Stratiform Mn carb+sil+oxides	Selwood, 1984
Stancombe Mine	28013	7393	TCH	Mn	Stratiform Mn carb+sil+oxides	Selwood, 1984
Portquin	19703	8058	TVS	Fe	Early volc-related sulphides	Selwood et al., 1998
Port Gaverne	20015	8095	TVS	Fe	Early volc-related sulphides	Selwood et al., 1998
Com Head	19388	8050	TVS	Fe (Cu,Zn)	Massive pyrite layer	Selwood et al., 1998
St Saviours Point	19225	7600	TVS	Fe (Cu,Zn)	Massive pyrite layers	Selwood et al., 1998
Bulkamore Mine	27490	6310	MDVS	Fe	Py+mag volc-related	Dines, 1956
Ladywell	26921	5681	Mdev	Sb (Zn)	Sulphides in dark slate	Leake and Norton, 1993

Deposit Name	National Grid Easting	National Grid Northing	Stratigraphy	Major ore elements (minor ore elements)	Remarks	Source
Higher Ludbrook	26651	5385	Mdev	Fe (Zn)	Ankeritic carbonate over massive pyrite (cpy) and tuffs	Leake et al 1985
Burraton	26140	5270	Mdev	Ba	Baryte-quartz with tuff	Leake et al., 1985
Whympston	26605	5016	Ldev	Fe, Cu, Pb	Minor sulphide (py cpy) in felsic volcanic	Leake et al., 1992
Egloskerry	22819	8524	LCarb	Pb,Fe,Zn	4.5m stratiform fine-grained galena in siltstone faulted on black shales	BGS records
Bridestowe	24932	8756	LCarb	Cu,Pb,Zn	disseminated pyrite in mudstone-cherts traces of galena sphalerite	BGS records

Formation Abbreviations:

BNF, Barras Nose Formation; IFS, Ilfracombe Slate; GSTN, Greystone Formation; LYDD, Lydford Formation; MCH, Meldon Chert Formation; TCH, Teign Chert Formation; FCF, Fire Beacon Chert Formation; TVS, Tintagel Volcanic Formation; MDVS, Mid-Devonian Volcanic Formation; NCH, Newton Chert Formation; Mdev, Middle Devonian; Ldev, Lower Devonian; Lcarb, Lower Carboniferous

Other abbreviations: ukn, National Grid Reference not known

Carb, carbonates; sil silica; py, pyrite; pyh, pyrrhotite; cpy, chalcopyrite; apy, arsenopyrite; mag, magnetite

Mine workings and mineral occurrence data have been incorporated into the prospectivity analysis in two ways. Firstly, many of the manganese mines represent stratiform deposition of oxide ores which may be lateral equivalents of base-metal sulphide deposits. Accordingly, in addition to known occurrences of stratiform base-metal mineralisation, the presence of manganese mineralisation has been used as a positive evidence to support the potential occurrence of sulphide ores. Secondly, the mine list provides evidence for the occurrence of various metals in hydrothermal vein systems. These data have been used to filter the drainage geochemical data in an attempt to remove the influence of vein mineralisation. In practice, geochemical anomalies for Cu, Zn and Pb have been excluded from the prospectivity analysis if the sample site is located within 2 km of a mine working which records one or more of these elements as either a main or secondary commodity.

8 Results of prospectivity analysis

8.1 TARGET MINERALISATION

By analogy with the geological setting of massive sulphide mineralisation elsewhere in the Variscan orogenic belt of Europe and on the basis of known mineralisation, the target region in south-west England is considered to be prospective for the following deposit types:

1. stratiform massive sulphides associated with the Middle to Late Devonian sedimentary and volcanic rocks.
2. sediment-hosted massive sulphides associated with the Late Devonian–Early Carboniferous sequence.

These may be similar to SHMS deposits found in the Iberian Pyrite Belt (IPB-type) or to the polymetallic SHMS deposits in the Harz Massif in Germany. Alternatively they may have characteristics of SEDEX deposit types related to volcanic activity in the Middle Devonian.

Prospectivity has been assessed across the region for stratiform sulphide deposits within the likely host formations in the Devonian and Carboniferous sequence. This includes aspects of both SEDEX deposits associated with volcanic activity in the Middle Devonian in south Devon; SHMS deposits associated with the Lower Carboniferous rocks north of Dartmoor and Bodmin Moor and SHMS deposits within the Middle–Upper Devonian rocks of Exmoor.

8.2 EXPLORATION CRITERIA

Assessment of the potential in the study region for the discovery of new sub-surface stratiform sulphide mineralisation is a challenging task. Parameters which can be related to key exploration criteria may not be available for the region, or, if they are, they may not be of appropriate quality or extend over sufficiently large areas to be useful in this analysis. There is also considerable commercial exploration data that has not been included in this study either because it is not in the public domain or because of its local nature.

Taking into consideration properties of the target mineralisation derived from published models and the particular features of the known occurrences in the study region, the following key parameters were used in the prospectivity analysis:

1. Record of stratiform sulphide mineralisation
2. Presence of Middle Devonian volcanic rocks
3. Presence of Middle–Upper Devonian slates
4. Presence of Lower Carboniferous spilites
5. Incidence of Variscan thrusts and slides
6. High-frequency magnetic anomalies reflecting pyrrhotite derived from stratiform pyrite.
7. Presence of anomalous levels of Cu, Pb, Zn in stream sediment and Mn, Ba, Ag Sb and As in panned concentrate data
8. Presence of positive residual gravity anomalies.

These parameters were translated into exploration criteria used in the prospectivity analysis (Table 18). Geochemical threshold values were set at the 95 percentile value of the total population, although, as discussed previously, in order to reduce the influence of the widespread vein mineralisation, anomalous values within 2 km of known mine occurrences were removed from the analysis. Stream sediment data for Cu, Pb, Zn on Lower Carboniferous sediments and lavas were considered in the analysis at threshold values set at the 95% level for the population on these formations. The weighting and zone of influence for each criteria used in the analysis are also specified in Table 18.

The selected geological data and the derived prospectivity contribution for these data are shown in Figures 40 and 41. Similarly, selected geophysical data and derived prospectivity are shown in Figures 42 and 43, and selected geochemical data and derived prospectivity are shown in Figures 44 and 45. All the selected data elements used in the prospectivity analysis are shown in Figure 46 and the calculated prospectivity in Figure 47. Details for the central region around Bodmin Moor and Dartmoor and over the intervening ground are shown in Figures 48 and 49.

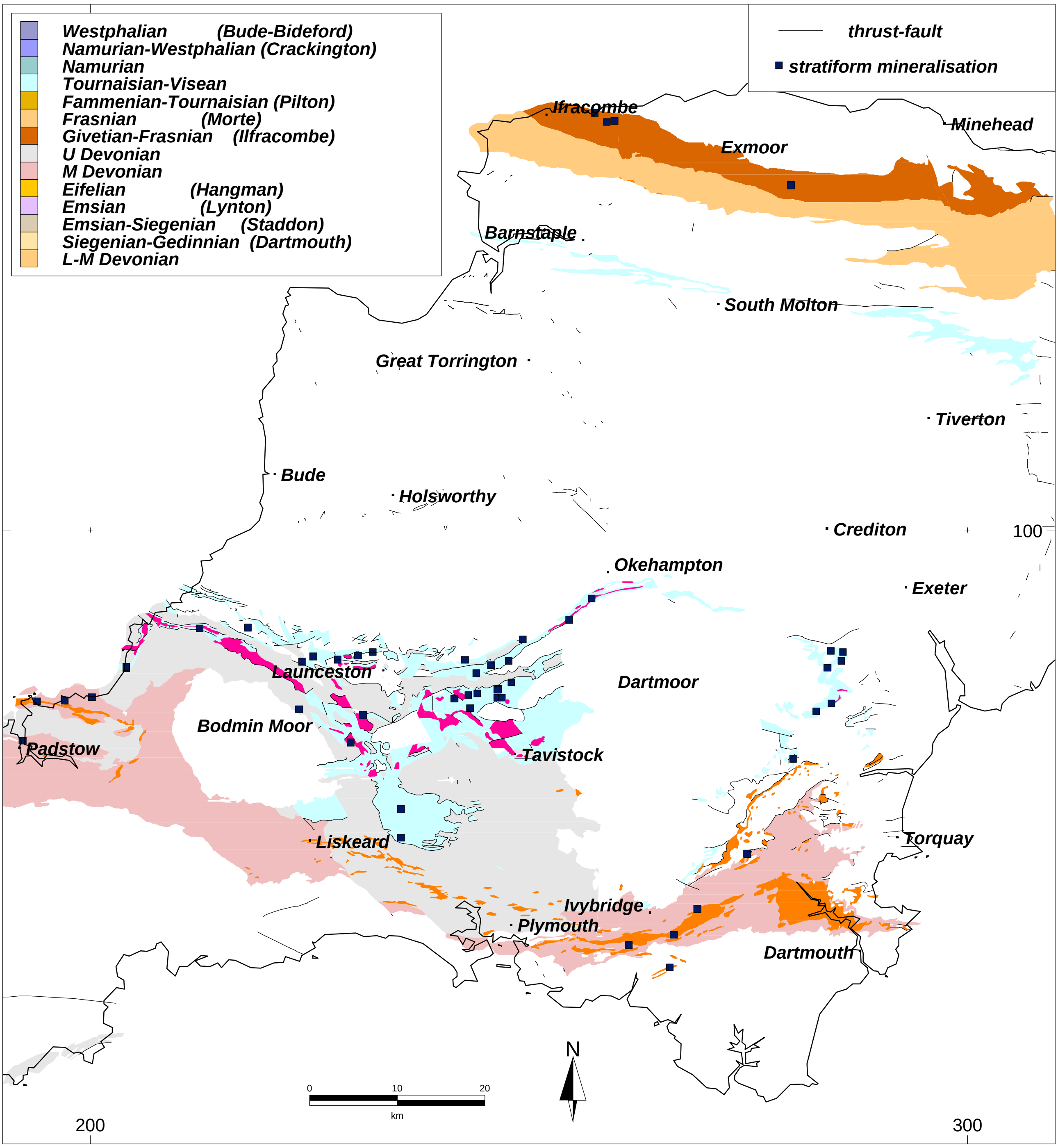

Figure 40 Selected geological data for prospectivity analysis

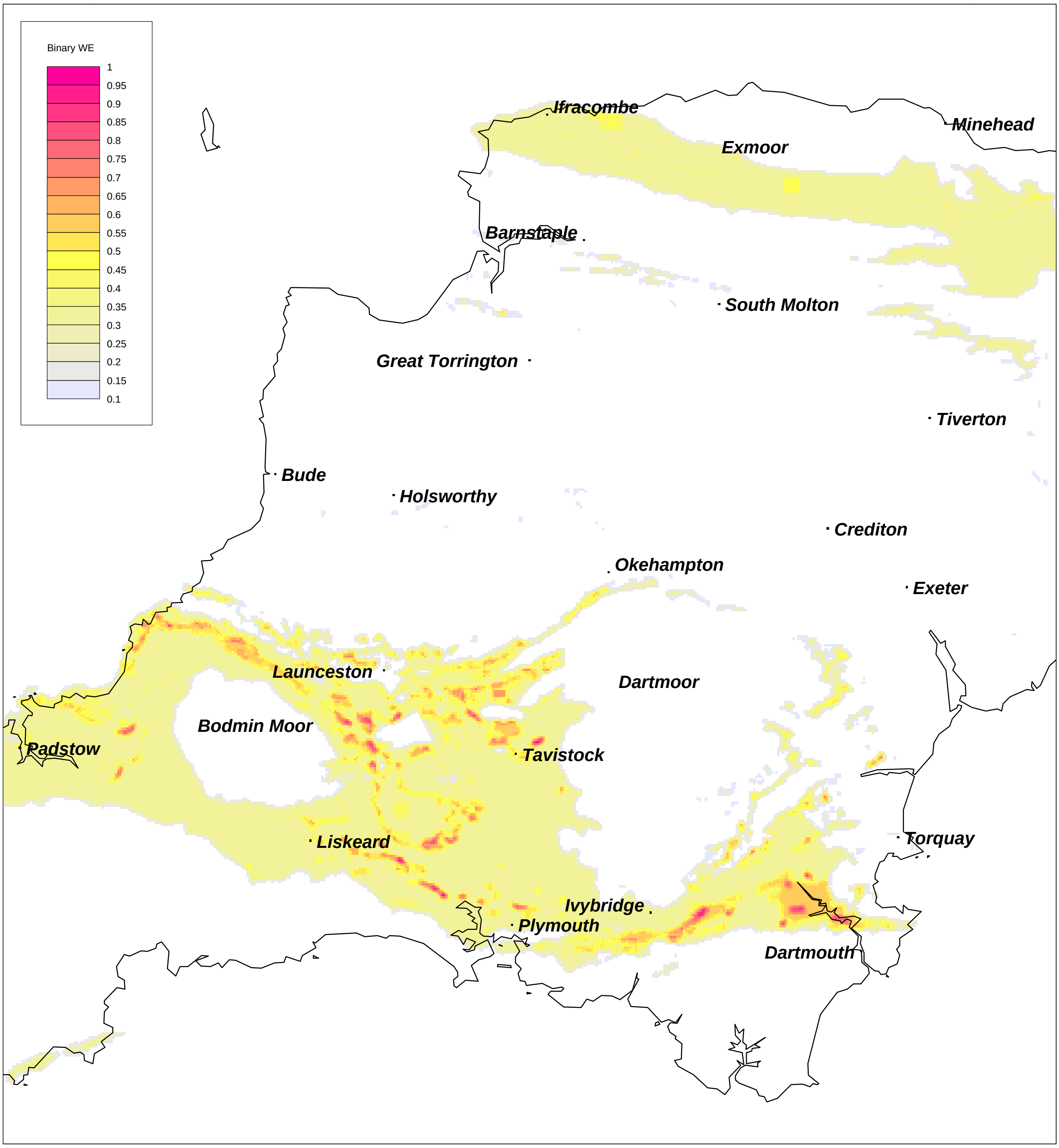

Figure 41 Prospectivity contribution for geological data based on a binary weights of evidence

