Mineralization of England and Wales

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Acknowledgements

Work on selecting sites for the GCR for what was to become the *Mineralization of England and Wales* GCR volume (and its companion volume on the *Mineralogy of Scotland*) began over 30 years ago, for the Nature Conservancy Council (NCC). The initial GCR site selection was co-ordinated largely by Dr L. Haynes for the NCC, with significant involvement from T.D. Ford, J. Horák, R.J. King, W.I. Stanton, R.F. Symes and B. Young. Dr Haynes also embarked on a comprehensive site documentation and text preparation programme for the metallogenetic sites from the various regionally based GCR site selection categories (called 'Blocks'; they covered the Lake District; the Mendips; the Peak District/Leicestershire/Cheshire and Shropshire (Southern Pennines); the Northern Pennines; South-West England; Scotland; and Wales). Dr Haynes produced a text prepared for publication under the guidance of the then GCR Editor-in-Chief, W.A. Wimbledon. The planned '*Metallogenesis*' title was in an advanced state when JNCC came into existence in 1990. A little while after the creation of JNCC and the country conservation agencies from what was formerly the NCC it was decided to publish accounts of the mineralization/mineralogy sites on a regional basis for the GCR Series of books. In part, this reflected the original site selection scheme and would help the newly formed country conservation agencies to justify the conservation case for the networks of sites in their care. Work began afresh on the present volume text in the late 1990s. However the initial documents were invaluable in the preparation of the new text, and great thanks are duly afforded to Dr Haynes.

The present volume is the combined work of the authors and contributors listed on page v. The Introduction (Chapter 1) was compiled and largely written by R.E. Bevins, but based in part on previous work by L. Haynes and B. Young. R.E. Bevins also compiled and wrote Chapter 5 (Wales) along with J.S. Mason, and R.E. Bevins oversaw the overall compilation and editing of the volume. Chapters 2 and 3 (The Lake District and The Pennines) were provided by B. Young; Chapter 4 (The Southern Pennines) by D.A.C. Manning (with contributions from R.A.D. Pattrick, A. Clark, A. Thurston, J. Vetterlein, J. Aumônier, M.L. White and G. Warrington); and Chapters 6 and 7 by R.F. Symes. The GCR editors, E.L. Durham and L.P. Thomas, provided feedback and guidance during the preparatory stages of the project. The project was managed by N.V. Ellis, GCR Publications Manager, JNCC and seen through to production by JNCC's editorial team, in particular E.L. Durham.

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On behalf of all of the authors and contributors, we would like to record our thanks to the owners and managers of land and quarries who have allowed access to the sites, either during previous work or specifically for this GCR volume.

Access to the countryside

This volume is not intended for use as a field guide. The description or mention of any site should not be taken as an indication that access to a site is open. Most sites described are in private ownership, and their inclusion herein is solely for the purpose of justifying their conservation. Their description or appearance on a map in this work should not be construed as an invitation to visit. Prior consent for visits should always be obtained from the landowner and/or occupier.

Information on conservation matters, including site ownership, relating to Sites of Special Scientific Interest (SSSIs) or National Nature Reserves (NNRs) in particular counties or districts may be obtained from the relevant country conservation agency headquarters listed below:

Countryside Council for Wales,
Maes-y-Ffynnon,
Penrhosgarnedd,
Bangor,
Gwynedd LL57 2DW.

Natural England,
Northminster House,
Peterborough PE1 1UA.

Scottish Natural Heritage,
Great Glen House,
Leachkin Road,
Inverness IV3 8NW.

Conserving our mineral heritage – JNCC policy statement

Sites that yield minerals are a key part of our natural heritage and a major scientific, educational and cultural resource. They are fundamental to understanding the character of ancient environments. The discovery, collection and study of minerals can be enjoyable and stimulating activities that give people a fascinating insight into the geological history of the Earth. However, the available mineral resource is finite. It is only through maintaining a prudent approach to the management of important mineral sites that future generations will be able to experience, study and enjoy them.

RESPONSIBLE MINERAL COLLECTING

In most circumstances, responsible mineral collecting is not harmful to the conservation of sites: it can actually benefit our understanding of geology. This is particularly true where the minerals are relatively common or the sites in which they are found are subject to high levels of natural or artificial degradation, such as coastal cliffs that are being eroded, or quarries that are being actively worked. In such situations collecting mineral specimens that might otherwise be destroyed can be beneficial to science, provided that they are properly documented and made available for study. Responsible mineral collecting can therefore be a valuable activity in the sustainable management and safeguard of our natural heritage.

IRRESPONSIBLE MINERAL COLLECTING

Irresponsible collecting provides no scientific or educational gain and is therefore an unacceptable activity resulting in irreparable damage to our mineral heritage. It will pose a clear threat where minerals are rare or the mineral source is limited in extent, for example in a localized lode. Collecting without proper recording and curation, inexpert collecting, over-collecting and inappropriate use of power tools and heavy machinery are likely to reduce or even destroy the scientific value of such sites. Unless the activity is undertaken in an appropriate manner, the statutory nature conservation agencies, the Countryside Council for Wales, Environment and Heritage Service, Natural England and Scottish Natural Heritage, will oppose mineral collecting on the small number of Sites of Special Scientific Interest / Areas of Special Scientific Interest where this activity would cause significant damage to the features of special interest.

Conserving our mineral heritage – JNCC policy statement

CODE OF GOOD PRACTICE

Adopting a responsible approach to collecting is essential for conserving our mineral heritage. The basic principles set out below should be followed by all those intending to collect minerals.

Access and ownership – permission to enter private land and collect minerals must always be gained and local bylaws should be obeyed. A clear agreement should be made over the future ownership of any rock material collected.

Collecting – in general, collect only a few representative specimens and obtain these from fallen or loose material. Detailed *scientific* study will require collection of minerals *in situ*.

Site management – avoid disturbance to wildlife. Many invertebrates and lower plants live on or under loose rocks that should be replaced in their original positions whenever possible. Do not leave the site in an untidy or dangerous condition for those who follow.

Recording and curation – always record precisely the locality at which minerals are found and, if collected *in situ*, record relevant details of the position of the rock from where the mineral was collected. Ensure that these records can be directly related to the relevant specimens. Where necessary, seek specialist advice on specimen identification and care. Minerals of prime scientific importance should be placed in a suitable repository, normally a museum with adequate curatorial and storage facilities.

MANAGEMENT OF OUR MINERAL HERITAGE

In order to achieve the successful management of the mineral heritage of the United Kingdom, the statutory nature conservation agencies will:

- Promote the responsible approach outlined in the *Code of Good Practice*, above.
- Encourage the placement of scientifically important minerals into a suitable repository (such as a museum) in order to ensure their proper curation, long-term security and accessibility.
- Recognize the contribution that responsible mineral collectors can make to geological and mineralogical study.
- Encourage collaboration within the geological community to ensure that maximum educational and scientific gain is made from our mineral resource.
- Support and encourage initiatives that increase awareness and understanding of the value of our mineral resource and the need to conserve it.
- Increase awareness and understanding of the differing management needs of mineral sites. In particular, encourage landowners and occupiers to become advocates for conservation of the mineral resource.
- Review the need for export and import controls on the international trade in mineral specimens.

JNCC, 1997

Preface

There is such a diversity of rocks, minerals, fossils and landforms packed into the piece of the Earth's crust we call 'Britain' that it is difficult to be unimpressed by the long, complex history of geological change to which they are testimony. But if we are to improve our understanding of the nature of the geological forces that have shaped our islands, further unravel their history in 'deep time' and learn more of the history of life on Earth, we must ensure that the most scientifically important Earth science sites are conserved for future generations to study, research and enjoy. Moreover, as an educational field resource and as training grounds for new generations of geologists on which to hone their skills, it is essential that such sites continue to remain available for study. The first step in achieving this goal is to identify the key sites, which is a primary aim of the Geological Conservation Review.

The GCR, formally launched in 1977, is a world-first in the systematic selection and documentation of a country's best Earth science sites. No other country has attempted such a comprehensive and systematic review of its Earth science sites on anything near the same scale. After three decades of site evaluation, consultation with the scientific community, and site documentation, we now have an inventory of over 3000 GCR sites, selected for 100 categories covering the entire range of the geological and geomorphological features of Britain.

The minimum criterion for GCR site selection is that sites should offer the finest and/or the most representative feature for illustrating a particular aspect of geology or geomorphology. The resulting GCR sites are thus, at the very least, of national scientific importance and many of these include features regarded as either 'classic' (i.e. a 'textbook example'), internationally important, or simply 'unique'. Some are, in addition, visually spectacular.

The present volume is the 36th to be published in the GCR series of books, which, when complete, will stretch to more than 40 volumes and provide a vast geoconservation information resource. This volume summarizes the considerable research that has been undertaken on the localities described and will be invaluable as an essential reference source for those engaged in their study and aims to provide a stimulus for further investigation. It will also be helpful to teachers and lecturers and for those people who, in one way or another, have a vested interest in the GCR sites: owners, occupiers, planners and those concerned with the practicalities of site conservation. The conservation value of the sites is mostly based on a specialist understanding of the Earth science features present

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and is, therefore, of a technical nature. The account of each site ends, however, with a brief summary of the geological interest, framed in less technical language, in order to help the non-specialist.

This volume deals with the state of knowledge of the sites available at the time of writing, and it must be seen in this context. There is still much to learn about the GCR sites documented here, in increasing our knowledge and understanding of geological history and processes. Geological studies, like any other science, are ever-developing, with new discoveries being made, and existing models being subject to continual testing and modification as new data comes to light. While the existing sites continue to enable us to add to our geological knowledge, increased or hitherto unrecognized significance may be seen in new sites. Indeed, during the writing of this volume, a number of additional localities were considered for inclusion and, after a period of assessment, were ultimately deemed to be worthy of GCR status and were included in this account. That fact is almost inevitable when one considers that some of the original networks of sites were drawn up over two decades ago.