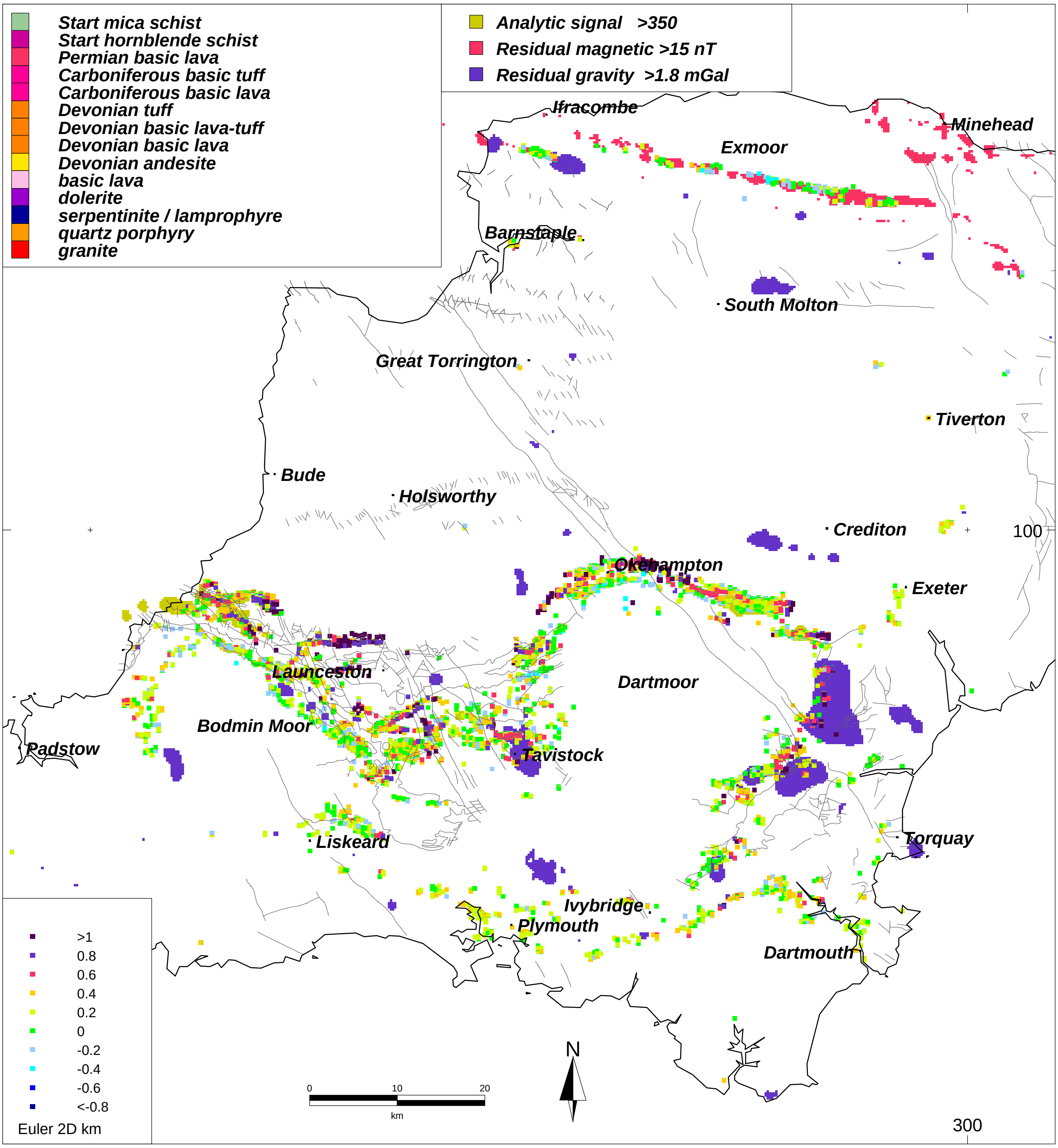

Figure 42 Selected geophysical data for prospectivity analysis

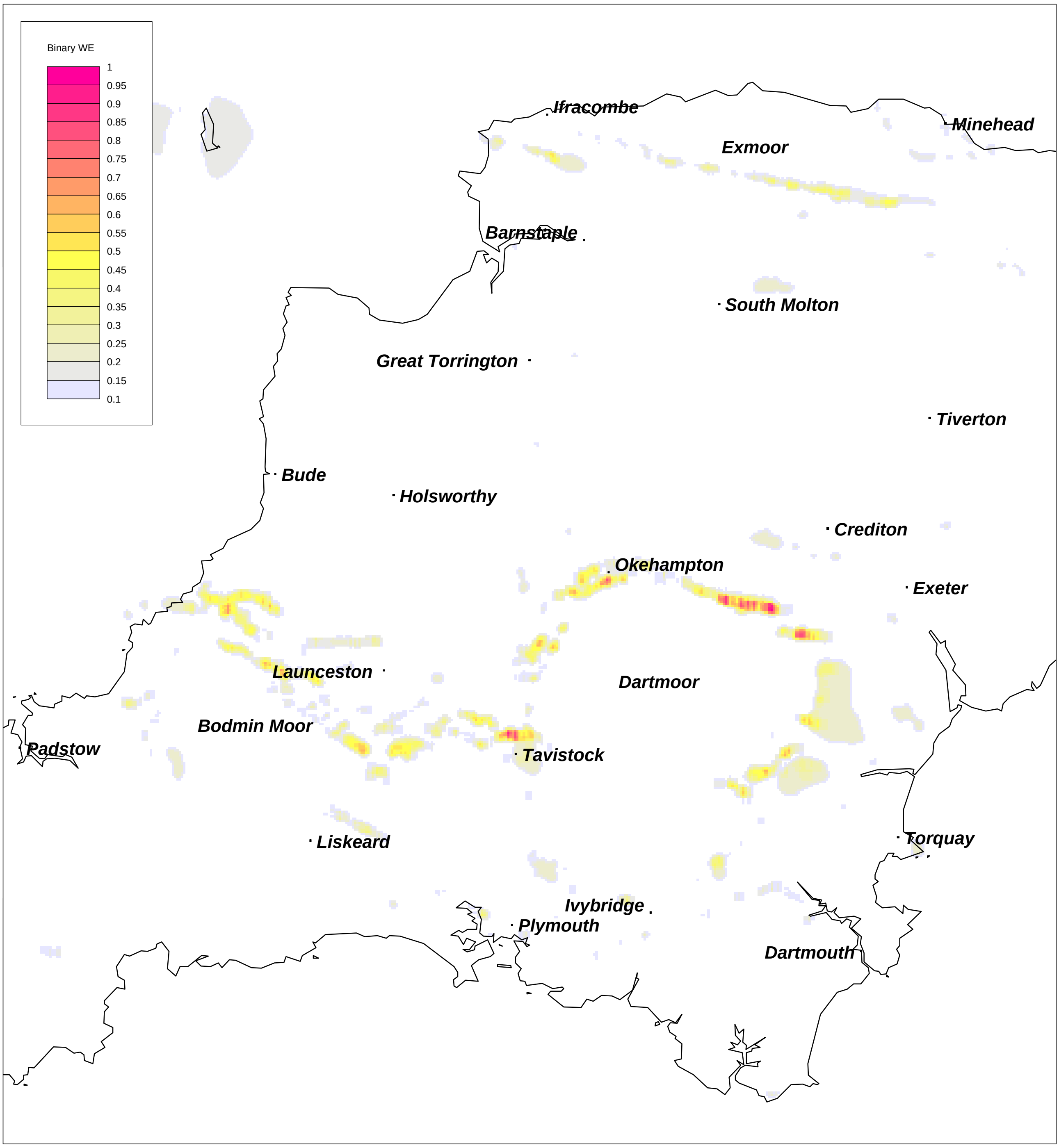

Figure 43 Prospectivity contribution from geophysical data based on a binary weights of evidence

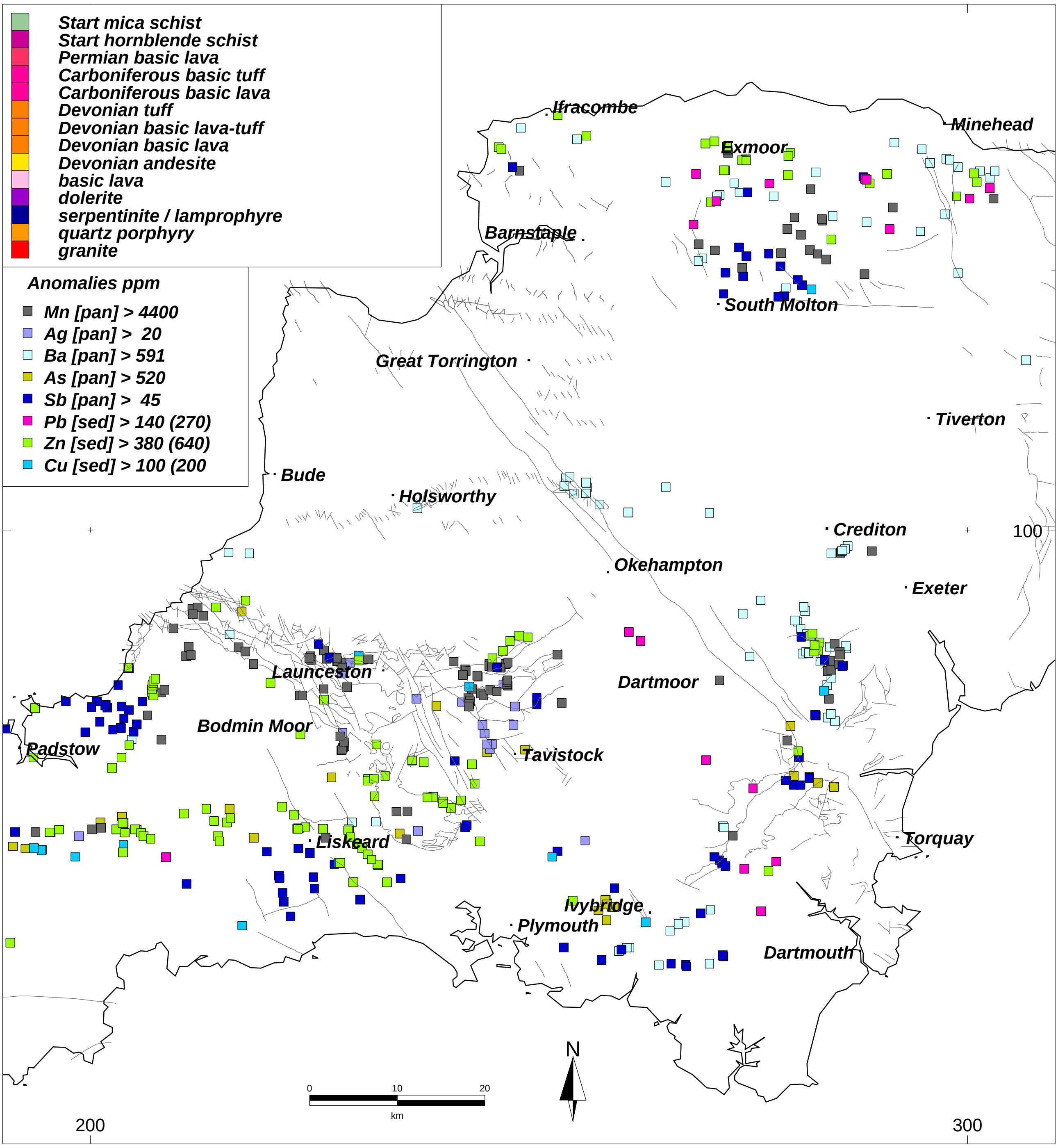

Figure 44 Selected geochemical data for prospectivity analysis

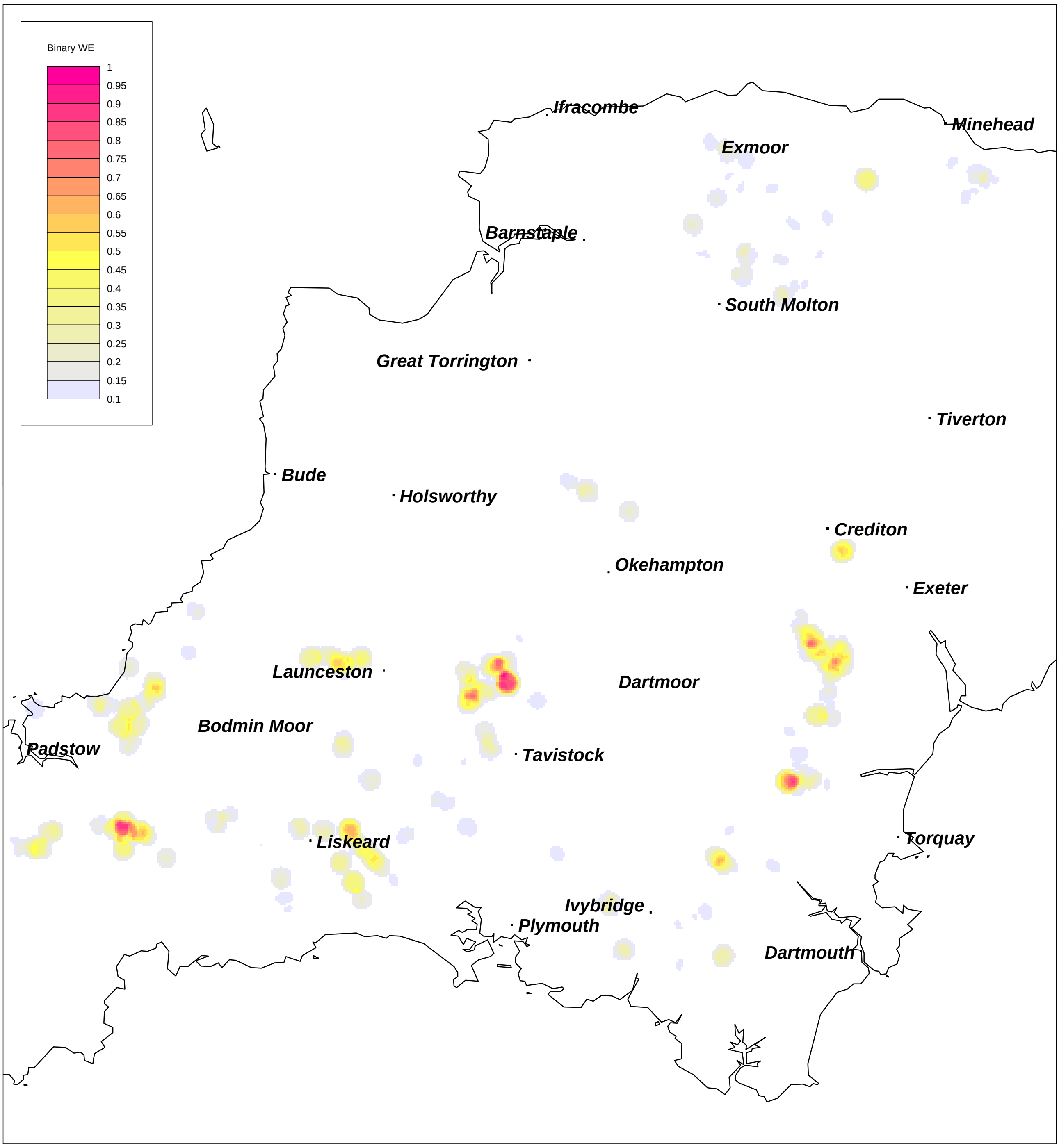

Figure 45 Prospectivity contribution from geochemical data based on a binary weights of evidence