Therefore, it is possible that further important sites will be identified in future years for the GCR as research continues. However, it must be stressed that the GCR is intended to be a *minimalist* scheme, with the selection of only the best, most representative, example of a geological feature, rather than the selection of a series of sites showing closely analogous features.

This account clearly demonstrates the value of the GCR sites to the study of mineralization and their importance within the wider context of Britain's outstanding scientific and natural heritage, and I am grateful to the authors for their perseverance and forebearance in the preparation of this book and their valuable contribution in assisting JNCC in its conservation goals.

N.V. Ellis,
GCR Publications Manager
January 2010

Chapter 1

Mineralization in England and Wales: an introduction

R.E. Bevins

BACKGROUND

The geological record in Great Britain reflects some 2900 million years of Earth history. A complex evolution through that time-period saw rock sequences developing in a wide range of tectonic settings, from the accumulation of thick sedimentary successions in extensional basins, sometimes associated with magmatism typically in the form of tholeiitic basaltic lava-flows and high-level intrusions, through subduction of these sequences as the Earth's plates came into contact, again associated with magmatism but this time with a calc-alkaline character, leading through to metamorphism in orogenic belts linked to major plate-collisional events. The complexity of the geology of Great Britain is illustrated in the geological map presented as Figure 1.1.

This volume relates to mineralization in England and Wales, and is a companion volume to that relating to mineralization in Scotland.

A consequence of this lengthy and complex evolution is the presence in Great Britain of a wide variety of mineralization styles, many of which provided deposits of economic importance, exploited over many centuries. There is evidence for extraction of copper as early as Bronze-Age times, for example at the **Great Orme Copper Mines** GCR site in North Wales, and at the **Cwmystwyth Mine** GCR site in the Central Wales Orefield. Also, there is abundant testimony to the activities of the Romans; Julius Caesar reported tin production in South-west England in the 1st century BC, and the Romans were known to have worked lead in Derbyshire, Yorkshire, the Mendips and Wales. The unique deposit at the **Seathwaite Graphite Mine** GCR site has evidence of the extraction of graphite as far back as Elizabethan times. When active, a number of the deposits in England and Wales were important on the world scale, for example the extraction of tin and copper in South-west England; whilst in its heyday, following discovery of the 'Great Lode' in 1768, the copper deposit at the **Parys Mountain** GCR site on Anglesey became the largest copper working in the world. Some sites bear testimony to former mining techniques, such as the 'hushes' at the **Pike Law Mines** GCR site. Other deposits, such as the Westphalian ironstones of South Wales, were crucial in the industrialization of Britain.

A small number of mineral deposits are still of economic or sub-economic importance today, such as the deposits of potassium salts, halite, anhydrite and gypsum of northern England that formed in the Zechstein and Bakevellia seas in Late Permian times, and developments of gypsum and celestine that occur in Late Triassic deposits of the Mercia Mudstone Group, and are represented by those at the **Gipsy Lane Brick Pit** and **Ben Knowle** GCR sites respectively. Some deposits remain on the fringe of economic viability, their exploitation being dictated by the world price for metals. A rise in tin prices in the 1960s saw a number of mines operating in South-west England, including Geevor, South Crofty, Pendarves, Mount Wellington and Wheal Jane. However, fortunes changed and the last of these to close was South Crofty in 1998. The complex base-metal volcanogenic massive sulphide deposit at the **Parys Mountain** GCR site continues to be reviewed, with the latest activity being the sinking of the Morris Shaft to a depth of 300 m by Anglesey Mining plc in the period 1985 to 1990, although exploratory drilling has continued subsequently. In early 2008, talks opened between Anglesey Mining plc and Western Metals, with a view to transfer of ownership. However, the decline in world zinc prices since 2007 has meant that those talks have now fallen through.

The legacy of this long history of mineral extraction is a large number of old mine sites which have, over the centuries, been the source of numerous mineral specimens, the more aesthetic of which reside in the world's major museum mineral collections. Certain localities are renowned by mineral collectors the world over, for example the **Roughtongill Mine** GCR site in the English Lake District for the very fine specimens of supergene lead and copper minerals; the **Florence Mine** GCR site, elsewhere in Cumbria, for spectacular 'kidney ore' hematite specimens; and the **Treak Cliff** GCR site in Derbyshire, famous for the unique deposits of 'Blue John' fluorite. However, it is not only for their aesthetic value that some localities are renowned. Some sites are famous for the sheer diversity of the minerals present, for example the **Penberthy Croft Mine** GCR site in South-west England, which has produced over 90 confirmed mineral species. Some sites contain mineral species which are extremely rare on a world-wide basis, such as the **Meldon**

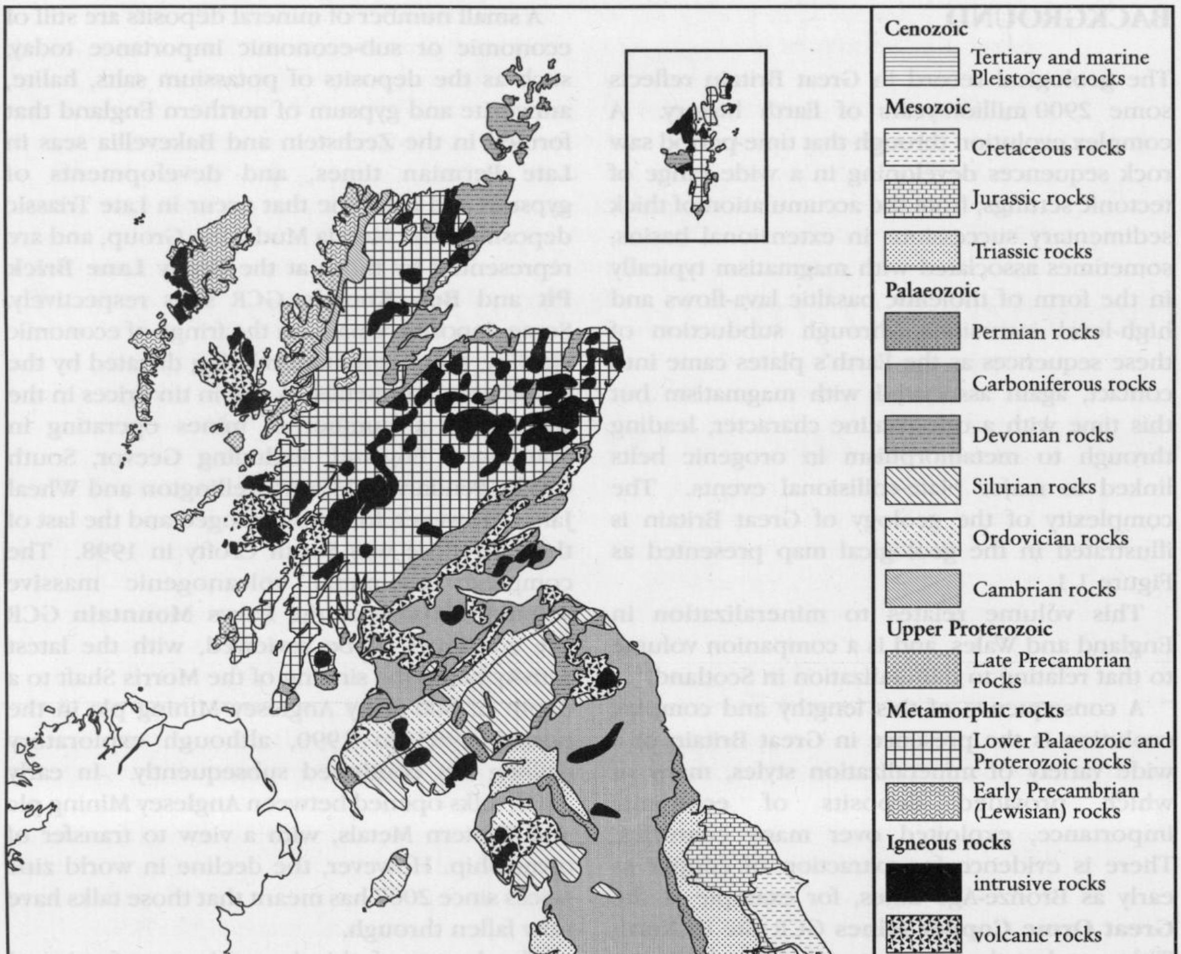

Figure 1.1 Geological map of Great Britain. Based on May and Hansom (2003), and British Geological Survey.

Aplite Quarries GCR site and the **Red-a-Ven Mine** GCR site, both in South-west England (but see the cautionary note at the end of this chapter). In addition, some sites are of importance for being type localities, that is a site from which a mineral species new to science was first described. For example, the **Bage Mine** GCR site in Derbyshire was the locality from which matlockite was first collected in 1851 by the famous mineral collector Bryce Wright. The **Benallt and Nant Mines** GCR site is the type locality for no less than three rare mineral species (banalsite, pennantite and cymrite). The **High Down Quarry** GCR site, in Devon, is the type locality for wavellite; the **Blagill Mine** GCR site, in the Northern Pennine Orefield, is the type locality for barytocalcite; and the **Hingston Down Quarry and Hingston Down Consols** GCR site in Cornwall is the type locality for arthurite. Other mineral type localities which are GCR sites include **Parys Mountain**, **Botallack Mine and Wheal Owles**, **Penberthy Croft Mine**, **Cligga Head**, and **Hope's Nose**. For some sites, however, the fact that it is a type locality is a subordinate interest, considering the importance for a particular feature or its place in a network of sites. The **Botallack Mine and Wheal Owles** and the **Cligga Head** GCR sites fall into this category.

Some mining districts in Great Britain have been studied in great detail and have become recognized worldwide as classic areas for understanding the processes of mineralization. Probably the most important regions in this context are the South-west England mineral province, with seminal contributions by Dines (1956) and Hosking (1964), and the Northern Pennine Orefield, with the classic accounts by Dunham (1948, 1990) and Dunham and Wilson (1985). Individual sites in these regions are difficult to recognize in terms of their international importance; rather it is the network of sites which combine to give a thorough appreciation of the mineralization history.