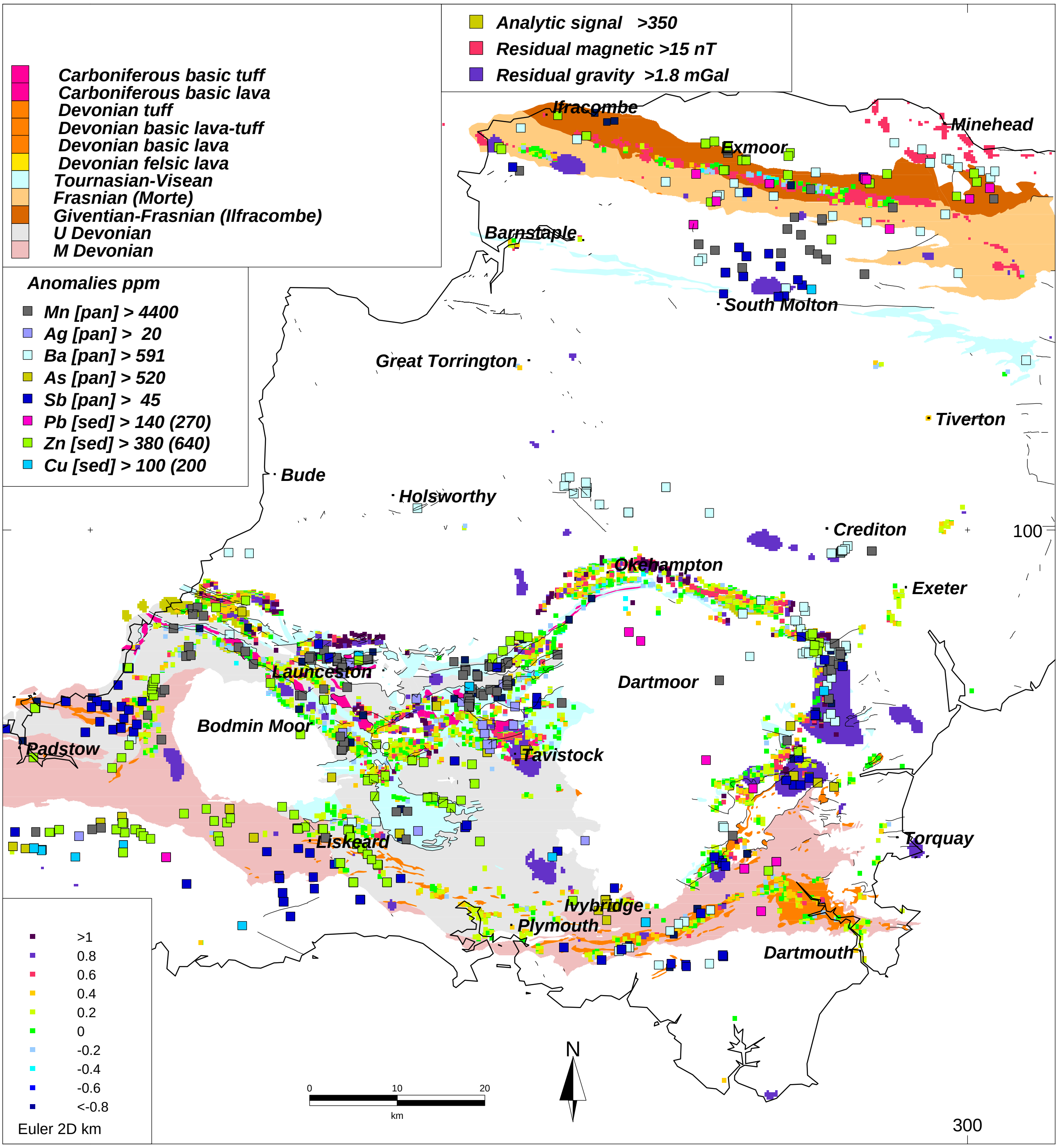

Figure 46 All selected data for stratiform sulphide prospectivity analysis

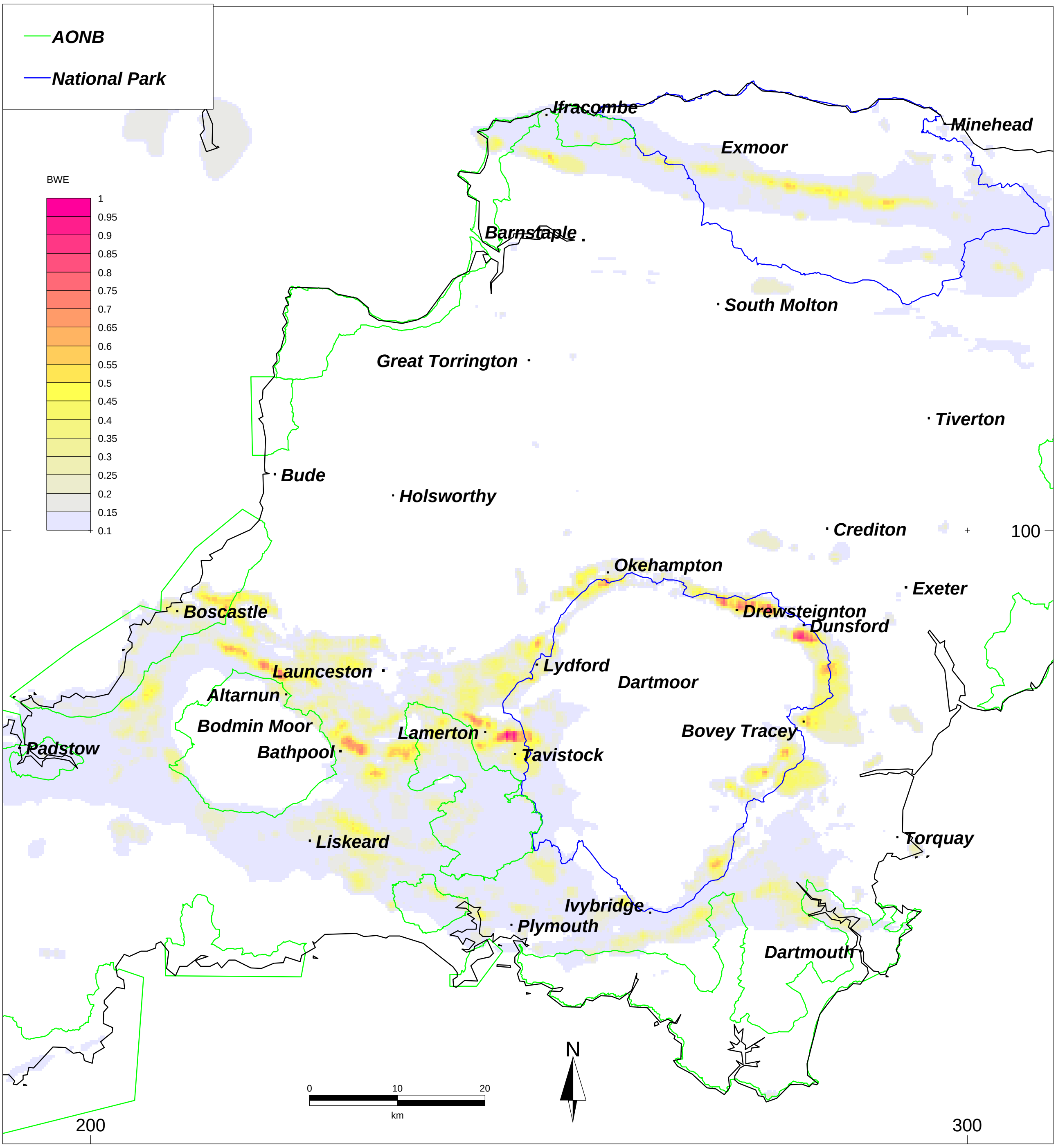

Figure 47 Calculated prospectivity for stratiform sulphide deposits

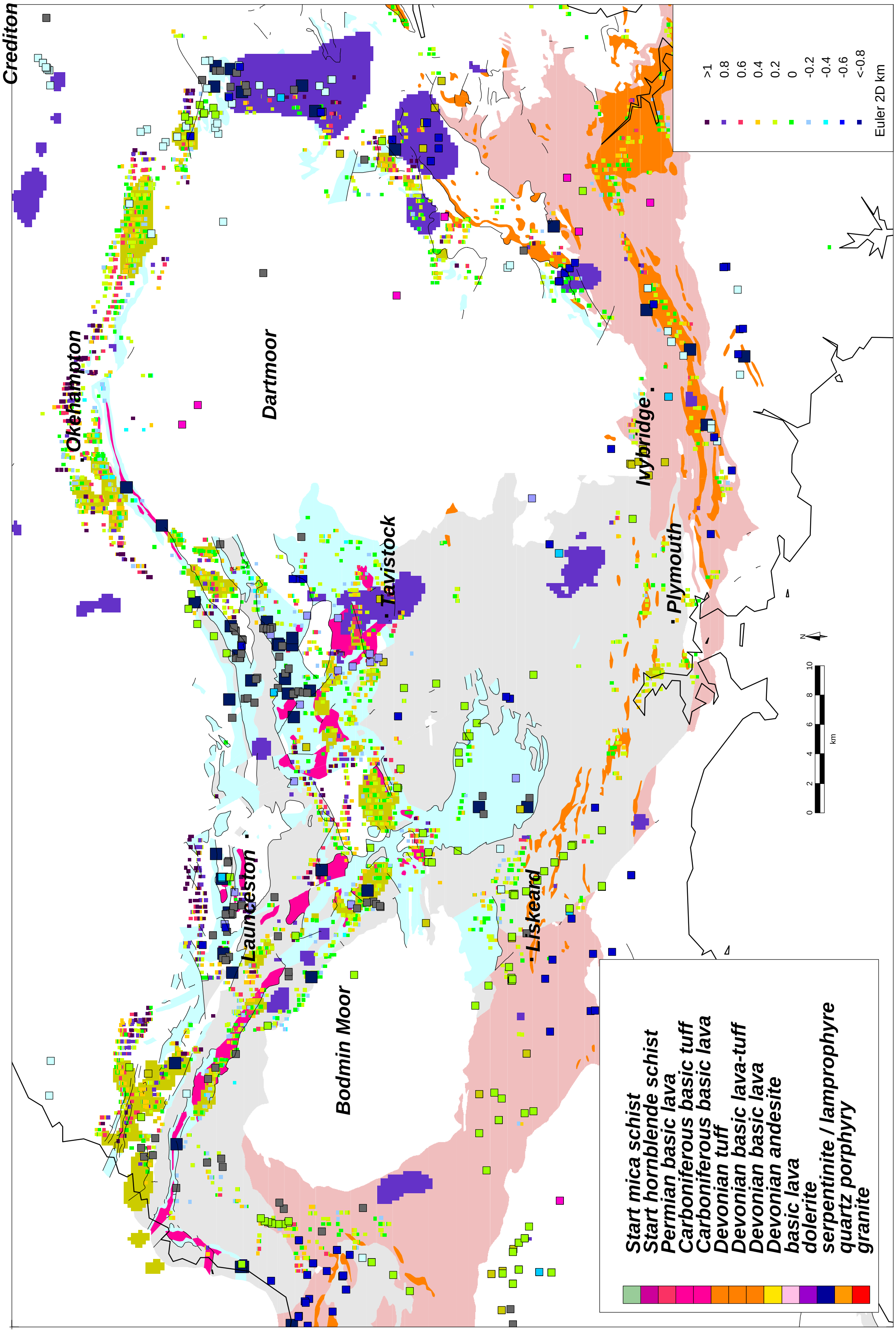

Figure 48 Selected data for stratiform sulphide prospectivity in the central region

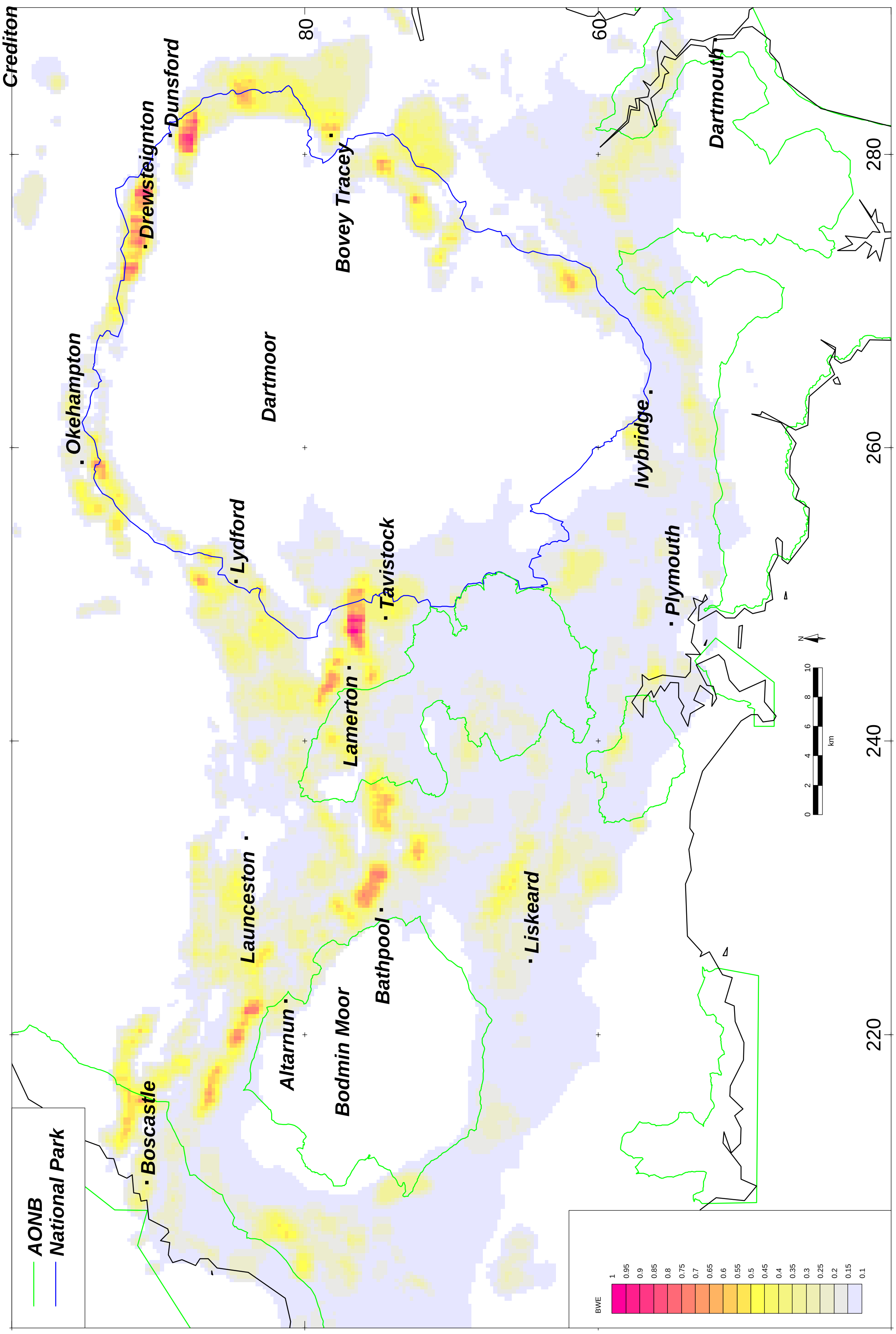

Figure 49 Calculated prospectivity for stratiform sulphide deposits in the central region

Table 18 Exploration criteria and data parameters used to assess prospectivity for stratiform sulphide deposits

Data type	Zone (number of pixels)	Distance exponent	Weight	Criteria
p	3	2.0	0.6	Stratiform metal occurrences
v	1	2.0	0.5	Middle Devonian volcanic rocks
v	1	2.0	0.3	Middle–Upper Devonian slates
v	1	3.0	0.5	Tournaisian–Visean rocks
v	1	3.0	0.5	Lower Carboniferous spilites
v	1	2.0	0.2	Variscan thrusts and slides (E–W azimuth)
g	1	2.0	0.6	Analytic signal of magnetic anomaly > 350
g	1	2.0	0.5	Residual magnetic anomaly on Exmoor >15 nT
g	1	2.0	0.6	Residual gravity anomaly >1.8 mGal
p	2	2.0	0.2	2D Euler solutions in the zone of high gradient
p	5	2.5	0.4	Zn in stream sediment >380 ppm (filtered for Zn mines)
p	5	2.5	0.4	Pb in stream sediment >140 ppm (filtered for Pb mines)
p	5	2.5	0.4	Cu in stream sediment >100 ppm (filtered for Cu mines)
p	5	2.5	0.4	Sb in panned concentrate >45 ppm
p	5	2.5	0.4	Ba in panned concentrate >591 ppm
p	5	2.5	0.4	Mn in panned concentrate >4400 ppm
p	5	2.5	0.4	Ag in panned concentrate >20 ppm
p	5	2.5	0.4	As in panned concentrate >400 ppm
P, point; v, vector; g, grid.				

8.3 PROSPECTIVE AREAS

The results of the prospectivity analysis are shown in Figures 47 and 49, together with areas designated as National Parks or Areas of Outstanding Natural Beauty (AONB). The main target areas identified are:

1. the central region along the northern edges of Bodmin Moor and Dartmoor and in the intervening ground underlain by Lower Carboniferous strata. This area contains numerous formations with black shales, many thrusts and the highest concentration of known occurrences of stratiform mineralisation. Manganese anomalies in drainage samples are widespread, while local high tenor stream-sediment anomalies for Zn are also present. There are also several zones where the magnitude of the analytic signal of the magnetic anomaly exceeds 350. Prospectivity to the east of Okehampton, near Drewsteignton, is based on shallow depth solutions from the magnetic data and a significant maximum in the analytic signal of the residual magnetic data. This suggests prospective terrain beneath Upper Carboniferous strata on Whiddon Down. This target area has not been drilled. Three other targets have been identified in this region: just north of Tavistock; near the north-east margin of the Bodmin granite; and close to the coast near Boscastle.
2. on Exmoor, where minor stratiform metal occurrences are associated with linear magnetic anomalies, shallow source-depth estimates and drainage geochemical anomalies for Zn, Mn and locally Pb. Local residual gravity anomalies also occur in the west of the area. Ground investigation of the magnetic anomalies and subsequent drilling indicated significant pyrrhotite mineralisation with low magnetic susceptibility but implied significant intensity of NRM. The potential for buried polymetallic mineralisation of the Harz massif type would be enhanced by positive evidence from alternative exploration methods such as high-resolution gravity survey.
3. around east Dartmoor, where prospective targets occur in the thrust-and-nappe terrane of the Lower Carboniferous strata associated with minor positive gravity anomalies. The larger residual gravity anomalies either side of the Bovey Tracy basin (and at Tavistock) cover a larger region and are more likely due to structure in the basement and to data sampling around the Dartmoor granite than to features in the thrust sequence. High contrast multi-site Ba anomalies in the Teign Valley area possibly reflect vein baryte mineralisation similar to that already known in the area. However associated Mn anomalies might indicate the presence of stratiform mineralisation.
4. in south Devon, where small positive gravity anomalies occur over the Devonian volcanic rocks near Ivybridge and at Hope's Nose near Torquay. There are also high amplitude Ba anomalies in panned-concentrate samples in the Ivybridge volcanic district but only one Zn anomaly close to the volcanic sequence. Exhalative mineralisation has been found in this district and further exploration is warranted to elucidate the sources of these anomalies.

9 Conclusions

1. Comparison of the geology and mineral deposits of the Iberian Pyrite Belt in Spain and Portugal with the geology and known occurrences in south-west England suggests potential for stratiform sediment-hosted (SHMS) zinc-copper-lead deposits in the Devonian-Carboniferous volcano-sedimentary sequence (VSC) in central Devon and east Cornwall.
2. By analogy with the geological setting and mineral deposits of the Harz Massif in Germany, there is potential in the Exmoor district of North Devon for the occurrence of stratiform sedimentary exhalative (SEDEX) polymetallic (zinc-copper-lead-silver) mineralisation.
3. Stratiform mineralisation is known to occur at three stratigraphical horizons and at over 60 sites in the East Cornwall–Devon target area. Economic mineralisation may be present in these horizons but current data does not provide clear targets for drilling.
4. Knowledge-based prospectivity analysis has been carried out over the target area on the basis of exploration models for SHMS and SEDEX deposit types. This has involved the integration of multivariate geological, geophysical, geochemical and mineral occurrence data and has successfully identified several new targets for stratiform base-metal sulphide mineralisation. The main prospective areas are: (i) in the central region along the northern edges of Bodmin Moor and Dartmoor and in the intervening ground underlain by Lower Carboniferous strata; (ii) in the Upper Devonian and Lower Carboniferous rocks on Exmoor; (iii) in the Lower Carboniferous strata on the eastern side of Dartmoor; and (iv) in south Devon, near Ivybridge and Torquay.
5. Underpinning the evaluation of the area to the north of Bodmin Moor and Dartmoor is the assumption that the high-frequency magnetic anomalies present are primarily related to stratiform sulphide mineralisation within the Fammenian-Visean sequence subsequently recrystallised to pyrrhotite at the time of granite intrusion. Modelling of these data suggest shallow sources for these magnetic anomalies most of which have not been tested by drilling.
6. It is important to note that the reliability of prospectivity or mineral potential maps is dependent on many factors including the accuracy of the deposit models for the target mineralisation, the quality and extent of the available data and the suitability of the data to define an exploration model. Consequently, as more data become available or as the deposit models are improved, so the prospectivity analysis can be refined.

10 Recommendations

1. This study has successfully identified potential new targets for stratiform base-metal mineralisation in east Cornwall and Devon. Further exploration is recommended to evaluate the targets north of the Bodmin and Dartmoor granites, in the Middle Devonian volcanic rocks south of Dartmoor and on Exmoor.
2. Further analysis of existing detailed data for these areas would provide useful guidance in planning new field surveys.
3. The nature of the relationship between syngenetic pyrite and magnetic pyrrhotite, on which the potential in some areas is partly based, needs further evaluation. For example, coastal sections near Boscastle might provide a location where the sources of the magnetic anomaly can be examined and samples collected for laboratory studies of Natural Remanent Magnetisation.
4. At the time of writing, digital geological data at 1:50 000 scale were not available for the whole of the study area. Improved resolution of the targets and a better indication of their relative priorities could be obtained by using the 1:50 000 scale digital geology which identifies favourable host lithologies and formations more precisely. Complete coverage of the 1:50 000 digital geology of the UK landmass will be available before the end of 2001. A more detailed evaluation of some areas within the region using the available extensive soil geochemical data is also recommended.
5. New regional drainage geochemical data with a uniform areal coverage and providing data for a wide range of elements in all samples would improve the quality of this analysis and also assist application of this method to other styles of mineralisation in the region. Utilisation of rock geochemical data from previous BGS or commercial surveys would help to characterise geochemical background values for the target formations and thus assist in the identification and prioritisation of anomalies and new targets.
6. Recommended exploration procedures to evaluate new prospects for stratiform base-metal deposits will depend on the mineral deposit model for the expected target. For example across the central belt, any massive sulphide deposits are expected to of the IPB type and exploration should involve high-resolution gravity surveys at a station spacing of about 400 m across the main interpreted source of the magnetic anomalies. Many of the identified targets are in zones of high gravity gradient so that surveys would require high-precision elevation observations and accurate terrain correction using digital elevation models. Regularity of station distribution would also be desirable. Differential GPS would therefore be the preferred method for location and height determination. Positive residual gravity anomalies should be surveyed with a ground electrical technique to identify the presence of low-resistivity targets.

Appendix 1 Summary log for the Wilsey Down borehole

LOCATION

About 165 m south-south-east of Tregray Farm. British National Grid Reference [21797 08890]. Borehole elevation 218 m. Drilled in May 1968. Taken from McKeown et al., 1973.

LOG

FORMATION	depth (m)
Recent and Pleistocene	
Head: yellow stoney clay	9.14
Carboniferous	
Crackington Formation: Grey slates siltstones and greywackes	76.2
Fire Beacon Chert Formation: Dark grey pyritous slates with thin locally crinoidal limestones; pyrrhotite common to 259m; several greenstone intrusions between 329-445m.	460.55
Low angle fault	
Devonian	
Upper Delabole Slates: Green slates with sporadic thin limestones	690.27
Devonian-Carboniferous	
Transition Group: Grey slates with limestones	703.78
Devonian	
Upper Delabole Slates: Green slates with limey bands	707.06
Low angle fault	
Carboniferous	
Black slates with limy bands at top and Silty bands lower down; several greenstone Intrusions	739.90
Greenstone	762.43

STRATIGRAPHY

Several bands of pale greyish green slates 230-247 m resemble the Buckator formation. Between 274-335 m are occurrences of *Posidonia becheris* and *Neoglyphioceras spirale* both characteristic of the Meldon Chert Formation. Cherts are not common, just a few cherty slates at about 316 m and at 352 m and about 360 m. Greenstone sills in the upper section are 1–17 m thick with baked siliceous margins.

The Upper Delabole slates (460–690 m) are pale green to grey green siliceous slates with scattered thin (25 mm) limy bands with a few specimens of Cyrtospirifer verneuilli. Grey slate (559–568 m and 582–592 m) contain thin slivers of fine slate characteristic of the junction between Tredorn Slates and Transition Group near Boscastle.

The Transition Group beds appear to lie in the core of a recumbent isocline with the thin sequence (3 m) of Upper Delabole Slates below are highly chloritic and fractured by a low angle fault. Beneath the fault grey and black pyritous shales with thin limestones and siltstones could be Trambley Cove Formation or Firebeacon Chert Formation. This sequence has several greenstone sills (0.1–20 m thick) again with baked margins.