As a result of the diverse range of mineralization styles and the related exploitation activities in Great Britain there is a wealth of former mining sites which provide the opportunity to study the mineral deposits and their mineral parageneses, sometimes *in situ*, more commonly in the spoil heaps left over from the extractive activities. In South-west England it has been estimated that there are over 2500 former mine sites (Alderton, 1993), while the Minescan survey in Wales (Bevins and Mason, 1997) determined over 1200 disused mine sites. However, not all mineralizing processes lead to the generation of deposits of economic significance. Diagenetic through to low-grade metamorphic processes generate mineral assemblages of petrogenetic importance but of little economic significance. The development of zeolites is of commercial significance in other parts of the world but not in Great Britain. However, there are a small number of sites of uniqueness in Great Britain that are important for this GCR compilation, such as the **Croft Quarry** GCR site in the English Midlands and the **Dean Quarry** GCR site in South-west England. Certain areas of Great Britain, especially Wales and the Lake District, are important regions worldwide for the occurrence of low-grade prehnite-pumpellyite metamorphic assemblages, although no sites provide sufficient field evidence to be listed; most of the information comes from detailed microscopic investigations of fine-grained recrystallization assemblages in basic igneous rocks, comprising chlorite, albite, prehnite, pumpellyite, epidote and actinolite, and more rarely laumontite and axinite. The presence of pumpellyite metadomains described from Llanelwedd Quarry in Wales by Bevins (1985), and Metcalfe *et al.* (1996) is perhaps a notable exception.

It has been the challenge of this Geological Conservation Review of the mineralization in England and Wales to select those critical sites for understanding the history of mineralizing and metallogenic processes across the region. The findings of this review have led to a total network of approximately 137 sites of mineralogical importance being listed for scheduling. The criteria for selection of the sites is explored further later in this chapter.

The task of site selection has been greatly aided by a number of systematic regionally based reviews of the topographical mineralogy of Great Britain which have been published in the last 20 years or so, covering the Lake District (Young, 1987a; Cooper and Stanley, 1990), South-west England (Embrey and Symes, 1987), Wales (Bevins, 1994), Scotland (Livingstone, 2002), and most recently Northern England (Symes and Young, 2008). In turn, of course, these have drawn on even earlier regional studies, such as those by Pryce (1778) and Collins (1871) for South-west England, Mawe (1802) for Derbyshire, and Heddle (1901) for Scotland, to name but a few. Until recently, only the work of Greg and Lettsom (1858) had presented in a single volume an overview of the mineralogy of Great Britain and Ireland. However, Tindle (2008) has completely updated that volume, a monumental contribution which serves as an ideal companion volume to the two Geological Conservation Review volumes detailing the mineralization of England and Wales, and of Scotland. The seminal works of Dines (1956), and Hoskins (1964) detailing the South-west England mineral province, and the classic accounts by Dunham (1948, 1990), and Dunham and Wilson (1985) for the Northern Pennine Orefield have been mentioned above. Acknowledgement must also be made, however, to the comprehensive review of the mineralization of the British Isles compiled by Pattrick and Polya (1993), which many of the site reports in this volume draw upon.

GCR SITE SELECTION

The Geological Conservation Review was established with a view to identifying the most important sites that require protection and conservation in order that the geological evolution and history of Great Britain can be understood. The aim is that these sites will be notified as Sites of Special Scientific Interest (SSSIs), under the current Wildlife and Countryside Act 1981. A full explanation of the Geological Conservation Review process and the relevant legislation, along with practical considerations of implementation of findings are explained in Volume 1 of this series, *An Introduction to the Geological Conservation Review* (Ellis *et al.*, 1996). The GCR has identified three fundamental site-selection criteria; *international importance*, *presence of exceptional features*, and *representativeness*. Each site selected fits into at least one of these criteria, some into two and a few into all three.

The criteria for site selection in the Mineralogy of England and Wales block follow two main threads. Firstly, as listed in Table 1.1,

Table 1.1 Selection criteria for sites fundamental to understanding the mineralization of England and Wales, tabulated on the basis of geological time (section 1) and sites showing special features (section 2). *Continued opposite.*

1. Sites representative of the mineralization history of England and Wales

1.1 Cambrian–Ordovician exhalative Mn and Fe mineralization, North Wales

- Llyn Du Bach Complex
- Benallt and Nant Mines
- Tyllau Mwn

1.2 Ordovician porphyry copper mineralization, North Wales

- Bryn-Coch and Capel Hermon
- Glasdir Mine
- Moel Hafod-Owen
- Turf Copper Mine

1.3 Lower Palaeozoic gold vein mineralization, North Wales

- Cefn-Coch Mine
- Foel-Ispri Mine
- Friog Undercliff

1.4 Ordovician volcanism in North Wales

- Lliwedd Mine
- Llanberis Mine
- Cwm Tregalan–Shadow Gully
- Llyn Cwellyn Mine
- Ffestiniog Granite Quarry
- Afon Stwlan
- Bwlch Mine, Deganwy
- Cae Coch Mine
- Parys Mountain

1.5 Syn-tectonic 'Alpine-type' veins in North Wales

- Manod Quarry
- Coed Llyn y Garnedd
- Penrhyn Quarry

1.6 Ordovician volcanism in the Lake District

- Coniston Copper Mines
- Dale Head North and South Veins
- Seathwaite Copper Mines

1.7 Ordovician- to Devonian-age intrusions of the Lake District

- Carrock Mine–Brandy Gill
- Wet Swine Gill
- Buckbarrow Beck
- Water Crag
- Long Comb

1.8 Stratabound gold-arsenopyrite mineralization, Wales

- Dolaucothi Mine

1.9 Post-orogenic (A1) lead-zinc-copper mineralization in Central Wales

- Darren Mine
- Erglodd Mine
- Eaglebrook Mine
- Cwmystwyth Mine
- Brynyrafr Mine

Table 1.1 *Continued.*

1.10 Mineralization associated with Devonian volcanism in South-west England

Lidcott Mine
Wheal Emily

1.11 Early Carboniferous extension-related mineralization – Mississippi Valley-type in Wales and Shropshire (including A2 mineralization in Central Wales)

Ceulan Mine Opencast
Nantiago Mine
Brynyrafr Mine
Nantymwyn Mine
Cwmystwyth Mine
Eaglebrook Mine
Halkyn Mountain
Pool Park and South Minera Mines
Pennant Mine
Great Orme Copper Mines
Huglith Mine
Snailbeach Mine

1.12 Late Carboniferous–early Permian Mississippi Valley-type mineralization of the Lake District, and the Northern Pennine and South Pennine orefields

Eagle Crag
Force Crag Mine
Lady's Rake Mine
West Rigg Opencut
Killhope Head
Smallcleugh Mine
Tynebottom Mine
Scordale Mines
Settlingstones Mine
Willyhole Mine
Fallowfield Mine
Closehouse Mine
Black Scar, Middleton Tyas
Cumpston Hill North and South Veins
Greenhow (Duck Street) Quarry
Blagill Mine
Gunnerside Gill, Swaledale
Foster's Hush
Pike Law Mines
Sir John's Mine
Stonecroft Mine
Dirtlow Rake and Pindale
Treak Cliff
Windy Knoll
Ecton Copper Mines
Masson Hill Mines
Fall Hill Quarry

1.13 Late Carboniferous–early Permian mineralization associated with the Cornubian Batholith

Skarns

Haytor Iron Mine
Red-a-Ven Mine, Meldon

Pegmatites and aplites

Trevalour Downs Pegmatite
Meldon Aplite Quarries
Tremearne Par

Greisens, stockworks, etc

Cameron Quarry (endogranitic)
St Michael's Mount (endogranitic)
Cligga Head
Mulberry Down Opencast (exogenetic)
Great Wheal Fortune

Tourmalinization

Priest's Cove, Cape Cornwall
Nanjizal Cove

Main-stage polymetallic veins

Cameron Quarry
Cligga Head
Wheal Coates
Trevaunance Cove, St Agnes
Wheal Alfred
Botallack Mine and Wheal Owles
Devon United Mine
Devon Great Consols
Penlee Quarry, Newlyn
Hingston Down Quarry and Consols
Great Wheal Fortune

Cross-course mineralization

Botallack Mine and Wheal Owles
Lockridge Mine
Penlee Quarry, Newlyn
Perran Beach to Holywell Bay
Wheal Penrose
Devon United Mine

Late-stage mineralization

South Terras Mine

1.14 Permian–early Triassic iron ores of Cumbria

Florence Mine
Nab Gill Mine

1.15 Triassic Fe-Mn mineralization in the Mendips and South Wales

Mwyndy Mine
Ogmore Coast
Compton Martin Ochre Mine
Hartcliff Rocks Quarry

1.16 Triassic evaporites and arid weathering products

Ben Knowle
Gipsy Lane Brick Pit
Warren Quarry

1.17 Mineralization related to Mesozoic basinal extension in South Wales, the Welsh Borderland and the Mendips

Ogmore Coast
Machen Quarry
Banwell Caves
Charterhouse Lead Orefield
Clevedon Shore
Wurt Pit
Dolyhir Quarry

1.18 Mesozoic–Tertiary sediment-hosted mineralization of the Cheshire Basin

Alderley Edge District

1.19 Pliocene to Pleistocene solution collapse and fill deposits in Derbyshire and Somerset

Portway Gravel Pits
Kirkham's Silica Sandpits
Banwell Ochre Caves

Table 1.1 *Continued.*

2. Sites showing other important aspects of mineralogy in England and Wales

2.1 Supergene alteration

- Turf Copper Mine
- Mynydd Nodol Mine
- Machen Quarry
- Parys Mountain
- Llechweddhelyg Mine
- Frongoch Mine
- Drygill Mine
- Roughtongill Mine
- Red Gill Mine
- Birk Fell Hawse Mine
- Dale Head North and South Veins
- Carrock Mine–Brandy Gill
- Seathwaite Copper Mines
- Pikedaw Calamine and Copper Mines
- Willyhole Mine
- Foster's Hush
- Pike Law Mines
- Newhurst Quarry
- Penberthy Croft Mine
- Alderley Edge District