STRUCTURE

Minor structures indicate two phases of folding. Early minor recumbent folds and associated pervasive cleavage appear to form clusters at about 20–30° and 60–80° anticlockwise from the slatey cleavage direction. This infers axial trend clusters at about 335° and 290°.

A later set of folds shows a variable trend generally between 60–90° clockwise from the direction of the dip of the slaty cleavage. Axial planes dip at 15–40° opposite to the dip of the slaty cleavage. They are clustered at the zones of low angle shearing. Early shearing is associated with early folding, later more significant low angle shearing is associated with brittle fracture and ruck folds. It also has numerous steep fractures with significant mineralisation.

MINERALISATION

Pyrite and pyrrhotite are common in the Firebeacon Chert Formation the latter mostly in the non-limy black slates. Some of the sulphides run parallel to the bedding is affected by the early folding and may have formed immediately after deposition. Some occurs as elongated spots in the cleavage and within fractures and joints. Pyrite cubes are common in the limestones. Rhodochrosite, calcite, dolomite and quartz with small amounts of galena and sphalerite occur mostly in steep mostly open fractures.

Sulphides are far less common in the Upper Delabole Slates and occur mainly as elongate slips on cleavages. Arsenopyrite occurs in the many irregular quartz masses found within the slates. Numerous steep fractures are often open and filled with quartz and calcite although rhodochrosite, pyrite and pyrrhotite are present occasionally.

Appendix 2 Summary log for the Honeymead borehole 2

LOCATION

About 2.3 km at 091.5° from Simonsbath Church, British National Grid Reference [27989 13935]. Ground elevation 391 m. Drilled in April 1974. Inclination details: vertical at surface; inclination 81° azimuth 348° at 101 m depth; inclination 61° azimuth 355° at 250 m depth. Taken from Jones et al. (1987) and associated data release.

SUMMARY

Honeymead boreholes 1 and 2 were drilled to explore a regional magnetic anomaly and sited on detailed ground magnetic anomaly at Red Deer Farm. Both holes were at the same site. Borehole 1 was to a depth of 253.7 m drilled to the north with a flattening inclination and ended in a water-filled fault zone. Borehole 2 was sited 10 m south of borehole 1, drilled inclined to the north and terminated at 324 m in a complex fracture zone with a south apparent dip. Exact stratigraphic correlation was not possible although core recovery was 88%.

Pyrite and pyrrhotite are the only significant mineralisation and never exceed 5%, generally as flakes or fine crystals on cleavage surface and joints in sandstones. Some sulphide is associated with minor quartz veins in sandstone units. The lower 20 m of borehole 2 had no visible sulphides. Veinlets of calcite without sulphides are common.

Geology Formation	Description	Thickness (m)	Depth (m)
Overburden	No core recovered	2.5	2.5
Ilfracombe Beds - Kentisbury slates?	Blue-grey slates, locally ferruginous or calcareous. Minor pyrite on joint surfaces.	9.7	12.2
Slates	Blue-grey, weakly-calcareous slates. Minor quartz-calcite veinlets.	1.05	13.25
Slates	Blue-grey slates, as above, but not calcareous. Pyrite also scattered on cleavage surfaces.	3.35	16.6
Impure limestone	Muddy limestone, blue-grey. Thin calcareous interleaves.	1.4	18
Slate	Blue-grey, striped slate w abundant fine spotty pyrite and pyrrhotite on cleavage surfaces	13.5	31.5
Sandstone	Sandstone, fine, pale-grey, with this shaley partings. Minor pyrite on cleavage surfaces	3.2	34.7
Fault zone	Highly contorted sheared grey slates	0.2	34.9
Slates	Blue-grey well-cleaved silty slates, tough. With sandstone horizons interbedded below 35.7 m	4.4	39.3
Sandstone	Sandstone - fine-grained and tough, with thin slaty schlieren. V little pyrite on cleavage surfaces	2.73	42.03
Slate	Striped, blue-grey silty slate, thinly irregularly quartz-veined. Sulphide occurs as mainly pyrite films on cleavage surfaces.	10.97	53
Slate	Calcareous, silty, blue-grey striped slate. Minor pyrite on cleavage surfaces.	0.8	53.8
Slate	Striped, blue-grey silty slate. Occasional films of pyrrhotite on cleavage surfaces	1.5	55.3
Slate	Calcareous silty slate. Limestone band, 50 mm thick, from 55.46 m	0.65	55.95
Slate	Blue-grey, well-cleaved silty slates. Subordinate sandstone bands. Scattered fine pyrite on cleavage surfaces	4.1	60.5
Sandstone - base of Kentisbury slates	Grey, fine-grained sandstone, with thin blue-grey argillaceous interleaves. Thin limestone beds and calcite veins within.	9.95	70

Geology Formation	Description	Thickness (m)	Depth (m)
Impure limestone	Striped, well-cleaved, bluish-grey to pale-grey slaty limestone. Numerous calcite-filled tension gashes also carry euhedral pyrite.	20.65	90.65
Slate	Blue-grey slate, with little or no calcareous content. Abundant calcite veining and rare quartz veins. Pyrite on some cleavage surfaces	0.85	91.5
Impure limestone	Striped blue-grey to pale-grey limestone. Cleavage surfaces show fine pyrite and occasional pyrrhotite	5.34	96.84
Slate	Bluish-grey silty slate, with gritty calcareous layer at 97 m. A little pyrite and lesser pyrrhotite on some cleavage planes. Becomes more calcareous below 104 m.	10.66	107.5
Impure limestone	Well-cleaved impure limestone, with distinct thin, pale-grey limestone layers. Some small pyrite flakes on cleavage surfaces.	3.05	110.55
Slates	Well-cleaved slightly calcareous slate. Fine pyrite and pyrrhotite on cleavage surfaces.	3.9	114.45
Impure limestone	Well-cleaved, slaty, impure limestone. Minor scattered pyrite on cleavage surfaces.	3.2	117.65
Slates	Slightly calcareous slates with occasional limestone and sandstone bands. Cleavage surfaces carry fine, occasionally euhedral pyrite.	3.85	121.5
Impure limestone	Impure, well-cleaved limestone. Little or no sulphide in upper part, becoming richer in pyrite and pyrrhotite with depth. Occasional thin pyrrhotite veinlets.	3.45	124.95
Slates	Slightly calcareous, blue-grey slates. Scattered pyrite and pyrrhotite on cleavage planes. Scattered calcite veining.	10.4	135.35
Slates	Generally non-calcareous, blue-grey slates. Rare pyrite on joints, cleavage surfaces have no visible sulphides.	5.1	140.45
Slates	Calcareous slates. Trace sulphides on cleavage planes.	0.8	141.25
Slates	Slightly calcareous, blue-grey silty slates, interbedded with dark-grey slates. Scattered fine pyrite on cleavage surfaces.	3.21	144.46
Slates	Slightly calcareous, blue-grey slates. Somewhat silty. Scattered calcite veins sometimes contain pyrite. Variably pyrite and pyrrhotite coated cleavage surfaces.	4.89	149.35
Slates	Dark-grey, fissile slates. Little or no sulphides.	2.4	151.75
Impure limestone	Impure, argillaceous limestone. Very fine tension cracks calcite-filled. Scattered very fine sulphides on cleavage planes.	3.15	154.9
Slates	Variably calcareous slates with calcite-filled fractures. Scattered fine sulphide on cleavage planes.	4.8	159.7
Impure limestone	Calcareous slate with argillaceous layers.	1.9	161.6
Slates	Virtually non-calcareous, blue-grey silty slates. Little sulphide evident.	2.8	164.4
Slates	Somewhat calcareous, blue-grey silty slates, striped in appearance. Some calcareous horizons and calcite veins. Small narrow veinlets of pyrrhotite. Fine pyrite and pyrrhotite on cleavage planes.	12.65	177.05
Slates	Calcareous, blue-grey silty slates, as above. A little pyrite and pyrrhotite on cleavage surfaces. Some silty layers.	13.73	190.78
Slates	Slightly calcareous, blue-grey slates. Scattered fine sulphides on cleavage surfaces.	1.02	191.8
Slates	Slightly calcareous blue-grey slates. Well-cleaved with little sulphide shown on cleavage surfaces. Calcareous mudstone band between 200.03 and 200.22 m.	18.74	210.54
Slates - base of Combe Martin Slates	Blue-grey slightly calcareous silty slates. Very little scattered sulphide on cleavage surfaces.	1.41	211.95
Slates/ sandstones - Lester Slates and sandstones	Pare-grey, tough silty sandstones up to 0.1 m thick in blue-grey silty slates. Abundant quartz veins below 212.9 m are weakly pyritic. Traces of spotty pyrrhotite on cleavage surfaces.	6.71	218.66
Sandstone	Pale-grey, rather argillaceous sandstone. Massive to weakly cleaved. Slaty cleavage planes carry films of pyrite. Also, irregular veins and patches of crystalline pyrite. Rock locally distinctly calcareous.	12.02	230.68
Slates	Blue-grey slates, locally banded. Scattered pyrite and pyrrhotite on cleavage surfaces.	14.54	245.22

Geology Formation	Description	Thickness (m)	Depth (m)
Sandstone	Pale-grey sandstone. Fine-grained and massive. Occasional pyrite spots and narrow sulphide veinlets. Considerable irregular quartz veining.	2.5	247.72
Slates	Dark grey, cleaved silty mudstones, with sandy silt layers. Locally abundantly quartz veined with abundant pyrite. Frequent spotty pyrite on cleavage planes.	14.68	262.4
Fault zone	Ferruginous clay gouge	1.45	263.85
Sandstones	Very well-cleaved, slaty, impure sandstones. Cleavages show hematite but without sulphides.	2.35	266.2
Sandstones	Impure sandstones, as above, but with trace pyrite on cleavage surfaces.	1.33	267.53
Slates	Silty to sandy slates. A little pyrite as films on cleavage surfaces.	0.82	268.35
Slates	Silty slates. No pyrite or pyrrhotite visible.	2.45	270.8
Sandstone	Grey argillaceous sandstone, partly calcareous.	0.8	271.6
Slates	Dark blue-grey silty mudstone, locally stripy. Erratic but locally abundant pyrite coatings on (cleavage?) surfaces	3.94	275.54
Slates	Grey to blue-grey slates, locally silty to sandy, locally argillaceous below 277. m. No sulphides recorded.	6.56	282.1
Sandstones	Massive, grey, fine-grained sandstone. Fine pyrite films on some cleavage surfaces. Scattered thin quartz and quartz-hematite veinlets.	2.17	284.27
Slates	Striped grey sandy slates. Considerable pyrite as fine films on fracture and cleavage surfaces.	0.64	284.91
Sandstones	Pale-grey sandstone. Spotty pyrite on cleavage surfaces.	1.04	285.95
Slates	Dark blue-grey slates. Patchy films of pyrite on cleavage surfaces. Somewhat hematitic towards base.	1.35	287.3
Vein	Quartz-hematite vein, with traces of carbonate.	0.05	287.35
Sandstone	Iron-stained, massive grey sandstone. Stained from calcite-hematite veinlets.	2.2	289.55
Slates	Dark blue-grey slates, with paler silty laminae. Localised ferruginous staining	1.48	291.03
Sandstone	Pale-grey, massive sandstone.	2.22	293.25
Slates	Ferruginous, very sandy slates, with much quartz veining.	1.01	294.26
Sandstone	Ferruginised, grey sandstone. No sulphides seen on fracture surfaces.	1.54	295.8
Slates	Very silty, striped, ferruginous slates, becoming less ferruginous down section.	0.55	296.35
Sandstone	Pale grey to pink sandstone. Spotty films of pyrite on cleavage and fracture surfaces. Hematitic below 302.95 m	7	303.35
Slates	Ferruginous, silty to sandy slates. No sulphides noted.	1.25	304.6
Sandstone	Pinkish, fine-grained sandstone. Rare quartz veinlets, but no sulphides.	2.4	307
Fault zone	Intensely fractured slates, with thin quartz-hematite veinlets. Poor core recovery.	4.55	311.55
Fault zone	Fragmentary recovery of brownish-grey slates and pinkish sandstones.	6.25	317.8
Fault zone	No core recovery. Flush water very ferruginous	6.45	324.25
	END OF HOLE AT 324.25 m		

Appendix 3 Locations of geochemical anomalies in panned concentrates from Exmoor

The panned-concentrate samples below were considered by Jones et al. (1987) to be anomalous in the elements indicated in relation to population clusters appropriate for the host formation.

BNG Easting (10m)	BNG Northing (10m)	Code	Number	Formation	Concentration (ppm)
24490	13920	BWZ	816	Pilton Beds	531 Sn; 280 Pb; 2280 Ca
24580	13945	BWZ	817	Pickwell Down Sandstone	277 Pb; 2730 Ca
24815	14630	BWZ	822	Morte Slates	516 Pb
24820	14635	BWZ	823	Morte Slates	474 Sn; 491 Pb
24885	14095	BWZ	128	Pickwell Down Sandstone	7700 Mn; 3700 Ca
25310	13925	BWZ	830	Pickwell Down Sandstone	274 Pb
25330	14725	BWX	650	Ilfracombe Beds	1469 Sn; 375 Pb; 1023 Ce; 2000 Ca
25350	14730	BWX	651	Ilfracombe Beds	335 Sn; 355 Pb; 981 Ce; 4150 Ca
25350	14740	BWX	652	Ilfracombe Beds	2139 Sn; 1816 Pb; 601 Ce; 9690 Ca
25390	14520	BWX	564	Ilfracombe Beds	288 Sn; 554 Pb
25535	14580	BWX	644	Ilfracombe Beds	318 Sn; 591 Pb; 1549 Ce
25560	14540	BWX	563	Ilfracombe Beds	437 Pb; 1371 Ce
25575	14640	BWX	646	Ilfracombe Beds	351 Sn; 501 Pb; 1103 Ce
25745	14695	BWX	643	Ilfracombe Beds	432 Pb; 1192 Ce
25910	14735	BWX	854	Hangman Grits	316 Pb
26175	14230	BWZ	805	Morte Slates	641 Sn; 419 Pb; 3153 Ce
26195	14270	BWZ	434	Ilfracombe Beds	343 Pb
26390	12990	BWX	566	Pilton Beds	575 Cu; 4160 Ca
26495	13305	BWX	617	Pilton Beds	1143 Pb
26770	13790	BWZ	316	Morte Slates	266 Cu; 445 Pb
26870	13490	BWX	548	Pickwell Down Sandstone	2926 Cu; 3787 Sn; 6481 Pb; 4670 Mn
26880	12980	BWX	610	Pickwell Down Sandstone	515 Pb; 3350 Ca
26935	13080	BWX	558	Pickwell Down Sandstone	4010 Mn
26935	13255	BWX	632	Pickwell Down Sandstone	4790 Mn
26960	14150	BWZ	278	Ilfracombe Beds	417 Pb; 1841 Ce
27170	13105	BWX	1007	Pickwell Down Sandstone	308 Pb
27235	12925	BWX	659	Pickwell Down Sandstone	10210 Mn; 40 116% Fe
27240	12905	BWX	669	Pickwell Down Sandstone	942 Sn; 491 Pb
27265	14308	BWP	980	Hangman Grits	5150 Mn
27270	14331	BWP	980	Hangman Grits	5300 Mn
27270	14347	BWP	983	Hangman Grits	5190 Mn
27335	13995	BWZ	297	Ilfracombe Beds	426 Sn; 5822 Pb
27390	13225	BWZ	385	Pickwell Down Sandstone	1152 Cu; 4770 Mn; 44.86 %Fe
27430	12985	BWZ	843	Pickwell Down Sandstone	394 Cu; 8820 Mn
27445	12895	BWZ	404	Pickwell Down Sandstone	255 Cu; 21480 Mn; 38.31%Fe
27470	13120	BWZ	355	Pickwell Down	6650 Mn
27472	14221	BWP	915	Hangman Grits	5030 Mn
27645	13390	BWZ	350	Pickwell Down Sandstone	4130 Mn
27650	13110	BWZ	402	Pickwell Down Sandstone	4220 Mn
27800	13870	BWZ	36	Ilfracombe Beds	4120 Mn

BNG Easting (10m)	BNG Northing (10m)	Code	Number	Formation	Concentration (ppm)
27830	12665	BWZ	826	Pilton Beds	304 Sn; 601 Pb; 4610 Mn
27870	13160	BWZ	400	Pickwell Down Sandstone	5580 Mn
27875	13010	BWZ	357	Pickwell Down Sandstone	15550 Mn; 31 084% Fe
27905	12665	BWZ	574	Pilton Beds	605 Ce; 4780 Mn; 35.80 %Fe
27950	13440	BWZ	22	Pickwell Down Sandstone	5160 Mn
28010	14030	BWZ	238	Ilfracombe Beds	272 Cu; 741 Ce
28035	13585	BWZ	19	Morte Slates	13700 Mn
28065	14020	bwz	236	Ilfracombe Beds	304 Pb; 1005 Ce
28110	13365	BWZ	48	Pickwell Down Sandstone	7460 Mn
28115	12790	BWZ	570	Pickwell Down Sandstone	324 Cu; 51 845% Fe
28130	13630	BWZ	17	Morte Slates	780 Ce; 4110 Mn
28155	13265	BWZ	43	Pickwell Down Sandstone	4030 Mn
28180	12840	BWZ	526	Pickwell Down Sandstone	288 Cu
28210	13195	BWZ	40	Pickwell Down Sandstone	4650 Mn
28215	13885	BWZ	147	Ilfracombe Beds	2916 Ce; 500 Mn
28225	12750	BWZ	538	Pilton Beds	1148 Cu
28245	12625	BWZ	534	Pilton Beds	572 Cu; 2100 Ca
28245	12705	BWZ	536	Pilton Beds	362 Cu; 548 Pb
28310	13145	BWZ	83	Pickwell Down Sandstone	6740 Mn
28350	13535	BWZ	10	Morte Slates	10450 Mn
28350	13540	BWZ	11	Pickwell Down Sandstone	5350 Mn; 1160 Ni
28390	12665	BWX	1012	Pilton Beds	274 Sn; 390 Pb
28400	13095	BWZ	80	Pickwell Down Sandstone	367 Pb
28660	13770	BWZ	224	Ilfracombe Beds	252 Pb; 623 Ce
28815	14030	BWP	873	Ilfracombe Beds	1850 Pb
28835	12930	BWZ	86	Pickwell Down Sandstone	6690 Mn
29035	13880	BWZ	179	Ilfracombe Beds	2413 Pb; 5650 Ce
29120	13425	BWZ	331	Pickwell Down Sandstone	1206 Pb
29140	13880	BWZ	200	Ilfracombe Beds	529 Ce; 400 Mn
29160	13670	BWZ	199	Morte Slates	1587 Ce; 9500 Mn
29225	13980	BWZ	252	Ilfracombe Beds	564 Pb; 5538 Ce
29230	13970	BWZ	251	Ilfracombe Beds	285 Pb; 1015 Ce; 5100 Mn; 32.67 %Fe
29445	13405	BWZ	325	Pickwell Down Sandstone	2114 Sn; 310 Pb
29573	14190	BWX	967	Ilfracombe Beds	10000 Ba; 1317 Ce
29580	13810	BWZ	281	Ilfracombe Beds	506 Pb; 1732 Ce; 200 Ca
29780	14240	BWX	960	Hangman Grits	3730 Ba
29890	12925	BWZ	344	Pickwell Down Sandstone	6416 Ba
30072	14070	BWX	954	Ilfracombe Beds	4029 Ba; 6040 Ca
30108	13976	BWX	953	Ilfracombe Beds	394 Cu; 924 Zn
30140	14090	BWX	957	Ilfracombe Beds	3572 Ba
30265	14018	BWX	958	Ilfracombe Beds	4567 Ba; 614 Ce; 2960 Ca
30322	14090	BWX	959	Ilfracombe Beds	6630 Ba; 680 Ce; 2400 Ca

Appendix 4 Location of mines and trials in the project area

BNG mE, British National Grid reference metres easting; BNG mN, British National Grid reference metres northing (empty when uncertain); Main, primary mined commodity; sub, secondary commodities; NK, main commodity not known; nk, subordinate commodity not known; COPP, copper; MANG, manganese; ARSC, arsenic; ANTI, antimony; WOLF, wolfram; TUNG, tungsten. All output in tons, except for silver (AG) in troy ounces.

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
AARON	186800	61800	NK	nk		
ABBOTS LEIGH	354000	173000	LEAD	nk		
ADIT1	200500	66900	NK	nk		
ADIT2	214400	65500	NK	nk		
ADIT3	217700	82200	NK	nk		
ADIT4	220500	90500	NK	nk		
AGAR EAST	226100	69600	COPP	nk	24	
AGAR	226100	69600	COPP	as sn w	+9128	
ALBION	190200	52800	TIN	nk		
ALEXANDRA	212000	82200	NK	nk		
ALFRED JAME	194800	59200	TIN	nk		
ALICE	191700	53800	TIN	nk	7	
ALLIFORD	242300	85300	MANG	nk		
ALTARNUN CONSOLS	220900	79500	NK	nk		
ALVENNY EAST	222400	79700	NK	nk		
ALVENNY	221200	78700	NK	nk		
ALVIGGAN AND BURNGULLOW	198300	54700	TIN	nk	3.5	
ALVIGGAN	197800	54600	TIN	nk		
AMBROSE LAKE	219400	67400	LEAD	ag sn as cu	80	150 CU
AMERY	283500	83900	LEAD	ag		
ANDERTON	248500	72300	TIN	nk	202	
ANN	213900	65200	NK	nk		
ANNA MARIA	243300	73400	COPP	nk		
ANNIE	223700	79400	TIN	nk	6	
APPLEDORE	233000	69500	NK	nk		
ARCHER	285800	86200	MANG	nk		
ARCHIE	210500	81700	LEAD	nk		
ARTHUR	200500	78900	COPP	sn as		
ARTHUR	243200	70000	COPP	sn	1613	
ARTHUR	243400	70000	COPP	sn as	10462	152 SN
ARUNDEL	274400	71600	NK	nk		
ARVOSE MINE	195900	50400	NK	nk		
ASHBURTON EAST			COPP	nk		
ASHBURTON UNITED	277100	73300	TIN	as	289	
ASHBURTON WEST			COPP	nk		
ASHBURTON	238400	70100	NK	nk		
ASHTON HILL			IRON	nk	27195	
ASHTON VALE	356000	170000	IRON	nk	+50000	
ATHILL WOOD	228100	85600	TIN	nk		
ATLAS IRON	277800	76200	IRON	nk	1300	
ATLAS	277800	76200	TIN	sn	56	

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
ATLEY	203500	66000	NK	nk		
ATWAY	230500	86100	MANG	nk		
BADGALL	223400	86800	NK	nk		
BAGTOR	276200	75900	TIN	nk	15	
BALLARAT	189600	60900	NK	nk		
BAMPFYLDE	273100	132700	COPP	mn fe au	+5300	7217
BANK	217900	68400	NK	nk		
BARBARA	201100	74600	NK	nk		
BARING AND LANGFORD	238200	69500	NK	nk		
BARNARD	239900	69900	ARSC	pb ag	2	
BARON	223400	86800	NK	nk		
BARTON			IRON	nk		
BASSET EAST	190800	55800	COPP	sn	15000	87
BATCHELORS HALL	259900	73400	NK	nk		
BATTISHILL DOWN	251500	86200	LEAD	nk		
BAWDEN	205900	79800	NK	nk		
BAZELEY	241600	67600	NK	nk		
BEALBURY	237000	66400	COPP	nk		
BEAM WEST	277100	73300	COPP	sn	186	
BEAM	276700	73400	TIN	nk	2	
BEDFORD CONSOLS			COPP	as	30	
BEDFORD SOUTH	243500	71800	COPP	nk	+4500	
BEDFORD UNITED	244100	72600	COPP	sn as w	+60000	
BEDFORD	247300	70000	COPP	nk	267	
BEENY	211000	92800	NK	nk		
BEER CHARTER MINE	253200	137600	COPP	nk		
BELOWDA	197200	62500	TIN	w	+50	
BELSTONE	263200	94500	COPP	au	439	
BENEATHWOOD	230500	72300	LEAD	nk	5.5	
BENNALLACK	190700	56800	IRON	nk		
BENNY	239700	73100	TIN	as w	23	
BERIOW(CONSOLS)	227200	75600	ZINC	cu py	+80	
BERTHA CONSOLS EAST	247800	69000	COPP	nk		
BERTHA CONSOLS	247100	68900	COPP	sn as	956	
BERTHA EAST LADY	247800	69000	COPP	nk		
BERTHA LADY	247100	68900	COPP	as	+5000	
BERTHA SOUTH LADY	247700	68200	COPP	nk		
BERTHA			MANG	nk		
BETSY SOUTH	251100	80900	LEAD	ag	40	
BETSY	251000	81200	LEAD	ag	994	
BETSY	251100	80900	LEAD	ag		
BICKLEY VALE PHOENIX	253100	64200	LEAD	nk		
BICTON CONSOLS	231400	70300	NK	nk		
BICTONWOOD	230800	69600	LEAD	ag	9.4	
BIRCH ALLER	282800	86900	LEAD	ag	25	
BIRCH TOR AND VITIFER	268000	81000	TIN	nk	+1200	
BIRCH TOR EAST	269300	81000	TIN	nk	7	
BISHOP’S WOOD ADIT	201300	69700	NK	nk		
BLACKHAY	198700	65700	IRON	nk	4330	
BLACKLAND	246400	136700	IRON	nk	134	
BLACKMOOR	301600	101800	LEAD	nk		
BLENCOWE CONSOLS	192900	52300	TIN	nk	34	

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
BLISLAND CONSOLS	211700	73700	NK	nk		
BLOGSTERS	234400	70600	TIN	nk		
BODINNICK	194600	51900	IRON	nk	3364	
BODMIN CONSOLS	207300	68500	LEAD	cu ag	+10	680
BODMIN MOOR CONSOLS	211700	73700	NK	nk		
BODWANNICK MINE	203800	65400	NK	nk		
BOODE	250100	138100	IRON	nk		
BORRINGTON CONSOLS	253100	58400	LEAD	ag zn as	397	147 AS
BORRINGTON CONSOLS	253100	58400	LEAD	nk		
BORRINGTON EAST	253700	58400	LEAD	nk		
BORRINGTON EAST	253700	58400	LEAD	nk	13	
BORRINGTON PARK	253100	58400	LEAD	ag	355	
BOSCARNE	203700	67300	IRON	nk	65	
BOTATHAN	229300	82000	MANG	nk		
BOTTLE HILL EAST	256800	58700	TIN	nk	1	
BOTTLE HILL	256400	58700	COPP	sn	195	258 SN
BOVEY TRACEY	280600	81000	IRON	nk	98	
BOWDEN COMMON	246500	81900	MANG	nk	131	
BOWDEN DOWN	246300	82000	IRON	nk	26	
BOWDEN	220500	69000	TIN	nk		
BOYS	200500	80000	ANTI	nk		
BRADBURY			IRON	nk		
BRADDOCK CONSOLS	213500	65300	NK	nk		
BRADSANDS			IRON	nk	3906	
BRADWORTHY	232000	114000	LEAD	nk		
BRAMBLE	241600	72300	NK	nk		
BRATTON FLEMING	282800	137000	MANG	nk		
BRAY	219800	82300	COPP	nk	508	
BRENDON HILLS	302500	134400	IRON	nk	726000	
BRENT	274900	63100	IRON	nk		
BREWER	240200	70300	NK	nk		
BRIMLEY	268000	128300	IRON	nk	10322	
BRINSLEY			IRON	nk	500	
BRITANNIA AND PRINCE REGENT	274600	133600	IRON	au		
BRITISH MANG			MANG	nk		
BRIXHAM			IRON	nk	114873	
BRIXHAM WEST			IRON	nk	400	
BROADGATE	238200	73700	NK	nk		
BROOKWOOD EAST	271700	68400	COPP	nk		
BROOKWOOD NEW	272100	67800	COPP	nk		
BROOKWOOD	271800	67500	COPP	as	20719	
BROTHERS SNELL'S	239200	68400	NK	nk		
BROTHERS	239100	70100	LEAD	ag cu sn as	1	
BRYNN MINE	198900	62300	TIN	nk	21	
BRYNN TYE	198100	62400	NK	nk		
BUCKLAND MINE	249100	140300	IRON	nk		
BULKAMORE	274900	63100	IRON	nk	4400	
BULLER AND BERTHA	248700	69600	COPP	nk		
BURCHETTS	272200	67900	COPP	nk		
BURNGULLOW IRON	196200	52800	IRON	py	3.5	5
BURNGULLOW	198100	54200	TIN	nk	8	
BURTHY ROW	190500	55700	TIN	nk		

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
BURY DOWNS	219800	69000	TIN	nk		
BUTTERCOMBE	249300	142200	NK	nk		
BUTTERDON	228700	66600	LEAD	nk	2	
BUTTERN HILL	217800	82200	TIN	w		
BUTTERN HILL	218200	82500	WOLF	w		
BUZZACOTT			LEAD	ag		
CABELLA	215100	69500	TIN	nk		
CALLEYS IRON PAINT			IRON	nk		
CALLINGTON CONSOLS	236300	70600	COPP	nk	10	
CALLINGTON MINES CO.	236100	71800	NK	nk		
CALLINGTON SOUTH	235600	67700	NK	nk		
CALLINGTON WEST	234500	69500	TIN	nk		
CALLINGTON	235700	71000	LEAD	ag	6464	
CALSTOCK CONSOLS	242600	69600	LEAD	ag cu as	29	2841 CU
CALSTOCK EAST	242600	69600	ARSC	nk	23	
CALSTOCK UNITED	240000	70200	TIN	nk	44	
CALSTOCK AND DANESCOMBE	241600	69500	ARSC	cu	3000	389.2 CU
CALSTOCK	242300	69400	ARSC	as		
CANAFRAME	219800	79000	TIN	nk		
CANN MINE	252400	59100	LEAD	nk		
CAPUNDA	240200	75400	COPP	zn pb		
CARADON AND PHOENIX	227100	75600	ZINC	cu	104	
CARADON CONS GLASGOW	228200	70200	COPP	nk	37000	
CARADON CONSOLS	225700	69800	COPP	nk		
CARADON EAST	227700	70400	COPP	nk	54049	
CARADON GREAT NORTH	210400	81700	LEAD	ag		
CARADON GREAT	229800	70700	COPP	nk		
CARADON HILL	224900	69100	NK	nk		
CARADON NEW SOUTH	223000	69200	TIN	cu		
CARADON NEW WEST	225600	69700	COPP	nk	293	
CARADON SOUTH	226800	69800	COPP	nk	202208	
CARADON VALE MINE	229400	71000	NK	nk		
CARADON WEST SOUTH	224700	69000	COPP	nk		
CARADON WEST	226200	70000	COPP	nk	84931	
CARADON WOOD MINE	230600	71600	NK	nk		
CARADON	229800	70200	LEAD	sn		
CARBON			BARI	nk		
CARDINHAM MINE	213600	65600	NK	nk		
CARDWELL	243300	79700	MANG	nk		
CARDWELL	243300	79700	MANG	nk		
CARGIBBIT MINE	229400	71000	NK	nk		
CARLOGGAS	195700	54300	NK	nk		
CARN VALLEY MINE	195300	58900	NK	nk		
CARN VIVIAN	215800	68500	LEAD	ag	1086	
CARNGLAZE SLATE	218900	66600	SLAT	nk		
CAROLINE	193200	78400	TIN	nk		
CAROLINE	218700	67400	TIN	nk		
CARPENTER CONSOLS	224100	62800	NK	nk		
CARPENTER	241400	76600	LEAD	ag zn	94	80 ZN
CARPUAN	220500	69000	TIN	nk		
CARTHEW CONSOLS	195500	71700	LEAD	ag cu	138	205 CU
CASSANDRA ANNE	236000	74400	NK	nk		

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
CASTLE-.AN'DINAS(NEW)	194700	62800	TIN	nk	6.4	
CATHERINE	216000	65100	NK	nk		
CATSBRIDGE	241800	75400	ZINC	nk		
CATTEDON MINES	249300	53800	NK	nk		
CAWSLAND VALE			COPP	nk	218	
CHAGFORD			TIN	nk	3	
CHALLACOMBE WEST	253100	147300	LEAD	ag fe		
CHALLACOMBE WEST	258500	147300	IRON	nk		
CHALLACOMBE	259300	147600	IRON	nk	50	
CHANCE	259700	70100	NK	nk		
CHAPEL PARK	247000	126400	COAL	nk		
CHARTERHOUSE	305000	105500	LEAD	nk		
CHEESWRING MINE	226200	71600	NK	nk		
CHEWTON MINERY			NK			
CHILLATON EAST	246500	81900	MANG	nk	132	
CHILLATON	243100	81200	MANG	nk	531018	
CHILSWORTHY MINE	241800	72300	NK	nk		
CHINTER			IRON	nk	+1524	
CH'TON E. AND ATWAY	230400	86200	MANG	nk		
CHURSTON	290800	56400	IRON	nk		
CHYPRAZE CONSOLS	190500	56400	TIN	nk	25	
CHYTANE	191700	55800	TIN	nk	4	
CICELY	213600	65200	COPP	pb		
CLANNACOMBE	226500	72400	NK	nk		
CLEARBROOK	252400	65900	NK	nk		
CLERKENWATER MINES	207300	68500	NK	nk		
CLICK	198700	59700	NK	nk		
CLINTON			MANG	nk		
CLITTERS UNITED	242100	72000	TIN	w as cu	655	462 W
COAD	211700	73700	NK	nk		
COADS GREEN	229700	75700	MANG	nk	21	
COCKE	190100	54600	NK	nk		
CODDEN HILL	257000	129600	NK	nk		
COLCHARTON	245000	73000	COPP	nk		
COLDVREATH	198500	58400	IRON	nk	13885	
COLJRTENAY	189600	60900	NK	nk		
COLLACOMBE WEST	241400	76600	COPP	pb zn ag	433	122 PB 142 ZN
COLLACOMBE	243300	77100	ZINC	cu	481	8502 CU
COLQUITE	235600	67700	COPP	py as		
COLTON	305300	135200	IRON	nk	920	
COMBE MARTIN NEW	253700	147300	LEAD	ag		
COMBE MARTIN WEST	256400	147300	LEAD	nk		
COMBE MARTIN	253100	146500	LEAD	ag	595	88 AG
COMBE MARTIN	258800	146500	LEAD	ag		
COMBE MARTIN	259000	146000	IRON	ag		
COMBE NORTH			IRON	nk		
COMBELAWN MINE	234500	69600	LEAD	zn as py		
COMMERCE	198700	49700	TIN	nk	156	
CONCORD NEW	243300	77100	NK	nk		
CONCORD	242700	77000	LEAD	ag cu	5	
CONSOLIDATED TAMAR	242200	69200	COPP	as sn w		

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
COOMBE WORKS	240300	69900	NK	nk		
COOMBE	256800	128500	LEAD	ag		
CORNISH NEW	240900	73200	COPP	nk	904	
CORNUBIA	199800	59700	TIN	nk		
CORNWALL GREAT UTD.	226500	72400	NK	nk		
CORNWALL GRT CONSOLS	237700	71000	TIN	nk	50	
CORNWALL ST VINCENT	238300	69500	TIN	nk		
CORNWALL STH.TAMAR	241900	61500	NK	nk		
CORNWALL	191800	58600	NK	nk		
CORYTON	220400	67000	MANG	nk		
CORYTON	247700	85100	MANG	nk	431	
COST ALL LOST	199800	59700	NK	nk		
COT QUARRY	280600	138400	MANG	nk	50	
COTEHELE CONSOLS	242300	69200	COPP	sn as	6	
COTEHELE MINE	242300	69400	NK	nk		
COUNTESBURY			IRON	nk		
COURTENAY			COPP	nk		
CRADDOCK MOOR	225900	70200	COPP	nk	20141	
CREBOR EAST	247800	72600	COPP	as	120	33 AS
CREBOR SOUTH	246400	71400	COPP	nk		
CREBOR WEST	245200	72100	COPP	nk	19	
CREBOR	246000	72400	COPP	sn as	35543	25018 AS
CRELAKE	247800	73600	COPP	pb ag	11607	1168 PB
CRIDDIS	191300	73100	NK	nk		
CROW HILL	193700	50900	LEAD	ag u	461	
CROWNDALE EAST	247800	72600	COPP	nk	608	
CROWNDALE	247000	72500	COPP	as sn	562	58 AS
CWM MOLTON	246500	128500	LEAD	ag	8	
CXOLLACOMBE WEST	241400	76600	LEAD	ag zn cu	21	137 ZN
DANESCOMBE VALLEY	242600	69600	COPP	as sn	917	+3000 ASPY
DARLEY	227300	73300	COPP	nk		
DARTMOOR NORTH	255900	85800	TIN	nk	3	
DAVEY	198900	49900	NK	nk		
DEAN PRIOR	272900	65700	TIN	nk		
DEER PARK	239100	73000	TIN	nk	0.1	
DEVIOCK MINE	211100	67500	LEAD	ag fl		
DEVON AND CORNWALL U	246300	70100	COPP	as	11705	
DEVON AND COURTENAY	247200	71700	COPP	pb	1786	3 PB
DEVON BULLER	250000	67100	COPP	sn as	1121	
DEVON BURRA BURRA	251400	74200	COPP	nk	187	
DEVON CONSOLS EAST			COPP	nk		
DEVON CONSOLS NEW	241100	73400	LEAD	nk	14	
DEVON CONSOLS NORTH	241800	74300	NK	nk		
DEVON CONSOLS WEST	239500	73800	COPP	nk		
DEVON CONSOLS	266600	67300	TIN	nk		
DEVON COPP AND BLENDE	243300	77100	COPP	zn	7	
DEVON COPP NEW	274400	71600	COPP	nk		
DEVON COPP	256500	92500	COPP	nk		
DEVON FRANCES	278300	78300	COPP	nk		
DEVON FRIENDSHIP	249200	78900	NK	nk		
DEVON GREAT CONSOLS	242600	73300	COPP	as	700979	75034 AS