2.2 Zeolitization

- Dean Quarry, Lizard
- Croft Quarry

2.3 Exceptional features

- Glasdir Mine
- Moel Hafod-Owen
- Turf Copper Mine
- Parys Mountain
- Cae Coch Mine
- Snailbeach Mine
- Seathwaite Graphite Mine
- Water Crag
- Long Comb
- Lady's Rake Mine
- Pikedaw Calamine and Copper Mines
- Foster's Hush
- Pike Law Mines
- Ton Mawr Quarry
- Treak Cliff
- Calton Hill
- Wurt Pit
- Gravel Hill Mine
- Penberthy Croft Mine
- Botallack Mine and Wheal Owles
- Hope's Nose
- Meldon Aplite Quarries
- Alderley Edge District

2.4 Aesthetic specimens

- Roughtongill Mine
- Red Gill Mine
- Dry Gill Mine
- Florence Mine
- Smallcleugh Mine
- Scordale Mines
- Blagill Mine
- Settlingstones Mine
- Fallowfield Mine
- Treak Cliff
- Parys Mountain
- Manod Quarry
- Hope's Nose
- Wheal Alfred

2.5 Rare mineral species/parageneses

- Benallt and Nant Mines
- Bwlch Mine, Deganwy
- Parys Mountain
- Erglodd Mine
- Eaglebrook Mine
- Dolyhir Quarry
- Llechweddhelyg Mine
- Frongoch Mine
- Seathwaite Graphite Mine
- Buckbarrow Beck
- Long Comb
- Water Crag
- Wet Swine Gill
- Carrock Mine–Brandy Gill
- Roughtongill Mine
- Red Gill Mine
- Dry Gill Mine
- Seathwaite Copper Mines
- Lady's Rake Mine
- Tynebottom Mine
- Blagill Mine
- Fallowfield Mine
- Settlingstones Mine
- Closehouse Mine
- Foster's Hush
- Gipsy Lane Brick Pit
- Warren Quarry
- Botallack Mine and Wheal Owles
- Cligga Head
- Hope's Nose
- Meldon Aplite Quarries
- Penberthy Croft Mine
- Red-a-Ven Mine, Meldon
- Alderley Edge District

2.6 Type localities

- High Down Quarry
- Blagill Mine
- Fallowfield Mine
- Bage Mine
- Benallt and Nant Mines
- Parys Mountain
- Botallack Mine and Wheal Owles
- Cligga Head
- Hingston Down Quarry and Consols
- Hope's Nose

2.7 Mining history significance

- Seathwaite Graphite Mine
- Coniston Copper Mines
- Dale Head North and South Veins
- Carrock Mine–Brandy Gill
- Roughtongill Mine
- Red Gill Mine
- Smallcleugh Mine
- Lady's Rake Mine
- Scordale Mines
- Settlingstones Mine
- Blagill Mine
- Fallowfield Mine
- Pikedaw Calamine and Copper Mines
- Sir John's Mine
- Gunnerside Gill, Swaledale
- Parys Mountain
- Cwmystwyth Mine
- Great Orme Copper Mines
- Pike Law Mines
- Alderley Edge District

2.8 Understanding mineral sciences

- Castle Hill Quarry
- Windy Knoll
- Treak Cliff

there is a group of sites (set 1.1 to 1.18), which demonstrate the mineralization history of England and Wales through time. Then there is a second set of sites (set 2.1 to 2.8) which are included because of a variety of exceptional features, including for example the range of rare mineral species present, the aesthetic qualities of specimens from the site, because they are type localities, or for the exceptional mineralization features present. Table 1.2 presents the same information as in Table 1.1 but formatted to highlight the geographical distribution of the sites on the basis of the major mineralization areas described in this volume, namely the Lake District (Chapter 2), the Northern Pennines (Chapter 3), the Southern Pennines of Derbyshire, but including also Cheshire, Leicestershire and Shropshire (Chapter 4), Wales (Chapter 5), the Mendip Hills (Chapter 6), and finally South-west England (Chapter 7). The geographical spread of the sites is illustrated in Figure 1.2.

The international importance of the mineral sites in England and Wales has already been highlighted above. To these could be added the **Botallack Mine and Wheal Owles** GCR site, which is of international significance in providing evidence of varying stages of mineralization in the tin zone and the lower part of the copper zone of the main-stage mineralization associated with the Cornubian Batholith. Unrelated to this scheduling, but indicative of the international importance of this site, is the fact that Botallack Mine was central to the inscription in 2006 of the 'Cornwall and West Devon Mining Landscape' onto UNESCO's World Heritage list.

There are a number of mineralogical sites in England and Wales which show the presence of exceptional features. In Wales, the **Glasdir Mine** GCR site represents a rare mineralized explosion pipe-breccia with mineralization linked to a porphyry copper system. The **Treak Cliff** GCR site, with its deposits of 'Blue John' fluorite, is undoubtedly unique; as is the **Turf Copper Mine** GCR site, associated with the Coed y Brenin porphyry copper deposit in southern Snowdonia. The **Hope's Nose** GCR site is unique in Great Britain for the style of gold mineralization present, as well as being the type locality for chrisstanleyite, while the celebrated graphite deposit at the **Seathwaite Graphite Mine** GCR site has no counterpart in Great Britain. Exceptional metasomatic cavity-fill mineral assemblages in Carboniferous carbonate host-rocks are seen at the **Ton Mawr Quarry** GCR site, in South Wales. In Cornwall, the Perran Iron Lode, best seen at the **Gravel Hill Mine** GCR site, has no counterpart in the South-west England mineral province. Finally, the uniqueness of a number of type localities for mineral species has been mentioned previously.

A number of sites listed have historic significance in the development of our understanding of mineralization processes; perhaps one of the more important in progressing our understanding has been the debate over the origin of organic material associated with mineral deposits, namely whether it is of biogenic or abiogenic origin. The GCR sites at **Windy Knoll** and **Treak Cliff** cover this, but most importantly this is the main criteria for listing of the **Castle Hill Quarry** GCR site, in the English Midlands.

The criterion of representativeness aims to ensure that all major elements of the mineralization are represented in the ultimate GCR site list. The majority of the sites listed in this volume fall into this category. However, within this category there are inter-related sites, which highlight a particular geological phenomenon. For example, the GCR sites at **Lliwedd Mine**, **Llanberis Mine** and **Cwm Tregalan–Shadow Gully** represent mineralization processes that have been identified as being generated in the Snowdon volcanic caldera in Ordovician times, and which formed the basis of the model presented by Reedman *et al.* (1985).

However there are some *regionally* important mineral sites that are not covered by the extensive listing in this volume. In some cases this is because there are no localities that show any exceptional features or there are none that exhibit the typical features of the suite any better than numerous other localities. It is important therefore to identify 'regionally important Geological/Geomorphological Sites' (RIGS) to represent such sites, even though this status carries no formal legal protection. Nevertheless, the importance of these sites needs to be recognized and recorded, facilitating conservation at a local level. In this volume there is no description, for example, of the claystone–ironstone nodule mineralization in the South Wales Coalfield. Unfortunately, most of the important sites from which the mineralized nodules have been collected have been landscaped, and presently no sites show evidence of their origin. Also, all but a few mines in the area

Table 1.2 Site selection criteria for sites fundamental to understanding the mineralization of England and Wales, tabulated on the basis of geographical distribution (* = national significance, I = international significance). *Continued opposite.*

	Sites representative of the mineralization history of England and Wales																				**Sites showing other important aspects of mineralogy in England and Wales**							
Selection Criteria	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**1.10**	**1.11**	**1.12**	**1.13**	**1.14**	**1.15**	**1.16**	**1.17**	**1.18**	**1.19**		**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**	**2.7**	**2.8**
Site name																												
Lake District																												
Seathwaite Graphite Mine																							I		*		*	
Water Crag							*																*		*			
Coniston Copper Mines						*																					*	
Birk Fell Hawse Mine																					*							
Dale Head North and South Veins						*															*						*	
Wet Swine Gill							*																		*			
Carrock Mine–Brandy Gill							*														*				*		*	
Buckbarrow Beck							*																		*			
Long Comb							*																*		*			
Red Gill Mine																					*			*	*		*	
Roughtongill Mine																					*			I	*		*	
Dry Gill Mine																					*			I	*			
Eagle Crag												*																
Florence Mine														*										I				
Nab Gill Mine														*														
Seathwaite Copper Mines						*															*				*			
Force Crag Mine												*																
Northern Pennines																												
West Rigg Opencut												*																
Killhope Head												*																
Smallcleugh Mine												*												*			*	

Table 1.2 *Continued.*

	Sites representative of the mineralization history of England and Wales																			Sites showing other important aspects of mineralogy in England and Wales							
Selection Criteria	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**1.10**	**1.11**	**1.12**	**1.13**	**1.14**	**1.15**	**1.16**	**1.17**	**1.18**	**1.19**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**	**2.7**	**2.8**
Site name																											
Tynebottom Mine												*												*			
Sir John's Mine												*														*	
Scordale Mines												*											*			*	
Lady's Rake Mine												*										*				*	
Willyhole Mine												*								*							
Pike Law Mines												*								*		*				*	
Blagill Mine												*											*	*	*	*	
Settlingstones Mine												*											*	*		*	
Stonecroft Mine												*															
Fallowfield Mine												*											*	*	*	*	
Closehouse Mine												*												*			
Foster's Hush												*								*		*		*			
Black Scar, Middleton Tyas												*															
Cumpston Hill North and South Veins												*															
Greenhow (Duck Street) Quarry												*															
Pikedaw Calamine and Copper Mines																				*		*				*	
Gunnerside Gill, Swaledale												*														*	
South Pennines Orefield: Cheshire, Leicestershire and Shropshire																											
Castle Hill Quarry, Mountsorrel																											*