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
DEVON GREAT ELIZABETH	271000	70700	COPP	nk		
DEVON GREAT ELLEN			COPP	nk		
DEVON GREAT MARIA	239500	73800	COPP	nk		
DEVON GREAT UNITED	241300	74000	COPP	as	1457	255 ASPY
DEVON KAPUNDA	240300	75400	NK	nk		
DEVON MINE SOUTH	241600	72300	NK	nk		
DEVON NORTH			LEAD	ag	456	
DEVON POLDICE	249300	70700	COPP	sn	46	C. 18 SN
DEVON SOUTH			IRON	nk	1111	
DEVON TIN	266800	73800	TIN	nk	1	
DEVON UNION	250500	76600	COPP	nk		
DEVON UNITED SOUTH	271800	67500	COPP	as	8188	
DEVON UNITED	251200	78600	COPP	sn as	226	994 AS
DEVON	243100	77000	COPP	pb		
DEVONSHIRE MANG	248300	82500	MANG	nk	77	
DICTORS ISLAND			IRON	nk	54	
DIMSON	242700	71800	TIN	w	6	0.5 W
DING DONG	243500	72100	TUNG	sn as cu	2598	
DING	203800	65400	NK	nk		
DIPPERTON	242300	85300	MANG	nk		
DODDISCOMBSLEIGH	284400	86300	MANG	nk		
DOLBERROW			IRON	nk	450	
DOWN WEST	248800	70500	IRON	nk		
DRAKEWALLS	242400	70700	TIN	as cu pb ag w mo	+5433	+2015 CU 2615 AS
DREWS			IRON	nk	+15175	
DRUIDS	274400	71600	COPP	py	38	
DUCHY GREAT CONSOLS	240900	73200	COPP	nk		
DUCHY AND STUKEY UTD.	217200	99400	NK	nk		
DUCHY	239100	70000	NK	nk		
DUKE LITTLE	247100	69500	ARSC	nk	166	
DUNMERE	204900	67700	NK	nk		
DYEHOUSE	198000	60000	IRON	nk	344	
EC WALL SILVER MINE	238500	69500	NK	nk		
EAST CORNWALL UTD.	235600	71100	NK	nk		
EAST'THE'WATER AREA	246700	126200	COAL	nk		
EAST'THE'WATER	245800	126500	COAL	nk		
ECKLEY	203800	80000	NK	nk		
EDGECUMBE	239700	79100	MANG	nk	30	
EDITH	192000	57100	IRON	nk		
EDWARD	242800	69900	COPP	nk	9779	
EGLOSHELLEN	195000	52800	NK	nk		
EISEN HILL	245200	137200	IRON	nk	16187	
ELEANOR GREAT	273500	83300	TIN	nk	19	
ELIOT	235200	63000	NK	nk		
ELIZA	251400	83000	NK	nk		
ELIZABETH	197100	50300	NK	nk		
ELIZABETH	235200	63000	NK	nk		
EMILY	239100	70100	LEAD	ag		
EMILY	254100	49900	ANTI	sb		
EMILY	265000	93000	COPP	sb	1954	
EMMA	223400	87100	NK	nk		

Mine name	BNG mE	BNG mN	Main	Sub	Output– main (tons)	Output– sub (tons)
EMMA	244200	73800	NK	nk		
EMMA	271500	67500	COPP	nk	14562	
EMMENS UNITED	235900	71900	COPP	aspy sn	714	3161 ASPY
ENGLAND AND TREDOWER	197400	76100	NK	nk		
ERRY VANE	204600	86300	NK	nk		
ESTER UNITED	215100	70600	TIN	nk		
EX			LEAD	nk	18	
EXCELSIOR	238100	72400	TIN	nk	1	
EXFORD	247800	138000	IRON	nk	1010	
EXMOOR	247000	137800	IRON	nk	1700	
EXMOUTH NORTH	283600	83700	LEAD	zn	16.5	73 ZN
EXMOUTH SOUTH	283500	80700	LEAD	ag	867	
EXMOUTH	283800	83200	LEAD	ag zn	11523	1561
FANNY	242400	73700	COPP	as		
FANNY	252100	88300	COPP	as		
FAT WORK	191700	58600	NK	nk		
FAWCETT	228600	71800	NK	nk		
FERNHILL	236000	87000	NK	nk		
FIR HILL	186900	61800	NK	nk		
FIVE ACRES			IRON	nk	3988	
FLOP	223700	79400	NK	nk		
FLORENCE NEW	274900	131900	IRON	cu pb	38386	
FLORENCE AND TONKIN UTD.	236500	70500	TIN	nk		
FLORENCE	236300	70600	COPP	as pb ag	255	
FLORENCE	251400	84700	LEAD	as pb ag	6	
FLORENCE	257000	59600	TIN	as pb ag		
FORD FARM	264300	93500	ARSC	nk		
FOREST	256100	91200	LEAD	nk		
FORTESCUE	195500	51400	TIN	nk	14	
FORTESCUE	241400	73900	LEAD	ag		
FORTUNE(EAST AND WEST)	240100	69800	NK	nk		
FORTUNE	239400	70100	LEAD	ag sn cu as		4 AG
FORTUNE	241500	62300	NK	nk		
FORTUNE	242400	73700	COPP	nk		
FOWSHAM			IRON	nk		
FOX TOR	221600	78400	NK	nk		
FRANCES	202700	65900	NK	nk		
FRANCO	250800	70200	COPP	nk	3856	
FRANKMILLS	283600	82000	LEAD	ag ba fe	14813	
FREDERICK	254600	85400	NK	nk		
FREMENTOR	242800	72800	ARSC	w		
FRIENDSHIP AND PROSPER			COPP	nk	124	
FRIENDSHIP EAST	251900	79400	COPP	nk	10156	
FRIENDSHIP NORTH	251200	82300	LEAD	ag	381	
FRIENDSHIP SOUTH	250900	78400	COPP	as	7	
FRIENDSHIP WEST	248500	79600	COPP	nk	177	
FRIENDSHIP	188400	74400	COPP	as pb zn sn ag		
FRIENDSHIP	218000	67800	COPP	as pb zn sn ag		
FRIENDSHIP	250800	79400	COPP	as pb zn sn ag		
FRIENDSHIP	250800	79400	COPP	pb zn ag as	36401	5689

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
				w		
FULLABROOK	247800	139800	MANG	nk		
FULLABROOK	251500	139800	MANG	nk		
FULLABROOK	271800	139800	MANG	nk	100	
FURGAM HILL			IRON	nk	636	
FURSDON	265000	93000	COPP	nk	4337	
FURZE HILL WEST			TIN	nk		
FURZE HILL	251600	69200	TIN	as	240	
FURZE PARK			COPP	nk	10	
FURZEHAM			IRON	nk	1300	
GALWAY	189600	77300	NK	nk		
GASSON	194800	59300	NK	nk		
GAVERIGAN	193500	59200	TIN	fe		
GAWNS WHEEL	211200	73300	NK	nk		
GAWTON	245200	68900	COPP	as	20441	16507
GAZELAND	216300	69300	TIN	nk		
GEM	249600	70600	TIN	nk	31	
GEORGE AND CHARLOTTE	245500	70000	COPP	nk		
GEORGE EAST	252900	70300	COPP	nk	443	
GEORGE AND MARY	239400	69400	NK	nk		
GEORGE	240200	70100	TIN	aspy	1	1389 ASPY
GEORGE	253000	70400	NK	nk		
GIBBET HILL	250200	80800	TIN	nk		
GILBERT AND MERRYM E	208900	73300	NK	nk		
GILL	229200	68000	COPP	nk	3	
GILLEY THE	197800	59200	NK	nk		
GILSONS COVE MINE	196600	80300	NK	nk		
GIRT DOWN	271700	148500	IRON	nk	400	
GLASSON	194800	59300	NK	nk		
GLYNN	211100	67600	LEAD	nk	17	
GOBBETT	264700	72800	TIN	nk	20	
GODDABRIDGE	189600	77300	NK	nk		
GOLDEN DAGGER	268000	80300	TIN	nk	221	
GOLDEN PARLOUR	196900	49900	NK	nk		
GOLDEN VALLEY OCHRE	192300	60000	NK	nk		
GONAMENA	226200	70600	COPP	sn	9693	11 SN
GOOD FORTUNE	189300	60300	NK	nk		
GOODAVER MINE	220700	74500	NK	nk		
GOODEVERE	220900	74700	TIN	nk	6	
GOOD'A'FORTUNE	215700	69700	NK	nk		
GOONHOSKYN MINE	187000	56800	NK	nk		
GOONZION	217900	67800	COPP	cu		
GOOSEFORD WEST	267200	92500	TIN	nk		
GOSS MOOR	195000	60000	TIN	nk	115	
GOULD	235800	67700	NK	nk		
GOVER	199800	52800	TIN	nk		
GRACE	242500	76900	NK	nk		
GREAT DEVON CONSOLS	242600	73300	COPP	nk		
GREAT DEVON UNITED	241300	74000	COPP	nk		
GREAT HILL ZINC MINE	215900	96100	NK	nk		
GREAT HUGO	242500	78300	NK	nk		
GREAT ONSLOW CONSOLS	209600	77700	COPP	nk		

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
GREAT ROCK	282700	81500	IRON	nk	1894	
GREAT SHEBA CONSOLS	237200	73700	COPP	nk		
GREAT TREVEDDOE	215100	69500	COPP	nk		
GREAT WEEK CONSOLS	271300	87500	TIN	nk	55	
GREAT WILLIAMS	240900	76100	NK	nk		
GRENVILLE	195200	50500	TIN	cu	25051	2334 CU
GREYSTONE MINE	235900	80400	NK	nk		
GREYSTONE WOOD	236200	79400	LEAD	pb		
GREAT DEVON AND BEDFORD	245000	73000	COPP	nk		
GRYLLS CONSOLIDATED	216900	67300	COPP	nk		
GUNNISLAKE CLITTERS	242100	72000	COPP	sn w as	30644	
GUNNISLAKE EAST	242100	72000	COPP	sn as pb	+135	
GUNNISLAKE OLD	243000	71900	COPP	sn	2157	153 SN
GUNNISLAKE	242100	72000	COPP	nk	337	
GUTT BRIDGE	197800	75200	NK	nk		
GWIA	194900	52800	IRON	nk	426	
GYMTON			IRON	nk		
HALLOON	191300	59700	NK	nk		
HALOWELL OCHRE PIT	230600	77500	NK	nk		
HALVANNA MINE	221100	78700	TIN	nk		
HALVIGGAN	198300	54700	NK	nk		
HAM			IRON	nk		
HAMERTON	255500	90700	COPP	nk		
HAMMET CONSOLS	218800	69300	COPP	sn		2 SN
HAPPY UNION	201600	67400	NK	nk		
HARBOUR FORD			IRON	nk		
HARDHEAD	214900	71800	TIN	nk		
HAREWOOD CONSOLS	245000	69500	COPP	nk		
HARPTREE EAST	354000	155000	IRON	pb	100	
HARRIS (LIFTON)	237300	82900	NK	nk		
HARRIS	242700	81300	LEAD	ag		
HARRISON	242500	57700	NK	nk		
HARROWBARROW EAST	240200	70300	NK	nk		
HARROWBARROW SOUTH	240100	70100	COPP	nk		
HARROWBARROW	239900	70000	NK	nk		
HARTLAND MINE	228200	124900	COAL	nk		
HARTLAND	227900	124500	COPP	nk		
HARTSWELL PLTN.AREA	247100	85300	NK	nk		
HARVEST MINE	195900	50400	NK	nk		
HARVOSE MINE	195900	50400	NK	nk		
HATHERBY			IRON	nk	550	
HAVE VALLEY ALLUVIAL	234100	68900	NK	nk		
HAVE VALLEY	234500	69500	TIN	nk		
HAWKMOOR WEST	242800	72400	TIN	nk		
HAWKMOOR	243400	72700	COPP	sn as w	3573	34 SN
HAWKMOOR	279800	81800	IRON	sn w as	1213	
HAWKRIDGE BARTON	260100	125200	COAL	nk		
HAWK’S WOOD	226900	75600	NK	nk		
HAXON DOWN	274900	137000	IRON	nk	20	
HAXON	272100	137000	IRON	nk	10	
HAYFORD UNITED	229200	68000	ZINC	nk	237	
HAYTOR CONSOLS	274500	76100	TIN	nk	16	

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
HAYTOR	277300	77100	IRON	nk	34787	
HAZEL	272800	71000	COPP	sn		
HEALE			MANG	nk		
HEART	205100	89000	NK	nk		
HECKWOOD MINE	254700	73800	NK	nk		
HEMERDEN	257300	58400	TUNG	nk		
HEMERDON CONSOLS	257200	58800	TIN	nk		
HEMERDON CONSOLS	257200	58800	TIN	nk	22	
HEA BRIDGE	226300	65700	NK	nk		
HENDRA	220300	79500	NK	nk		
HENNOCK	283600	81400	LEAD	ag fe	29	
HERBERT	218400	68700	TIN	nk		
HERODSCOOMBE	221900	60300	LEAD	nk		
HERODSFOOT NORTH	221200	60400	LEAD	nk	92	
HERODSFOOT SOUTH	221200	59400	LEAD	nk		
HERODSFOOT SOUTH	222500	51500	NK	nk		
HERODSFOOT	221200	60000	LEAD	ag cu w	19316	17 CU
HEWAS EAST	198900	49900	NK	nk		
HEWAS GREAT	197600	50200	TIN	pb ag	867	20 PB
HEWAS NEW	198500	49900	TIN	nk		
HEWAS WATER	196900	50000	NK	nk		
HEXWORTHY	265500	71000	TIN	nk	198	
HIGHER PITS	353000	149000	MANG	nk	80	
HIGHMOOR	216300	81700	TIN	w		
HILL MINE	215900	96100	NK	nk		
HILLBRIDGE CONSOLS	253400	80600	NK	nk		
HINGSTON DOWNS	241000	71500	NK	sn as w	55203	249 SN
HINGSTON SOUTH	238800	70700	NK	nk		
HINGSTON AND CLITTERS	241000	71800	NK	nk		
HOBBS HILL	218600	69400	TIN	nk	15	
HOGSTOR	243100	81200	MANG	nk		
HOLLOWMARSH WOOD	215900	65300	NK	nk		
HOLMBUSH EAST	236800	72100	NK	nk		
HOLMBUSH NORTH	236500	73100	COPP	nk		
HOLMBUSH WEST	235400	71800	NK	nk		
HOLMBUSH	235800	72100	COPP	pb as w f	30651	1477 PB
HOLNE CHASE	272300	71500	TIN	nk	5	
HOLNE MOOR	267500	69800	TIN	nk	1.1	
HOLSTON DOWN			IRON	nk		
HOLWOOD	235200	63000	NK	nk		
HONEYMEAD	255900	139000	IRON	nk	500	
HONY	228900	64600	LEAD	nk	88	
HOOE MINES	249600	52900	NK	nk		
HOOE NEW SOUTH	242300	64400	NK	nk		
HOOE NORTH	242700	66100	TIN	nk		
HOOE SOUTH NEW	242300	64400	NK	nk		
HOOK HILL			IRON	nk		
HOOLE NORTH	242700	66100	LEAD	sn		
HOOPER CARADON SOUTH	227200	69700	COPP	nk		
HOOPER’S BRIDGE MINE	203800	65400	NK	nk		
HOPE	250500	79400	NK	nk		
HORSE BURROW	220900	79400	NK	nk		

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
HORSE BURROW	220900	79500	TIN	nk		
HUCKWORTHY BRIDGE	253300	70700	COPP	nk		
HUEL LOPEZ	252000	63700	TIN	nk		
HUEL VIRGIN	252000	63200	TIN	nk		
HUNTINGDON	266600	67300	TIN	nk		
HURSTOCK	211100	67500	LEAD	ag		
HERODDSFOOT SOUTH TALL-D	222500	51500	NK	nk		
IDA	230300	69300	LEAD	ag		
INDIAN QUEEN CONSOLS	191800	58600	TIN	nk	35	
INDIAN QUEENS NO1 AND 2	192300	60100	IRON	nk	12164	
INNY CONSOLS	227200	81900	NK	nk		
IRON MINE	212500	74800	IRON	nk		
ISLINGTON	277300	77100	IRON	nk	2000	
IVY TOR	262800	93600	COPP	bi		
IVYBRIDGE	264700	55100	LEAD	ag zn	285	
IVYLEAF FARM	223900	108900	COAL	nk		
JACOB	199800	54300	NK	nk		
JAMES	245100	67400	NK	nk		
JANE SOUTH	213600	65200	NK	nk		
JANE	219800	78900	LEAD	ag		
JENKIN	226500	71200	TIN	nk		
JERK	218500	67200	NK	nk		
JEWEL	252600	81400	TIN	nk		
JOB	223000	87000	NK	nk		
JOSIAH SOUTH	241300	72900	NK	nk		
JOSIAH	243300	73700	NK	nk		
JUBILEE	190900	75100	NK	nk		
JULIAN	255100	59700	TIN	nk		
KEAGLESBOROUGH	257200	70100	NK	nk		
KELLY BRAY	236100	71400	COPP	aspy	16445	300 ASPY
KELLY	279500	81800	IRON	nk	2013	
KELLYHOLE	237600	73600	NK	nk		
KILLHAM MINE	220500	67000	NK	nk		
KILLHAM	220400	67000	TIN	nk	0.2	
KILLIVREATH	198500	58400	IRON	nk	1967	
KING ARTHUR MINE	205100	89000	LEAD	nk	2	
KINGBEAR	227000	75000	TUNG	nk		
KINGS OVEN AND WATERHILL	267400	81300	TIN	nk		
KINGSDOWN	196800	50200	TIN	nk		
KINGSTON CONSOLS	236200	75700	LEAD	ag zn cu	311	1125 ZN
KIRLAND	206000	65400	NK	nk		
KIT HILL EAST	238900	71100	TIN	nk	63	
KIT HILL MINE	237500	71300	NK	nk		
KIT HILL SOUTH	237400	71000	TIN	nk		
KIT HILL TUNNEL	238100	72300	NK	nk		
KIT HILL UNITED	237500	71300	TIN	nk		
KIT	256300	67500	TIN	nk		
KNAPDOWN	259700	146600	NK	nk		
LADOCK IRON MINE	191500	52600	IRON	nk		
LADY ASHBURTON	236800	70200	LEAD	ag	3	
LADY BERTHA EAST	247800	69000	COPP	nk		
LADY BERTHA SOUTH	247700	68200	COPP	nk		