Table 1.2 *Continued.*

	Sites representative of the mineralization history of England and Wales																			Sites showing other important aspects of mineralogy in England and Wales							
Selection Criteria	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**1.10**	**1.11**	**1.12**	**1.13**	**1.14**	**1.15**	**1.16**	**1.17**	**1.18**	**1.19**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**	**2.7**	**2.8**
Site name																											
Croft Quarry																					*						
Newhurst Quarry																				*							
Warren Quarry																*								*			
Gipsy Lane Brick Pit																*								*			
Calton Hill																						*					
Masson Hill Mines												*															
Dirtlow Rake and Pindale												*															
Bage Mine																									*		
Fall Hill Quarry												*															
Treak Cliff												*										I	I				*
Windy Knoll												*															*
Portway Gravel Pits																			*								
Kirkham's Silica Sandpits																			*								
Ecton Copper Mines												*															
Alderley Edge District																		*		*		*		*		*	
Snailbeach Mine											*											*					
Huglith Mine											*																
Wales																											
Llyn Du Bach Complex	*																										
Benallt and Nant Mines	*																							I	I		
Tyllau Mwn	*																										
Bryn-Coch and Capel Hermon		*																									

Table 1.2 *Continued.*

Selection Criteria	Sites representative of the mineralization history of England and Wales																			Sites showing other important aspects of mineralogy in England and Wales							
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.19	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8
Site name																											
Glasdir Mine		*																				*					
Moel Hafod-Owen		*																				*					
Turf Copper Mine		*																		*		*					
Foel-Ispri Mine			*																								
Cefn-Coch Mine			*																								
Friog Undercliff			*																								
Lliwedd Mine				*																							
Llanberis Mine				*																							
Cwm Tregalan–Shadow Gully				*																							
Llyn Cwellyn Mine				*																							
Bwlch Mine, Deganwy				*																				*			
Parys Mountain				*																*		I	*	*	*	I	
Cae Coch Mine				*																		I					
Ffestiniog Granite Quarry				*																							
Afon Stwlan				*																							
Manod Quarry					*																		*				
Coed Llyn y Garnedd					*																						
Penrhyn Quarry					*																						
Dolaucothi Mine								*																			
Cwmystwyth Mine									*		*															*	
Brynyrafr Mine									*		*																
Darren Mine									*																		
Erglodd Mine									*															*			
Eaglebrook Mine									*		*													*			

Table 1.2 *Continued.*

	Sites representative of the mineralization history of England and Wales																			Sites showing other important aspects of mineralogy in England and Wales							
Selection Criteria	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**1.10**	**1.11**	**1.12**	**1.13**	**1.14**	**1.15**	**1.16**	**1.17**	**1.18**	**1.19**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**	**2.7**	**2.8**
Site name																											
Ceulan Mine Opencast											*																
Nantiago Mine											*																
Nantymwyn Mine											*																
Dolyhir Quarry																	*							*			
Halkyn Mountain											*																
Pool Park and South Minera Mines											*																
Pennant Mine											*																
Great Orme Copper Mines											*															*	
Mwyndy Mine															*												
Ton Mawr Quarry																						*					
Ogmore Coast															*		*										
Machen Quarry																	*			*							
Llechweddhelyg Mine																				*				*			
Frongoch Mine																				*				*			
Mynydd Nodol Mine																				*							
Mendip Hills																											
Banwell Caves																	*										
Banwell Ochre Caves																			*								
Ben Knowle																*											
Charterhouse Lead Orefield																	*										

Table 1.2 *Continued.*

	Sites representative of the mineralization history of England and Wales																			Sites showing other important aspects of mineralogy in England and Wales							
Selection Criteria	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**1.10**	**1.11**	**1.12**	**1.13**	**1.14**	**1.15**	**1.16**	**1.17**	**1.18**	**1.19**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**	**2.7**	**2.8**
Site name																											
Clevedon Shore																	*										
Wurt Pit																	*					*					
Compton Martin Ochre Mine															*												
Hartcliff Rocks Quarry															*												
South-west England																											
Meldon Aplite Quarries													*									*		*			
Priest's Cove, Cape Cornwall													*														
Trevalour Downs Pegmatite													*														
Tremearne Par													*														
Red-a-Ven Mine, Meldon													*											*			
Haytor Iron Mine													*														
Botallack Mine and Wheal Owles													*									I		*	*		
Wheal Coates													*														
Lidcott Mine										*																	
Wheal Emily										*																	
Cligga Head													*											*	*		
Cameron Quarry													*														
St Michael's Mount													*														

Table 1.2 *Continued.*

Selection Criteria	Sites representative of the mineralization history of England and Wales																			Sites showing other important aspects of mineralogy in England and Wales							
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.19	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8
Site name																											
Mulberry Down Opencast													*														
Great Wheal Fortune													*														
Nanjizal Cove													*														
Devon Great Consols													*														
Devon United Mine													*														
Trevaunance Cove, St Agnes													*														
Perran Beach to Holywell Bay													*														
Lockridge Mine													*														
South Terras Mine													*														
Wheal Penrose													*														
Wheal Alfred													*										*				
Penberthy Croft Mine																				*		*		*			
Hope's Nose																						*	*	*	I		
High Down Quarry																									*		
Hingston Down Quarry and Consols													*												*		
Penlee Quarry, Newlyn													*														
Gravel Hill Mine																						*					
Dean Quarry, Lizard																					*						

have closed and so there is little chance of new exposures. To illustrate this episode of mineralization, a broad overview is presented, along with references to key publications.

The site reports are presented in this volume on a regional basis. In light of this, a brief overview of the major mineralization episodes in England and Wales is presented in the following paragraphs. This is presented largely on a time basis, although it has not been possible yet to date accurately all of the mineralization events present.

MINERALIZATION HISTORY OF ENGLAND AND WALES

The oldest significant mineralization determined in Great Britain is the Besshi-style copper-zinc-gold mineralization which occurs in deformed Lewisian Loch Maree Group metabasic supracrustal rocks near Gairloch and which has been shown to contain a sub-economic deposit known as the 'Kerry Road sulphide deposit' (see Jones *et al.*, 1987). No rocks as old as the Lewisian occur in England and Wales. Indeed, the oldest rocks in this region date back only to *c.* 700 Ma. These Neoproterozoic rocks formed part of Eastern Avalonia, which was situated on the north-east margin of Gondwana and were associated with subduction along this margin which generated magmatism and basin development. No significant mineralization episodes have been determined in this region of southern Britain, although the **Newhurst Quarry** GCR site in Leicestershire shows mineralization concentrated at the unconformable boundary between Neoproterozoic Charnian Supergroup rocks and overlying Triassic rocks, the mineralization being concentrated at this horizon because of lithological contrasts across the boundary.

Early Palaeozoic times saw the geological history of southern Britain dominated by the separation of Avalonia from Gondwana and its migration towards Laurentia. Again, this period was dominated by basin generation and magmatism associated with the south-eastwards subduction of Iapetus oceanic crust beneath Avalonia. Terranes identified in the Lower Palaeozoic sequences of England and Wales reflect the accretion of various crustal fragments as Avalonia drifted towards Laurentia. The earliest significant mineral deposits in the Lower Palaeozoic sequences of England and Wales relate to sedimentary exhalative processes in Cambrian times, generating bedded manganese and iron silicate and carbonate deposits. This episode is best seen at the **Llyn Du Bach Complex** GCR site, with the mineralization being dominated by rhodochrosite and kutnohorite, along with more minor spessartine, hematite, magnetite and ferropyrophanite. The structurally more complex manganese mineral deposits at the **Benallt and Nant Mines** GCR site are also considered to be sedimentary exhalative in origin, although here barium is more common in association with the manganese, and the site is important for the large number of rare, sometimes well-crystallized manganese and barium silicates present, including banalsite, pennantite, cymrite and bannisterite, the site being the type locality for the first three of those species.

Ordovician times were dominated by volcanic activity, as noted above, linked to the south-eastwards subduction of Iapetus oceanic crust. The earliest eruptive events occurred in late Tremadoc to early Arenig times, with calc-alkaline magmas occurring in southern Snowdonia, forming the Rhobell Volcanic Complex, and in Pembrokeshire, forming the Treffgarne Volcanic Group. In Pembrokeshire, there is evidence for copper mineralization in the Treffgarne area, as well as farther west, around Llandeloy, where contemporary dioritic intrusions are associated with a hidden porphyry copper deposit (see Allen *et al.*, 1976). However, exposures are slightly better developed in southern Snowdonia, where a major porphyry copper deposit has been identified in the Coed y Brenin region, a system which represents one of the oldest and best-preserved examples of a porphyry copper system in the world. The mineralization is associated with a suite of altered microtonalites and dolerites, comprising thin veinlets and disseminations of pyrite and chalcopyrite. Fresh, primary mineralization is rarely seen, the **Bryn-Coch and Capel Hermon** GCR site offering the best opportunity to study this mineralization episode. Associated with this mineralizing event, the **Glasdir Mine** GCR site records an intrusive explosion event, unique in the southern Caledonide region, while the **Moel Hafod-Owen** GCR site shows higher-level sinter-like textures within a breccia pipe, linked to fumarolic activity. A site unique to Great Britain is the **Turf Copper Mine** GCR site, where copper mobilized from the Coed y Brenin porphyry copper deposit has been precipitated as native copper on organic matter in a peat bog.