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
LADY BERTHA	247100	68900	COPP	as sn		
LADY GRENVILLE	195200	50500	NK	nk		
LADY PARK CONSOLS	223700	64500	NK	nk		
LAMBERT	192900	52300	TIN	nk	0	
LAMERHOOE	239700	73800	LEAD	ag	15	
LAMPEN CONSOLS	218500	67200	NK	nk		
LANGDON	236600	100900	MANG	nk		
LANGFORD NEW	238100	69500	NK	nk		
LANGFORD	238300	69500	LEAD	ag	110	
LANGFORD	290100	97800	MANG	ag mn cu		
LANGMEAD	248300	60100	LEAD	nk		
LANGORE	230100	86500	MANG	nk		
LANGSTONE	248300	82600	MANG	nk	60	
LANJETH	197000	52800	TIN	nk		
LANJEW	198600	65300	IRON	nk	+197	
LANOY(LENOY)	230100	78400	NK	nk		
LARRICK HIGHER	231100	78900	NK	nk		
LATCHLEY	240900	73200	COPP	nk		
LAUNCESTON	232900	84400	NK	nk		
LAVEDDON	205300	66000	NK	nk		
LAWHITTON CONSOLS	236400	83100	LEAD	nk		
LEATHER	218900	66200	NK	nk		
LEE WOOD	245700	84600	MANG	nk	118	
LEGOSSICK	194800	72500	LEAD	cu		
LEIGH DURRANT	239200	62800	NK	nk		
LEIGH(LEE)	238100	62600	NK	nk		
LEISURE EAST	189600	60900	NK	nk		
LEW TRENCHARD	245700	84600	MANG	nk		
LEW WOOD SHAFTS	245700	84700	NK	nk		
LIDCOTT	224100	85000	MANG	nk	308	
LIFTON			MANG	nk		
LILL COVE ADIT	204900	86600	NK	nk		
LISKEARD CONSOLS	224600	67000	NK	nk		
LITTLE DUKE	247100	69500	ARSC	as		
LITTLE SKEWS	197400	65400	IRON	nk		
LOBB MINE	257000	59600	COPP	nk		
LOCKRIDGE	243900	66500	ZINC	flsp pb		
LODMORE POOL AND HAYDEN			IRON	nk		
LONGHAM DOWN AREA	248100	83800	NK	nk		
LONGSTONE EAST	236000	80500	NK	nk		
LOPWELL	247400	65500	LEAD	zn		
LOUISA	194200	50800	NK	nk		
LUCKY	258300	73500	TIN	nk		
LUCKYARD	272900	135000	IRON	nk		
LUDCOTT NORTH	229200	68400	NK	nk		
LUDCOTT AND WREY UNITED	229800	66400	NK	nk		
LUDCOTT	229800	66100	LEAD	nk	4977	
LUSCOMBE	244400	71500	COPP	nk		
LUSKEY	225600	77600	LEAD	nk		
LYDFORD CONSOLS	251700	84600	LEAD	ag	11	
MAEX SOUTH	248700	130100	LEAD	nk	25	
MAGNETIC	198800	59700	IRON	nk	+200	

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
MALAGO VALE	357000	169000	IRON	nk		
MANG WORKINGS	242500	122500	MANG	nk		
MARCIA	272200	130100	IRON	nk	400	
MARIA EAST	241300	74000	COPP	nk		
MARIA SOUTH	241300	73400	COPP	nk		
MARIA WEST	241300	74100	COPP	sn as pb	10891	971 AS
MARIA	241700	73800	COPP	nk	45716	
MARISTOW	247000	64800	NK	nk		
MARKE VALLEY	228000	71800	COPP	sn	128540	388 SN
MARSHALL	194700	51300	NK	nk		
MARSHALL	222900	69300	NK	nk		
MARTHA WEST	237200	73700	COPP	nk	370	
MARTHA GREAT	238800	73700	COPP	nk	+2965	
MARY EMMA	253300	85300	TIN	nk		
MARY GREAT CONSOLS	218700	67200	COPP	nk	2111	
MARY HUTCHINGS	256500	58100	TIN	as	422	263 AS
MARY	195500	57500	TIN	cu	4	
MARYTAVY			TIN	nk		
MELLS	372000	147000	IRON	nk		
MENDIP HILLS	353000	152000	IRON	nk	176	
MERRIPITT LOWER			TIN	nk	1	
METAL LAKE	228500	70800	NK	nk		
MEXICO	239200	69700	NK	nk		
MICHELL CONSOLS GRT.	209600	77700	NK	nk		
MID DEVON	263200	94500	COPP	as	1832	
MILOOK	217500	99400	ZINC	pb cu		
MINE	211600	82200	COPP	nk		
MITCHELL	185200	54400	NK	nk		
MOD-HAM AND MARR.CONS.	241900	61500	NK	nk		
MOLESWORTH	197800	70100	COPP	nk		
MOLLAND	242600	128300	COPP	fe	1758	15738 FE
MOLTON CONSOLS SOUTH	243300	128500	LEAD	ag cu	80	2 CU
MOLTON NORTH			COPP	nk	9	
MONKSTON	246900	80900	MANG	nk	3265	
MORLEY IRON MINE	249100	53000	IRON	nk		
MORSHEAD	243500	69700	COPP	nk		
MORWELLHAM	244300	69700	NK	nk		
MOUNT ALEXNDER	188300	60200	NK	nk		
MULBERRY EAST	202700	65900	NK	nk		
MULBERRY	201800	65800	TIN	nk	1309	
NANJETH	197000	52800	NK	nk		
NANTALLON	202100	67000	IRON	nk	2125	
NANZEARTH	197000	52800	NK	nk		
NAPDOWN	259700	146600	NK	nk		
NARRACOTT	243000	81200	MANG	nk	336	
NETHERDOWNS	247200	123200	CLAY	nk		
NEW CONSOLS	238800	73700	COPP	nk		
NEW GREAT CONSOLS	238800	73700	COPP	nk		
NEW MARTHA	238800	73700	COPP	nk		
NEW MILLS AND PAWTON	195200	70100	NK	nk		
NEWDOWNS	202200	66900	NK	nk		
NEWNHAM PARK AREA	255300	57500	TIN	nk		

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
NEWTON MINING COMPANY	287600	96500	NK	nk		
NEWTON ST CYRES	288000	97300	MANG	nk	1261	
NEWTON	239900	69900	COPP	as aspy		6589ASPY
NINNIS DOWNS	198000	50900	TIN	nk	2	
NOEMIA	253500	63800	IRON	nk	647	
NORRIS	224700	69800	TIN	cu	96	
NORTH C-WALLMIN.CO.	200800	80500	NK	nk		
NORTHAM AREA	246500	129900	LEAD	nk		
NORTHWOOD	220200	69900	TIN	nk	2	
NOTTER	238600	61000	NK	nk		
NUNS CROSS	260200	69900	TIN	nk		
OAKHAMPTON CONSOLS	257100	93500	COPP	nk		
OKEL TOR	244400	68900	COPP	nk		
OLD TREBURGETT	205700	79700	LEAD	nk		
OLD VIRGIN	185400	53400	NK	nk		
OLDERTOWN			IRON	nk		
ONSLOW CONSOLS GREAT	209600	77700	NK	nk	933	
OWLACOMBE	277100	73300	COPP	sn as	9	64 AS
PADSTOW CONSOLS	189600	77300	LEAD	nk		
PARK GWYN	194200	53000	TIN	nk	1	
PARK OF MINES	191100	58800	TIN	nk		
PARK VALLEY	271300	99000	LEAD	ag		
PARKA CONSOLS	191100	58800	TIN	nk		
PARKINS			IRON	nk	1650	
PARKWYN AND C	194200	53000	TIN	nk	1	
PARRACOMBE DEVON	246300	144000	LEAD	ag		
PARRACOMBE	266500	145300	LEAD	ag		
PAWTON	195200	70100	IRON	nk	54741	
PAYNTER	192000	71200	NK	nk		
PEAT COT AREA	259500	70500	NK	nk		
PEEK HILL AREA	255200	69700	NK	nk		
PENBUGLE AND LANCARFFE	207300	68500	TIN	nk		
PENCORSE CONSOLS	187000	55800	ZINC	pb cu	3438	15 PB
PENCREBAR ADIT	235400	68200	NK	nk		
PENDOGGETT	202100	79900	ANTI	pb	S	N
LODES	N-S					
PENGELLY	196700	49600	NK	nk		
PENGENNA	205100	78800	ANTI	zn sb	+15	
PENGIRT ADIT	194300	80100	NK	nk		
PENHALE AND LARKHOLES	224200	68900	TIN	nk	4	
PENHALE MOOR	190500	57800	COPP	sn		
PENHALE	196200	72300	ANTI	nk		
PENHALE	224200	68900	NK	nk		
PENHANGER	229200	67500	LEAD	ag	1	
PENHARGARD	206500	69600	NK	nk		
PENHARGET MINE	229700	70700	NK	nk		
PENHAWGER	229200	67500	LEAD	nk		
PENROSE	194800	59300	NK	nk		
PENSILVA TIN MINE	220500	67000	NK	nk		
PENTIRE GLAZE	194100	79900	LEAD	ag	1411	
PENTIRE	193000	79900	ANTI	nk		
PETERS MARLAND	250700	112700	BALL	nk		

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
PETERTAVY			COPP	sn as	1 SN	
PETHERWIN SOUTH	230800	82000	MANG	nk		
PHOENIX DUNSLEY	226800	71800	NK	nk		
PHOENIX EAST	227400	72200	COPP	sn	31	31
PHOENIX MINE	195500	71700	NK	nk		
PHOENIX NEW	223500	79400	TIN	mn	49	470 MN
PHOENIX NORTH	227300	73400	COPP	nk	7	
PHOENIX SOUTH	226200	71600	COPP	sn		431 SN
PHOENIX UNITED	226700	72400	NK	nk		
PHOENIX WEST	225600	72100	COPP	sn		307 SN
PHOENIX	226700	72400	COPP	sn	80188	16459
PHOENIX	226800	71800	TIN	nk		
PICKARDS DOWN MINE	257800	133000	LEAD	nk		
PILLATON	235600	65000	MANG	nk		
PILLATON	236000	64000	ANTI	nk		
PILTON	255700	134100	LEAD	nk		
PINES DENE AREA	250100	140600	IRON	nk		
PITS MINGLE	198000	60000	NK	nk		
PLAISTOW	246500	138700	IRON	nk	240	
PLAISTOW	256700	138700	IRON	nk		
PLEASANT	240400	70600	NK	nk		
PLUMLEY	280400	80600	IRON	nk	695	
PLUSHABRIDGE	230100	72600	LEAD	nk		
PLUSHEYS	230300	72600	LEAD	nk		
PLYMPTON MINING	256500	58100	TIN	nk		
POLBROCK BRIDGE ADIT	201300	69500	NK	nk		
POLGOOTH SOUTH	198900	49900	TIN	nk		
POLGOOTH WEST	198100	50100	TIN	nk		
POLHARAN	208400	56700	COPP	nk	292	
POLLARD	224500	70000	COPP	nk		
POLTIMORE	245000	132200	COPP	fe	13	
POLTRAVORGIE	201300	79500	IRON	sb		
POLTREWORGY	201400	79400	NK	nk		
POLYEAR	199400	50800	TIN	nk	169	
POLZEATH CONSOLS	193800	79100	LEAD	nk	6	
POLZEATH	193700	78600	LEAD	nk		
PORTHILLY MINE	193900	75500	NK	nk		
PORTHILLY NORTH	192700	76500	LEAD	ag	8	
PORTHKELLY NORTH	192700	76600	LEAD	nk		
PORTLEDGE	239500	126300	COPP	nk		
PORTLEMOUTH CONSOLS	275800	38900	IRON	nk	1922	
PORTQUIN	197200	79700	ANTI	nk		
POSSIBLE WORKINGS	214600	67700	NK	nk		
POULDISTE MINE	218500	67200	NK	nk		
PRAWLE	277200	35300	IRON	nk	300	
PRIDDEY			LEAD	nk		
PRIDE OF THE EAST	234400	70700	NK	nk		
PRINCE ARTHUR CONSOL	251000	81200	LEAD	nk		
PRINCE ARTHUR CONSOLS	251000	81200	LEAD	ag	463	
PRINCE OF WALES NEW	239000	70500	NK	nk		
PRINCE OF WALES STH.	239900	69900	NK	nk		
PRINCE OF WALES WEST	238900	70700	TIN	as	12	

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
PRINCE OF WALES	237800	70500	COPP	cu as ag		
PRINCE OF WALES	240100	70500	LEAD	sn pb ag	11326	482 SN
PROCKTER	203800	80000	NK	nk		
PROSPER(OLD)	198000	50000	NK	nk		
PROSPER	226100	71300	IRON	nk	2686	
P-HALE AND TRCARNE UTD	224900	69100	NK	nk		
QUEEN OF DART	273400	68800	COPP	nk	658	
QUEEN OF TAMAR	245000	67400	LEAD	nk		
QUEEN	239400	70100	TIN	pb ag aspy		3151 ASPY
RAMSDOWN	241400	67400	LEAD	nk		
RAMSDOWN	241400	80800	MANG	nk		
RAMSLEY	265000	93000	COPP	mn	3552	
RATTLEBROOK	256000	85700	TIN	nk		
RAVEN ROCK	247100	69400	TIN	nk	4	
RED HILL	221800	78900	NK	nk		
RED HOUSE	362000	156000	IRON	nk	4151	
REDDYFORD MILL	220800	89300	NK	nk		
REDMOOR	235600	71100	COPP	pb ag sn	54	
REGIL	353000	162000	IRON	nk		
RESUGGA	193500	52300	NK	nk		
RETANNA HILL	192000	57100	IRON	nk	1648	
RETEW	192100	57000	NK	nk	0	
RICHARDS FRIENDSHIP			COPP	nk	256	
RIDGE HILL NO 1			IRON	nk	1454	
RIDGE HILL NO 2			LEAD	fe		
RIDGE HILL NO 3			IRON	nk		
RILEY	284400	80000	MANG	nk	118	
RIVER TAMAR	241700	72300	TIN	nk		
RIX HILL	248200	72300	TIN	nk	134	
ROBERT NORTH	251300	70800	COPP	pb sn	10732	
ROBERT SOUTH			TIN	nk	23	
ROBINS WEST	218100	68400	NK	nk		
ROBINS	218400	68400	TIN	nk	26	
ROBOROUGH DOWN			NK	nk		
ROCHE CONSOLS	197200	62500	TIN	nk		
ROCHE ROCK MINE	199800	59700	NK	nk		
ROCK HILL			IRON	nk		
ROOD GREAT	228600	75100	TIN	nk		
ROOSE	217500	90000	NK	nk		
ROSCARROCK	197800	81000	ANTI	nk		
ROSE CARDINHAM	211100	67500	NK	nk		
ROSE DOWN WEST	227300	71300	COPP	nk	10	
ROSE NANCEMEOR	185200	55300	NK	nk		
ROSE SOUTH	185400	53400	NK	nk		
ROSE	202100	79900	ANTI	nk		
ROSE	247200	124300	MANG	nk	135	
ROSEDOWN	227500	71800	NK	nk		
ROUGHTER CONSOLS GT	216400	82800	NK	nk		
ROWBOROUGH			IRON	nk		
ROYALTON GREAT	197700	61700	TIN	nk	88	
ROYALTON MINE	195000	61600	NK	nk		
RUSSELL EAST	245000	71000	COPP	nk	9950	

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
RUSSELL NEW EAST	246500	71400	COPP	nk	312	
RUSSELL	243800	71100	COPP	sn as	10038	
RUTHERS	192300	60100	TIN	mn	6	1072 MN
RUTHVOES	192300	60000	NK	nk		
SALCOMBE			IRON	nk	100	
SALISBURY	229100	70800	NK	nk		
SAMPSON	202800	81900	IRON	nk		
SARAH	203700	78900	NK	nk		
SCRAWSDON	231400	70300	NK	nk		
SEDLEY	229100	70800	NK	nk		
SHAFTS	187700	61900	NK	nk		
SHALLOW WATER	214400	76000	IRON	nk		
SHAPTOR	280600	81000	IRON	nk	815	
SHARKHAM	293400	54700	IRON	nk	18913	
SHARPTOR EAST	227300	73300	COPP	nk		
SHARPTOR WEST	226000	73200	COPP	nk		
SHARPTOR	225900	73200	TIN	cu		
SHAUGH	253300	63300	IRON	nk	5070	
SHEBA CONSOLS GREAT	237200	73700	COPP	nk	3998	
SHEBA	237600	73600	NK	nk		
SHEPERDS EAST	187000	55800	NK	nk		
SHIRWELL FORD	259900	137800	IRON	nk	5	
SHIRWELL	260600	138300	MANG	fe	5	290 FE
SHOTTS	277300	77300	IRON	nk		
SHUTTAMOOR	282300	82900	IRON	nk		
SICILY	213600	65100	LEAD	ag		
SIDNEY	255100	59400	TIN	as	437	11 AS
SIGFORD CONSOLS	277400	75000	COPP	nk		
SILVER BROOK	278900	75900	LEAD	zn	92	1797
SILVER HILL	237700	69600	LEAD	ag		
SILVER VALLEY MIN.CO	190200	52800	NK	nk		
SILVER VALLEY	225500	71600	TIN	sn cu	9	
SILVER VALLEY	238500	70200	LEAD	sn cu		
SISTERS	197800	74400	TIN	cu as		
SISTERS	219300	67600	TIN	cu as		
SISTERS	239400	70100	TIN	cu as		
SLADE	229800	70200	COPP	nk		
SLIME VEOR	243300	70000	NK	nk		
SLIMEFORD	243700	69800	TIN	nk	16	
SMALLACOMBE	277700	76600	IRON	nk	8618	
SMITHS WOOD	277300	74800	TIN	nk	7	
SMITH-S VENTURE	234500	69500	NK	nk		
SNOWBALL HILL MINE	251800	140900	MANG	nk		
SOFIA	241900	61500	NK	nk		
SOMERS/HISCOTT	255500	125500	COAL	nk		
SOMERSET MINES			IRON	nk	1506	
SOMERSET			NK	nk		
SOPHIA	236000	80500	NK	nk		
SORTRIDGE CONSOLS	251000	70800	COPP	sn as	7792	18 SN
SORTRIDGE GREAT WEST	250800	72500	COPP	nk		
SORTRIDGE WEST	249600	70600	TIN	nk	6	
SOURTON DOWN	254100	91500	NK	nk		