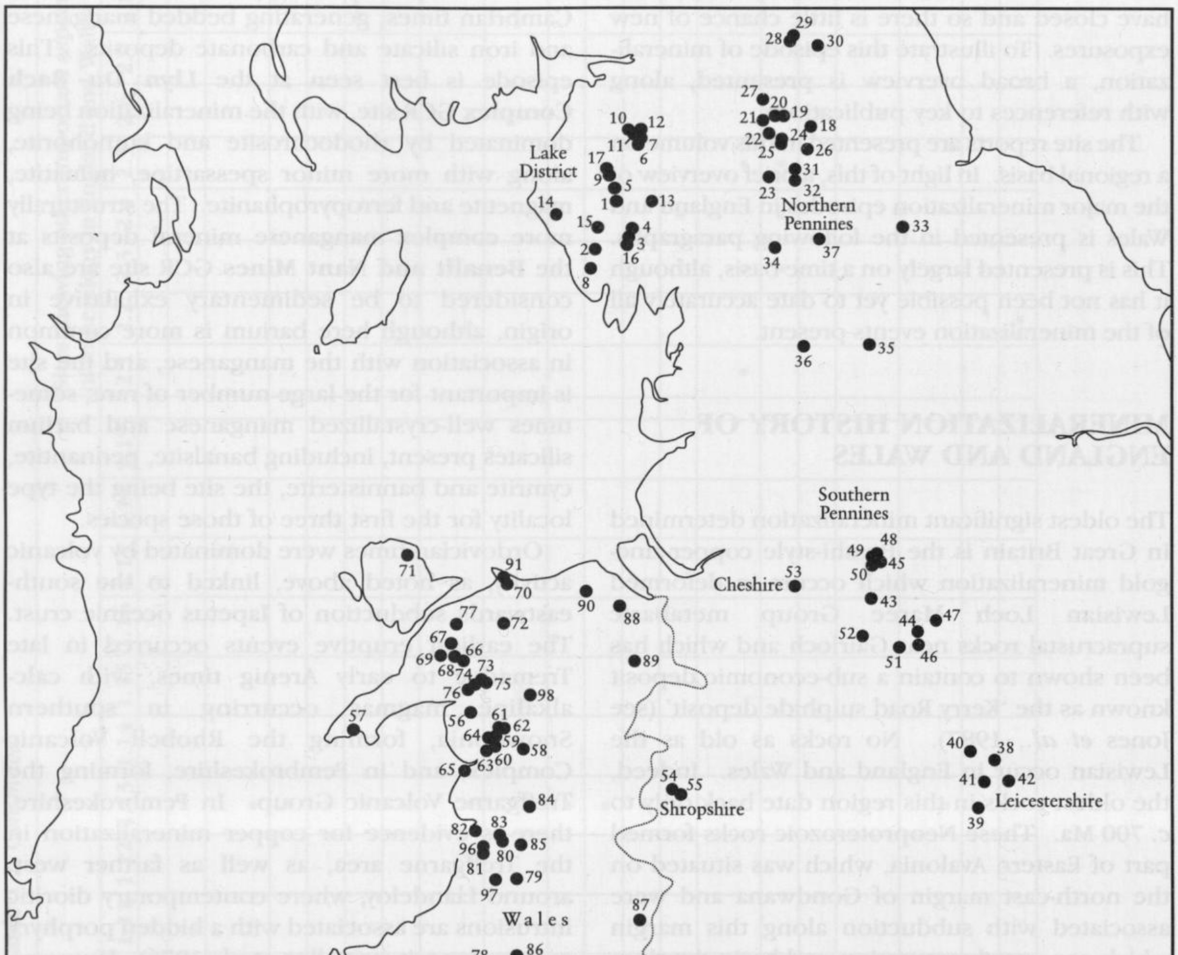

Figure 1.2 **Map showing the locations of the mineralization GCR sites in England and Wales.**

1	Seathwaite Graphite Mine, Cumbria
2	Water Crag, Cumbria
3	Coniston Copper Mines, Cumbria
4	Birk Fell Hawse Mine, Cumbria
5	Dale Head North and South Veins, Cumbria
6	Wet Swine Gill, Cumbria
7	Carrock Mine–Brandy Gill, Cumbria
8	Buckbarrow Beck, Cumbria
9	Long Comb, Cumbria
10	Red Gill Mine, Cumbria
11	Roughtongill Mine, Cumbria
12	Dry Gill Mine, Cumbria
13	Eagle Crag, Cumbria
14	Florence Mine, Cumbria
15	Nab Gill Mine, Cumbria
16	Seathwaite Copper Mines, Cumbria
17	Force Crag Mine, Cumbria
18	West Rigg Opencut, Durham
19	Killhope Head, Durham
20	Smallcleugh Mine, Durham
21	Tynebottom Mine, Durham
22	Sir John's Mine, Durham
23	Scordale Mines, Durham
24	Lady's Rake Mine, Durham
25	Willyhole Mine, Durham
26	Pike Law Mines, Durham
27	Blagill Mine, Durham
28	Settlingstones Mine, Northumberland
29	Stonecroft Mine, Northumberland
30	Fallowfield Mine, Northumberland
31	Closehouse Mine, Durham
32	Foster's Hush, Durham
33	Black Scar, Middleton Tyas, North Yorkshire
34	Cumpston Hill North and South Veins, North Yorkshire
35	Greenhow (Duck Street) Quarry, North Yorkshire
36	Pikedaw Calamine and Copper Mines, North Yorkshire
37	Gunnerside Gill, Swaledale, North Yorkshire
38	Castle Hill Quarry (Mountsorrel Granite Quarry; Main Quarry), Leicestershire
39	Croft Quarry, Leicestershire
40	Newhurst Quarry, Leicestershire
41	Warren Quarry, Leicestershire
42	Gipsy Lane Brickpit (Gypsy Lane Brickpit), Leicestershire
43	Calton Hill, Derbyshire
44	Masson Hill Mines, Derbyshire
45	Dirtlow Rake and Pindale, Derbyshire
46	Bage Mine, Derbyshire
47	Fall Hill Quarry, Derbyshire
48	Treak Cliff, Derbyshire
49	Windy Knoll, Derbyshire
50	Portway Gravel Pits, Derbyshire
51	Kirkhams Silica Sand Pits, Derbyshire
52	Ecton Copper Mines, Derbyshire
53	Alderley Edge, Cheshire
54	Snailbeach Mine, Shropshire
55	Huglith Mine, Shropshire
56	Llyn Du Bach Complex, Wales
57	Benallt and Nant Mines, Wales
58	Tyllau Mwn, Wales
59	Bryn-Coch and Capel Hermon, Wales
60	Glasdir Mine, Wales
61	Moel Hafod-Owen, Wales
62	Turf Copper Mine, Wales
63	Foel-Ispri Mine, Wales
64	Cefn-Coch Mine, Wales
65	Friog Undercliff, Wales
66	Lliwedd Mine, Wales
67	Llanberis Mine, Wales
68	Cwm Tregalan–Shadow Gully, Wales
69	Llyn Cwellyn Mine, Wales
70	Bwlch Mine, Deganwy, Wales
71	Parys Mountain, Wales
72	Cae Coch Mine, Wales
73	Ffestiniog Granite Quarry, Wales
74	Afon Stwlan, Wales
75	Manod Quarry, Wales
76	Coed Llyn y Garnedd, Wales
77	Penrhyn Quarry, Wales
78	Dolaucothi Mine, Wales
79	Cwmystwyth Mine, Wales
80	Brynyrafr Mine, Wales
81	Darren Mine, Wales
82	Erglodd Mine, Wales
83	Eaglebrook (Nant y cagl) Mine, Wales
84	Ceulan Mine Opencast, Wales
85	Nantiago Mine, Wales
86	Nantymwyn Mine, Wales
87	Dolyhir Quarry, Wales
88	Halkyn Mountain, Wales
89	Pool Park and South Minera Mines, Wales
90	Pennant Mine, Wales
91	Great Orme Copper Mines, Wales
92	Mwyndy Mine, Wales
93	Ton Mawr Quarry, Wales
94	Ogmore Coast, Wales
95	Machen Quarry, Wales
96	Llechweddhelyg Mine, Wales
97	Frongoch Mine, Wales
98	Mynydd Nodol Mine, Wales
99	Banwell Caves, Avon
100	Banwell Ochre Caves, Avon
101	Ben Knowle, Somerset
102	Charterhouse Lead Orefield, Somerset
103	Clevedon Shore, Avon
104	Wurt Pit, Somerset
105	Compton Martin Ochre Mine, Somerset
106	Hartcliff Rocks Quarry, Avon
107	Meldon Aplite Quarries, Devon
108	Priest's Cove, Cape Cornwall, Cornwall
109	Trevalour Downs Pegmatite, Cornwall
110	Tremearne Par, Cornwall
111	Red-a-Ven, Meldon, Devon
112	Haytor Iron Mine, Devon
113	Botallack Mine and Wheal Owles
114	Wheal Coates, Cornwall
115	Lidcott Mine, Cornwall
116	Wheal Emily, Devon
117	Cligga Head, Cornwall
118	Cameron Quarry, Cornwall
119	St Michael's Mount, Cornwall
120	Mulberry Down Opencast, Cornwall
121	Great Wheal Fortune, Cornwall
122	Nanjizal Cove (Mill Cove), Cornwall
123	Devon Great Consols, Devon
124	Devon United Mine, Devon
125	Trevaunance Cove, St Agnes, Cornwall
126	Perran Beach to Holywell Bay, Cornwall
127	Lockridge Mine, Devon
128	South Terras Mine, Cornwall
129	Wheal Penrose, Porthleven, Cornwall
130	Wheal Alfred, Cornwall
131	Penberthy Croft Mine, Cornwall
132	Hope's Nose, Devon
133	High Down Quarry, Devon
134	Hingston Down Quarry and Hingston Down Consols, Cornwall
135	Penlee Quarry, Newlyn, Cornwall
136	Gravel Hill Mine, Cornwall
137	Dean Quarry, Lizard, Cornwall

Figure 1.2 *Continued.*

Wales is renowned for its gold deposits, which occur in veins cutting Cambrian strata flanking the Harlech Dome in the Dolgellau area, and also unrelated stratabound gold-arsenic deposits in Upper Ordovician pyritic shales farther south, around Pumpsaint, at the **Dolaucothi Mine** GCR site. The Dolgellau gold mineralization has long been considered to have been generated in late Silurian to early Devonian times, associated with Acadian deformation and metamorphism. However, more recently field relationships in cliffs and wave-cut-platform exposures at the **Friog Undercliff** GCR site have provided evidence which demonstrates that the veins are in fact pre-tectonic in age (Mason *et al.*, 1999). The veins are now thought to have been emplaced during depressuring and dewatering of sediments during post-tectonic uplift of the Harlech Dome. The veins typically exhibit book-and-ribbon textures as a result of repeated mineralizing events; these are well displayed at the **Cefn-Coch Mine** GCR site. A four-stage paragenetic sequence has been determined (Mason *et al.*, 2002). The richest gold levels occur in irregular, so-called 'bonanza-shoot' areas, which were once worked at the **Foel-Ispri Mine** GCR site.