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
SOURTON QUARRY	252200	89600	COPP	nk		
SOUTH BEDFORD	243500	71800	COPP	nk		
SOUTHWAY	248200	60600	LEAD	nk		
SPECULAR IRON ORE MINE			IRON	nk		
SPREADCOMBE VALLEY	247700	141200	IRON	nk	780	
ST AUSTELL CONSOLS	196700	51200	TIN	cu ni pb zn	1074	
ST BREWARD CONSOLS	209600	77700	COPP	nk		
ST CUTHBERTS WORKS			LEAD	nk	1541	
ST DENNIS CONSOLS	195400	57700	TIN	nk	70	
ST DENNIS CROWN	195500	57500	TIN	nk	22	
ST GENNYS MINE	217600	99500	NK	nk		
ST ISSEY	195500	71700	COPP	pb		
ST VINCENT	220700	79500	IRON	nk		
ST.CLEER CONSOLS	225400	69200	NK	nk		
ST.CLEER	223800	69200	NK	nk		
ST.COLUMB EAST	194300	63700	NK	nk		
ST.GEORGES	222800	86300	NK	nk		
ST.NEOT CONSOLS	218700	66700	NK	nk		
ST.STEPHENS	232200	86100	MANG	nk		
ST.STEPHENS	196300	51300	NK	nk		
ST.VINCENT GT.CONS	238600	69500	NK	nk		
STALLARDS	313000	118000	IRON	nk	185	
STANBEAR COTT	226800	78900	NK	nk		
STANCOMBE	280100	74000	MANG	nk	40	
STEEPERTON TOR	261500	88400	TIN	nk	1	
STENNAGWYN	192700	55000	NK	nk		
STOCKLAND			IRON	nk		
STOKE CLIMSLAND CONS	238600	76500	NK	nk		
STOKE GABRIEL			IRON	nk	4790	
STONEHOUSE AREA	246700	54900	COPP	nk		
STONEYARD WOOD	250700	140300	IRON	nk		
STORMSDOWN	276800	73100	COPP	sn as	11	752 AS
STOWE-S MINE	226200	71600	NK	nk		
STOWFORD	247700	131900	IRON	nk	2382	
STRAWBERRY EAST	196600	51000	NK	nk		
SUNDRIES			LEAD	zn	50	388 ZN
SWEETHEART MINE	201800	80600	NK	nk		
SWINCOMBE VALE	264700	72800	TIN	nk		
TAMAR CONSOLS EAST	243700	65800	LEAD	ag	2500	
TAMAR CONSOLS SOUTH	243700	64500	LEAD	ag	7117	
TAMAR CONSOLS	242400	65600	LEAD	ag	728	
TAMAR NEW SOUTH	243300	62900	LEAD	ag		
TAMAR NORTH	235900	80400	NK	nk		
TAMAR RIVER	241700	72300	ARSC	zn		
TAMAR SILVER LEAD	242400	65600	LEAD	ag f	4356	
TAMAR VALLEY	243700	67900	LEAD	ag f	93	1315 F
TAMAR	242400	65600	LEAD	ag	11964	
TAMWORTH	220400	67000	NK	nk		
TAR HALL			LEAD	nk		
TARN			IRON	nk	50	
TAVISTOCK GREAT CONSOLS EAST			COPP	sn as		
TAVISTOCK UNITED	248500	72300	NK	nk		

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
TAVY CONSOLS	246900	68800	COPP	as sn	3009	+3000 ASPY
TEIGN VALLEY	271300	87500	TIN	nk		
TEIGN VALLEY	283000	86500	BARI	pb	10357	
TEMPLE CLOUD			IRON	nk	219	
TERRAS SOUTH	193500	52400	TIN	fe	5	5423 FE
TERRAS	193200	52800	TIN	nk		
THISTLEMOOR CONSOLS	203500	66500	NK	nk		
THOMAS UNITED			LEAD	ag	70	
THOMAS	200800	80500	NK	nk		
THORNE LOWER			IRON	nk		
TIN HATCHES	219000	66700	NK	nk		
TIN HILL	195700	54300	TIN	nk	4	
TIN VALE CONSOLS	220700	74500	NK	nk		
TIN VALLEY	218700	67200	TIN	as	2	11
TINCROFT EAST	241100	73400	NK	nk		
TINERA	220900	74700	TIN	nk		
TIN-RS HILL+PHILLIPA	193600	79000	NK	nk		
TOKENBURY	229100	70800	COPP			
TOLDISH	191100	55800	TIN	nk		
TOLGARRICK(URANIUM)	193400	51900	NK	nk		
TOLGARRICK	193500	52400	ARSC	nk	10	
TOLPETHERWIN	227200	81900	IRON	nk		
TOM	237700	72900	LEAD	nk		
TONKIN	236900	70500	COPP	nk		
TOR WOOD	235600	65000	NK	nk		
TOR WOOD	253700	89100	NK	nk		
TORBAY IRON			IRON	nk	17300	
TOWER CONSOLS	198800	59700	IRON	nk		
TOY TOR			TIN	nk		
TREBARTHA LEMARNE	225500	77600	TIN	as w	20	201 AS
TREBEIGH CONSOLS	230200	69700	LEAD	ag	0.5	
TREBETHERICK	193700	77500	NK	nk		
TREBOROUGH			IRON	nk		
TREBULLETT	232800	78800	ANTI	nk	10	
TREBURGETT DUCHY GT.	207800	80800	NK	nk		
TREBURGETT OLD	205700	79700	LEAD	zn cu fe	2178	44 ZN
TREBURGETT SOUTH	205700	79100	NK	nk		
TREBURGETT UTD.	205800	80300	NK	nk		
TREBURGETT WEST	205300	79300	NK	nk		
TREBURLAND MANG	223800	79600	NK	nk		
TREBURLAND	223700	79400	TIN	w as	1	
TREBURSYE MINE	231300	84200	NK	nk		
TREBURTLE	225500	89000	NK	nk		
TREDARRUP	219100	90300	NK	nk		
TREDINNICK	236000	59700	LEAD	sb	14	
TREEBY			TIN	nk		
TREFFRY VIADUCT	191400	75400	NK	nk		
TREFRESA	195200	75600	IRON	nk		
TREFULLOCK MINE	189800	55700	NK	nk		
TREFULLOCK UTD.MINES	189900	55900	NK	nk		
TREFULLOCK	190200	56100	TIN	nk		

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
TREGARDOCK MINE	204100	83900	LEAD	ag fe	60	
TREGEAGLE	217500	68700	TIN	nk	128	
TREGEARE CONSOLS	203800	80000	NK	nk		
TREGELLES(TREGELLIS)	201500	77300	NK	nk		
TREGIRLS	221700	80200	NK	nk		
TREGLUM	223400	87100	NK	nk		
TREGLYN	197500	76400	LEAD	nk		
TREGODWELL Cu MINE	211100	84100	NK	nk		
TREGONETHA	195200	62700	IRON	nk	1543	
TREGONNA	191600	72300	COPP	ag zn		
TREGOODWELL	211300	83800	NK	nk		
TREGORDEN MINE	200100	73700	LEAD	nk	73	
TREGOSS MOOR	196600	60500	NK	nk		
TREGOSS	197700	61700	TIN	nk	3	
TREGUDDICK	228000	82000	NK	nk		
TREGUNE CONSOLS	222400	79700	COPP	nk	52	
TREHANE	228700	63800	LEAD	nk	4531	
TREHEAGLE MINE LTD.	218000	68400	NK	nk		
TREHILL	237200	73700	COPP	nk	540	
TRELAWNEY EAST	229500	64200	NK	nk		
TRELAWNEY NEW	231100	68300	ARSC	nk		
TRELAWNEY NORTH	229700	65600	LEAD	nk	327	
TRELAWNEY SOUTH	228500	62800	NK	nk		
TRELAWNEY	228700	63500	LEAD	ag as	24653	626 AS
TRELAWNEY	243800	69300	NK	nk		
TRELAWNY CONSOLS	243100	69600	NK	nk		
TRELEATHER	191200	76800	LEAD	ag		
TRELETHER GREAT OLD	191200	74500	NK	nk		
TRELIVER	192100	60600	IRON	nk	1378	
TRELOW	192100	69500	LEAD	ag		
TRELOWETH	198900	49900	COPP	nk	6283	
TREMAINE	188000	71000	NK	nk		
TREMOLLET	229700	75800	NK	nk		
TRENUTE	232900	79000	ANTI	nk		
TREORE	202000	80000	ANTI	ag pb cu au		
TRERANK	198000	60000	IRON	nk		
TRERETHERN	191600	73900	NK	nk		
TREROOSEL	205700	80800	NK	nk		
TRESAVEAN ST.COLUMB	189600	60900	NK	nk		
TRESELLYN	218800	78800	TIN	nk	4	
TRESILLIAN	218800	78800	NK	nk		
TRESPARRET	214600	91600	NK	nk		
TRESUNGERS OLD ROSE	200500	78900	NK	nk		
TRESWEETA MINE	193300	53700	NK	nk		
TRETHEVY COPP MINE	226400	69300	NK	nk		
TRETHIN	209400	84300	LEAD	ag		
TRETHIN	210400	81700	LEAD	nk		
TRETHOSA	194600	55400	IRON	nk		
TREVAN WOOD MINE	193600	50000	NK	nk		
TREVANION MINE	192900	51400	NK	nk		
TREVARRA	194300	75100	LEAD	nk		
TREVEDDOE	215100	69500	COPP	sn	2353	925 SN

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
TREVEGLOS MINE	188400	74400	NK	nk		
TREVELL	225400	81200	NK	nk		
TREVENA MANG	205700	88700	NK	nk		
TREVENNA	218100	68500	COPP	nk		
TREVESSA MINE	186500	55500	NK	nk		
TREVILLICK	206800	78900	LEAD	nk		
TREVINNICK	200700	78400	LEAD	ag sb sn	15	
TREVISSA	187000	56100	ZINC	pb	640	4 PB
TREVONE CONSOLS	189600	77300	NK	nk		
TREVORGUG	188500	73900	NK	nk		
TREW AND TREGLUM	222300	87300	NK	nk		
TREWALDER	207200	81700	NK	nk		
TREWANE	203600	68200	ANTI	nk		
TREWEATHA	229100	65400	LEAD	ag	4369	
TREWEETHA	193400	53700	IRON	nk		
TREWENNAN	206100	80300	NK	nk		
TREWETHA OLD CONSOLS	200800	80500	NK	nk		
TREWETHART	201800	80600	NK	nk		
TREWETHEN AND PENGENNA	205100	79000	ANTI	nk		
TREWETHEN	204900	78800	LEAD	zn sb		
TREWETLE	225500	89000	NK	nk		
TREWHEELA	191100	57200	IRON	nk		
TREWINT CONSOLS	221200	80000	TIN	nk	7	
TREWINT DOWNS MINE	221000	79900	NK	nk		
TREWINT MARSH	221500	80100	NK	nk		
TREWINT	220700	81000	WOLF	nk		
TREWISTON	193600	77500	NK	nk		
TREWITHEN	196900	50900	NK	nk		
TREWITTON	222900	71700	TIN	nk		
TREWOLVAS	194300	63700	NK	nk		
TREWORNAN	197800	74400	NK	nk		
TREZELL-D AND BL-KADON	218800	78500	NK	nk		
TROON	189100	57600	TIN	nk		
TRUE BLUE			LEAD	ag		
TRUGO	189400	60600	COPP	nk	43	
TRUSCOTT HIGHER	230400	85700	NK	nk		
TRUSCOTT	230500	85700	IRON	mn	540	
TUNNEL WOOD	256500	122200	NK	nk		
TURNCHAPEL IRON MINE	249300	52800	IRON	nk		
TWO WATERS MEET			IRON	nk		
UBLEY			LEAD	nk		
UGBOROUGH			IRON	nk	2233	
UNION MINES	193500	52200	NK	nk		
UNITED DART MINES			COPP	nk		
UNITED MINES	248500	72300	TIN	nk		
UNITED MINES	248500	72300	TIN	cu	173	
UNNAMED1	213700	91600	NK	nk		
UNNAMED2	214100	91600	NK	nk		
UNNAMED3	217400	99500	ANTI	nk		
UNNAMED4	217900	99200	NK	nk		
UNNAMED5	221900	88600	NK	nk		
UNNAMED6	223400	86800	NK	nk		

Mine name	BNG mE	BNG mN	Main	Sub	Output–main (tons)	Output–sub (tons)
UNNAMED7	223900	88700	NK	nk		
UNNAMED8	242500	59400	SLAT	nk		
UPTON			IRON	nk	5972	
URANIUM MINES	193500	52400	URAN	nk	655	
VENLAND	225400	68100	NK	nk		
VENTON	229300	66300	LEAD	nk	4	
VENTONWYN LITTLE	197100	50300	NK	nk		
VENTONWYN	196200	50400	TIN	nk	166	
VEOLAND CONSOLS	251400	66300	TIN	nk		
VICTORIA MINING CO.	235900	80400	NK	nk		
VICTORIA NEW	274400	71600	NK	nk		
VICTORIA	222200	68600	NK	nk		
VICTORIA	274400	71600	COPP	nk		
VINCENT	220900	79500	TIN	w	62	
VIOLET	194700	51300	NK	nk		
VIRGIN OLD	185400	53400	NK	nk		
VIRGIN	201200	69400	NK	nk		
VIRGIN	239100	69200	NK	nk		
VIRTUOUS LADY	247400	69800	COPP	sn	384	
VITIFER CONSOLS NEW	267800	82700	COPP	nk		
VITIFER EAST	270800	82300	TIN	nk	44	
VIVEHAM MINE	256800	138900	IRON	nk		
VIVIAN	193500	59200	NK	nk		
WALDEGRAVE WORKS			LEAD	fe		
WALKHAM AND POLDICE	249300	70700	LEAD	cu	5	25 CU
WALKHAM UNITED	249000	70800	TIN	nk	1.5	
WALKHAMPTON CONSOLS	252500	69700	COPP	nk		
WALTER	243200	78300	NK	nk		
WARD SOUTH	242700	67700	LEAD	ag	124	
WATERMOUTH GREAT	257300	147100	LEAD	ag		
WATSONS MINE	244100	73100	NK	nk		
WEBBERLEY WOOD	250500	125800	COAL	nk		
WEEK	245100	81100	NK	nk		
WELLINGTON EAST	189500	54300	NK	nk		
WEST DOWN	248800	70500	NK	nk		
WESTDOWNEND MINE	225400	85600	MANG	nk	+115	
WESTERLAKE	221900	71600	NK	nk		
WESTLEIGH	247500	128500	COAL	nk		
WHIDDON	275700	72100	COPP	sn		
WHISPER	215200	69600	TIN	nk	48	
WHITEMOOR	257200	130400	NK	nk		
WHITEWELL	205800	80300	LEAD	nk		
WHITEWORKS	261200	70800	TIN	nk	86	
WHITLEIGH	248300	59800	LEAD	ag	62	
WHITSTONE	246400	81800	MANG	pbo	61	
WILHEMINA	220900	79400	TIN	nk	+98	
WILLIAM AND MARY	246600	70200	COPP	nk		
WILLIAM AND MARY WORTH	238400	70100	LEAD	ag w sn as py	+10	
WILLIAMS SOUTH	240800	73200	NK	nk		
WILLIAMS	240800	73800	COPP	nk	170	
WIMBLEFORD	220700	74200	TIN	nk		

Mine name	BNG mE	BNG mN	Main	Sub	Output– main (tons)	Output– sub (tons)
WINFORD NO 1			IRON	nk	13530	
WINFORD NO 2			IRON	nk	1256	
WINFORD NO 3			BARI	nk	10	
WINFORD NO 4			MANG	fe	11	86 FE
WINFORD NO 5			IRON	nk		
WINFORD NO 6			IRON	nk		
WINFORD NO 7			IRON	nk		
WINFORD NO 8			IRON	nk		
WITHY BROOK MINE	225700	72100	NK	nk		
WOLBOROUGH	283900	69800	IRON	nk	1240	
WOLSTON'S IRON PAINT			IRON	nk	154	
WOOD MINE	247600	66100	LEAD	nk	13	
WOODCLOSE	198300	50300	TIN	nk	5	
WOOLACOMBE DOWN	246500	142200	IRON	nk		
WORKINGS	225400	89000	NK	nk		
WREY CONSOLS	230200	67900	LEAD	ag	5435	
WREY CONSOLS	271600	68400	TIN	nk		
WREY CONSOLS NORTH	230200	67900	LEAD	nk	10	
WREY	229800	66500	LEAD	ag		
YANNADON	254300	68300	IRON	nk		
YARNER	278300	78300	COPP	nk	2071	
YARNSCOMBE MINE	254100	124100	LEAD	nk		
YATTON			IRON	nk	3106	
YEALMPTON			IRON	nk	250	
YENNADON	254300	68300	IRON	nk		
YEO MILLS			NK	nk		
YEOLAND CONSOLS	251400	66300	TIN	nk	470	
YEOLAND SOUTH	251300	66000	TIN	nk	4	
YETLAND	247800	145000	LEAD	nk		
YOLLAND MINE	228500	70800	NK	nk		
ZEAL CONSOLS SOUTH			COPP	nk		
ZION	243100	69600	COPP	nk		

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