Although for most of Ordovician times environments in Wales were dominated by basinal conditions, periodically through from Arenig to Caradoc times shallow-marine conditions prevailed, which led to the development of ooidal and pisolitic iron ore-beds. These were exploited as low-grade ores across Snowdonia. They were ubiquitously altered by low-grade metamorphic processes, while at the **Tyllau Mwn** GCR site the ore-bed has been affected by contact metamorphism, leading to a rare assemblage containing chlorite, magnetite, stilpnomelane and apatite, whilst preserving the original sedimentary ooidal textures.

Caradoc times saw a period of major volcanic activity in southern Britain, especially in Wales and the Lake District, focused on the development of major calderas, notably the Snowdon Caldera in Wales, and the Scafell, Langdale and Haweswater calderas in the Lake District. The Snowdon Caldera was thought to be responsible for the focus of an important episode of copper mineralization, as described by Reedman *et al.* (1985). Evidence for the pre-tectonic (Acadian) age for this mineralization is seen at the **Lliwedd Mine** and **Afon Stwlan** GCR sites. There is some evidence of a zonation to the mineralization, for example lower-temperature arsenopyrite-bearing parageneses being present at the **Llanberis Mine** GCR site. A possible magmatic input to Snowdon Caldera mineralization is suggested by the presence of minor tin and tungsten in magnetite- and hematite-bearing veins at the **Cwm Tregalan–Shadow Gully** GCR site. Copper trials showing the presence of fluorite, and a range of bismuth and lead tellurides are present at the **Llyn Cwellyn Mine** GCR site, located at the margin of the Mynydd Mawr riebeckite-bearing microgranite, while the **Ffestiniog Granite Quarry** GCR site exposes pipe-like bodies containing allanite and molybdenite, the pipes being considered to be late-stage magmatic features. To the north of the Snowdon Caldera a separate, minor volcanic centre contains low-temperature lead-antimony mineralization at the **Bwlch Mine** GCR site, showing a number of rare lead antimony sulphosalt minerals in veins and irregular quartz-bearing patches in silicified rhyolitic ignimbrites. Caradoc-age volcanism has been considered to have developed in a back-arc extensional tectonic setting, and elsewhere, away from the Snowdon Caldera, volcanic exhalative mineralization occurred, seen at the **Cae Coch Mine** GCR site. This mine worked a massive stratiform pyrite deposit. The **Parys Mountain** GCR site represents another volcanic exhalative deposit, although this is thought to be of early Silurian (Llandovery) age. The mine exploited a complex sulphide ore deposit, dominated by the extraction of copper on a major scale. A well-developed gossan cap once covered the Parys Mountain deposit and although now removed, evidence is provided by samples preserved in museum collections. This gossan contained an abundance of the lead sulphate anglesite, for which Parys Mountain is the type locality.

In contrast, the Borrowdale Volcanic Group, of Caradoc age, exposed widely in the Lake District and responsible for the dramatic mountainous scenery of the region, is considered to have developed in a volcanic-arc environment on the basis of the calc-alkaline character of the erupted lavas. Copper mineralization cutting the volcanic sequences, seen at the **Coniston Copper Mines**, **Seathwaite Copper Mines**, and **Dale Head North and South Veins** GCR sites has previously been considered to be related to late Silurian to early Devonian Acadian deformation and metamorphism. More recently, Millward *et al.* (1999) have argued that it is related to the Ordovician volcanic activity, as has been argued in Wales.

Associated with this magmatic episode was the generation of a number of major intrusions, emplaced in the Ordovician to Devonian period. These were best developed in the Lake District and northern England, with relatively minor intrusive bodies and complexes being developed in Wales. The Eskdale Granite, in the Lake District, has been determined to be of Caradoc age, and at the **Water Crag** GCR site greisenization of country rocks has led to the development of remarkable quartz-topaz and quartz-andalusite rocks. Tungsten mineralization at the **Buckbarrow Beck** GCR site also appears to be related to the Eskdale Granite magmatic event. The **Long Comb** GCR site comprises a unique assemblage in the Lake District, showing co-existing apatite and arsenopyrite together with cobalt minerals in what is termed the 'Crummock Water thermal aureole', linked to a postulated unexposed granitic intrusion. The

Skiddaw Granite was emplaced in early Devonian times and was responsible for mineralization at the **Carrock Mine–Brandy Gill** GCR site, the only economic tungsten mineralization identified to date in England and Wales outside of the South-west England mineral field. The intrusion was also related to the antimony mineralization seen at the **Wet Swine Gill** GCR site. To the east of the Lake District, two major concealed intrusions, the Weardale and Wensleydale granites, had major influences on the location and character of mineral deposits of the Northern Pennine Orefield (see below).

Final closure of the Iapetus Ocean led to collision between Avalonia and Laurentia, an event termed the 'Acadian Orogeny'. Early tectonic models attributed many mineralization events as being related to this episode; however as has been shown above some of these have been subsequently re-assigned to other ages, such as the Dolgellau gold deposits. In North Wales, however, a distinctive mineral assemblage is present in syn-tectonic 'Alpine-type' veins, dominated by quartz-albite-chlorite but containing a suite of titanium dioxide minerals including anatase, brookite and rutile, as seen at the **Manod Quarry** GCR site. They occur along with the rare-earth-element-bearing phases monazite, xenotime and synchysite-(Ce). Their syn-tectonic origin is demonstrated clearly by the presence of boudinaged dacite intrusions with 'Alpine-type' mineralization occurring in the boudin necks. Similar veins occur at the **Penrhyn Quarry** GCR site, where they contain specular hematite and are hosted by Ordovician metabasite dykes cutting slates of Cambrian age.

The Central Wales Orefield contains two generations of mineral veins, which have been termed the A1 'Early Complex' veins and the A2 'Late Simple' veins, the ages of which are thought to be early Devonian and early Carboniferous to Permian, respectively. The veins commonly occupy the same fractures and demonstrate re-activation over a considerable period of geological history. This is best demonstrated by complex, cross-cutting vein systems at the **Brynyrafr Mine** GCR site, as well as the dramatic and archaeologically important **Cwmystwyth Mine** GCR site. The A2 veins are described later in this introduction. The A1 veins predominantly trend ENE–WSW and typically comprise fractured country rock cemented by sulphide-bearing quartz. Lead, copper and silver were the predominant metals worked but a range of other elements are present in minor amounts, namely zinc, antimony, nickel, cobalt, arsenic and gold. The **Darren Mine**, **Erglodd Mine** and **Eaglebrook Mine** GCR sites contain mineral assemblages which demonstrate this complexity, the veins containing many uncommon, and sometimes rare, minerals, such as cobalt pentlandite, gersdorffite and tucekite. The veins are thought to have been generated in early Devonian times as a result of post-Acadian orogenic relaxation.

The Acadian tectonic event in southern Britain led to the development of widespread arid, terrestrial environments across much of England and Wales in Devonian times. In the southernmost regions of England, however, lay the Variscides of northern Europe, a totally separate orogenic belt with a contrasting evolution. Devonian and Carboniferous times saw the presence of a series of basins which extended eastwards for around 800 km, through to Germany, and comprised the Rhenohercynian Zone. These basins were associated with sporadic volcanism and minor mineralization episodes. Manganese ores are widespread in east Cornwall and west Devon in strata of Lower Carboniferous age. At the **Lidcott Mine** GCR site Carboniferous cherts are rich in manganese. It is not wholly clear when the manganese was introduced into the cherts, but it is almost certainly of volcanic origin. It is certainly not related to the main mineralization episodes in this region which are linked to the intrusive history of the Cornubian Batholith (see later). Lead-antimony mineralization at the **Wheal Emily** GCR site may well be linked to Devonian volcanism, and is possibly epigenetic in origin, perhaps similar in origin to the **Bwlch Mine** GCR site mineralization in North Wales.

Carboniferous times saw the establishment of emergent to shallow-water conditions across much of southern Britain in environments that led to the development of thick carbonate sequences, combined with shale accumulations in peripheral basins. This combination led to the subsequent localization of important lead-zinc-fluorite mineral deposits in the classic mining orefields of the Northern Pennine district (in the Alston and Askrigg blocks, but possibly also expressed in the Lake District, to the west), the Southern Pennine district, the north-east Wales (Halkyn–Minera) area, and the Mendips. Mineral deposits in Central Wales and Shropshire are also possibly linked genetically, representing a deeper structural expression. What was critical to these mineral deposits, which relate to so-called Mississippi Valley-type (MVT) mineralization, was the expulsion and migration of fluids from basin environments from late Palaeozoic through to Mesozoic times. The mineralizing process is linked to periods of active rifting, thermal subsidence and basin inversion, which caused fluid expulsion from rapidly buried sediments. However in some cases it is still a matter of conjecture as to which deposit relates to which mineralizing event, while for other deposits there is critical geological evidence for their genesis, as described below.

In the Northern Pennine Orefield a critical site in determining the age of the mineralizing event is the **Lady's Rake Mine** GCR site, which demonstrates that the lead and zinc mineralization present at this site very closely post-dates the emplacement of the Whin Sill, which is now regarded as having taken place during the interval represented by the unconformity between upper Carboniferous and lower Permian times. It has therefore been suggested that MVT mineralization of the Northern Pennine Orefield is of latest Carboniferous to early Permian age.

A key feature in the localization of mineralization in the Northern Pennine Orefield is the presence of the subjacent unexposed Caledonian intrusions, namely the Weardale and Wensleydale granites. These controlled the development of the Alston and Askrigg blocks. These areas remained as positive highs from mid-Devonian times onwards which led to the development of thin, rhythmic, sedimentary cycle deposits, known as the 'Yoredale facies'. The Alston Block is bounded to the north and south by the Stublick and Lunedale faults, passing respectively into the Northumberland Basin and Stainmore Trough. To the south of the Stainmore Trough the Askrigg Block is defined at its southern extremity by the Craven Fault. Mineralization in the Alston Block is present as fissure-vein infills and metasomatic flat replacements. The mineral veins show their richest development in the Great Limestone. Metasomatic flats are less common than the veins and occur largely at vein intersections and in the crests of small anticlines.

The Alston Block mineralization shows a broad concentric zoning, from inner to outer as follows:

- fluorite-quartz-chalcopyrite-galena (+/– pyrrhotite and marcasite)
- fluorite-quartz-galena (+ sphalerite or siderite)
- galena-quartz (+ sphalerite or siderite)
- galena-barite (+ sphalerite or witherite)
- barite-witherite-barytocalcite

The **Killhope Head** GCR site provides a fine demonstration of fissure-vein mineralization, along with iron-rich metasomatic replacement flat deposits in the Great Limestone, in the central fluorite zone, while the **Tynebottom Mine** GCR site provides excellent evidence for the relationships between fissure veins and metasomatic flats. The **Smallcleugh Mine** GCR site shows extremely important exposures of lead- and zinc-rich metasomatic replacement flat mineralization within the Great Limestone. The **West Rigg Opencut** GCR site provides one of the finest examples of a Northern Pennine Orefield vein and associated iron flat within the Great Limestone. The **Scordale Mines** GCR site demonstrates vein and flat mineralization within the outer barite zone of the orefield, where the mineralizing fluids were confined to the Melmerby Scar Limestone by the lithological control of the Whin Sill and its adjacent, thermally altered shales. One of the densest concentrations of mineralized veins and associated replacement deposits, however, is seen at the **Pike Law Mines** GCR site, which also shows extensive supergene mineralization. One of the major mineralized structures of the Alston Block is the Great Sulphur Vein, material from which can be examined in spoil heaps at the **Sir John's Mine** GCR site. The **Blagill Mine** GCR site lies in the outermost zone of the orefield and is the type locality for barytocalcite. Fine specimens of barytocalcite are also found at the **Foster's Hush** GCR site, where small exposures of the mineral can be observed *in situ* in the parent vein, while the **Closehouse Mine** GCR site represents a barium-rich mineral deposit which includes a replacement of the Whin Sill intruded into the Lunedale Fault. Although lying outside of the Alston Block and in the Northumberland Trough, the **Settlingstones Mine** GCR site, notable for the occurrence of witherite, and the **Fallowfield Mine**, also notable for witherite but especially for alstonite, are considered to represent the outermost zone of the Alston Block mineralization, while spoil heaps at the **Stonecroft Mine** GCR site provide evidence of the lead and zinc mineralization associated with the Stublick Fault Zone.

The geological history of the Askrigg Block is similar in most ways to the Alston Block, although the zonal distribution present in the Alston Block is by no means as discernable. The **Gunnerside Gill** (potential) GCR site, in Swaledale, represents a typical fissure-vein lead-fluorite-barite deposit, while the **Greenhow (Duck Street) Quarry** GCR site, at the southernmost extremity of the Askrigg Block, provides one of the finest examples of galena-fluorite vein mineralization in the area. At the easternmost and westernmost extremity of the Askrigg Block occur copper-bearing mineral veins, seen at the **Black Scar** and **Cumpston Hill North and South Veins** GCR sites.

It is possible that this episode of mineralization has an expression farther to the west, in the Lake District, where rich lead-zinc-dominated mineralization is present, which has been estimated to be of Carboniferous age (Stanley and Vaughan, 1982a). This episode of mineralization is especially well-developed at the **Force Crag Mine** and **Eagle Crag** GCR sites.

The age of MVT mineralization farther south, in the South Pennine, or Peak District, Orefield is more contentious. Various lines of evidence have suggested that the mineralization may be younger than that in the Northern Pennine Orefield, perhaps in the Triassic to Jurassic age bracket. However, geothermal modelling and consideration of high heat-flows associated with extensive magmatic activity across northern England favour a Westphalian to Stephanian age. The mineralization, which is dominated by a simple sulphide mineralogy of galena and sphalerite, occurs principally in veins, which range from a millimetre to a few metres in thickness, and the veins commonly show crustiform textures. In addition, there are a number of important flat deposits where shale or volcanic horizons have acted as acquicludes. The mineralization is present chiefly in limestones of Asbian to Brigantian age and is controlled principally by stratigraphical and lithological, rather than structural, controls. Wall-rocks adjacent to veins are sometimes silicified.

The best example of vein mineralization in the South Pennine Orefield is seen at the **Dirtlow Rake and Pindale** GCR site. This major hydrothermal fissure, lying to the south of Castleton, can be traced for over 6 km, and varies between 3 m and 12 m in width. The site is important for showing a wide variety of mineralization styles, including breccia domes with silica floors, as well as chimneys and pipes. In contrast, the mineralization at the **Masson Hill Mines** GCR site is an excellent example of a replacement fluorite-galena flat, where mineralizing fluids have been trapped in limestones between lavas and bentonites ('wayboards'). Lavas, and to a lesser extent, mafic sills, occur across the orefield, and at the **Calton Hill** GCR site volcanic rocks contain a rare assemblage of spinel lherzolite and harzburgite nodules.

Overall the South Pennine Orefield is hosted by a structure called the 'Derbyshire Dome', a gentle anticlinal structure which is surrounded on all sides by younger Namurian strata. Small, peripheral anticlines expose inliers of Visean limestones, such as in the Ashover Anticline. These anticlines show crestal mineralization associated with hydrocarbons, as at the **Fall Hill Quarry** GCR site, and provide an important insight into fluid-migration modelling. Fluorite is common in mineralization at the crest of the Derbyshire Dome, and the unique variety 'Blue John' is found at the **Treak Cliff** GCR site, while at the nearby **Windy Knoll** GCR site fluorite is accompanied by a variety of solid and liquid hydrocarbons, possibly reflecting ponding of fluids in a structural trap.

There has been considerable debate not only concerning the age of mineralization associated with the Derbyshire Dome but also as to the source of the fluids. Originally a magmatic source was favoured. The generally accepted model now, however, is one of their derivation from adjacent sedimentary basins. Cycles of active rifting, thermal subsidence and basin inversion would have been conducive to the expulsion of fluids from the rapidly buried sediments. There has been much discussion as to which basin might be the source of the lead-zinc-fluorite-bearing fluids, including the North Sea basins, or, closer to the Derbyshire Dome, the East Midland Basin, the Edale Gulf and the Widmerpool Trough. An apparent anomaly in this model is the MVT mineralization at the **Ecton Copper Mines** GCR site, which represents one of the few sites in England where copper was worked from limestones of Carboniferous age. The Ecton Copper Mines lie on the margin of the Cheshire Basin, and hence a derivation of fluids from the Cheshire Basin or the Irish Sea Basin has been proposed.

Further MVT mineralization occurs to the west of the Cheshire Basin, in the North-east Wales Orefield, and indeed may be of similar derivation, with basinal fluids being driven out of the Cheshire Basin and the Irish Sea Basin. Again, the timing of mineralization is not wholly clear, but it is considered to be 'Variscan', which accords with ages from some of the lead-zinc mineral veins in the Central Wales Orefield, which may well represent the deeper structural expressions of the carbonate-hosted veins, pipes and metasomatic flats seen in carbonate rocks of Carboniferous age, as for example at the **Halkyn Mountain** GCR site. Here the mineralization comprises a simple galena-sphalerite-fluorite assemblage, whilst farther to the south-east it becomes dominated by sphalerite with quartz as a major gangue phase, as seen at the **Pool Park and South Minera Mines** GCR site. Mineralization at the **Great Orme Copper Mines** GCR site is a further carbonate-hosted MVT deposit, but in this case copper is the dominant ore, and the deposit is considered to belong to the 'copper-dolomite' class. The **Pennant Mine** GCR site, lying near to the outcrop of the mineralized Halkyn Mountain, shows barite-witherite-calcite-sphalerite-galena-chalcopyrite mineralization cutting Silurian strata, which might well represent the deeper-level expression of the MVT mineralization, the veins having the same east–west orientation which predominates in the structurally higher-level Carboniferous sequences. The **Huglith Mine** GCR site, in the West Shropshire Orefield, may also be related to this style of mineralization but at a deeper structural level, where copper and barite mineralization cutting Neoproterozoic quartzites is considered to be of Carboniferous age. The related nearby **Snailbeach Mine** GCR site shows a greater abundance of galena and also bitumens that might relate to a Carboniferous petroleum reservoir system.

As mentioned earlier, the Central Wales Orefield shows evidence of two mineralizing events, the A1 ('Early Complex') veins of probable early Devonian age, and the A2 ('Late Simple') veins, of probable early Carboniferous to Permian age. The latter sometimes occupy the same lodes as the former, providing evidence of cross-cutting relationships and for the re-activation of previously existing structures, such as at the **Brynyrafr Mine** and **Cwmystwyth Mine** GCR sites. The A2 veins show simple galena-sphalerite-chalcopyrite parageneses cutting brecciated mudstones, best seen at the **Ceulan Mine Opencast** GCR site. Commonly the A2 mineralization shows crustiform textures similar to those in the MVT deposits of the Pennine orefields. These are best developed at the **Nantiago Mine** GCR site. A rare A2 assemblage variation, containing 'giant' quartz crystals, is present at the **Nantymwyn Mine** GCR site.

Late Carboniferous times saw the generation of a foreland basin in South Wales, linked to the advancing Variscan Orogen. High sediment inputs led to thick accumulations of sandstones and shales which, along with the compaction of abundant vegetation in fluvial and deltaic environments, led to the development of the thick sedimentary sequences of Namurian, Westphalian and Stephanian age. Claystone–ironstones of diagenetic origin developed and were worked from numerous horizons in strata of Westphalian age, and indeed their presence was fundamental to the industrial revolution in this part of Great Britain. The claystone–ironstone horizons are important for the range of minerals present in cavities and cracks in the nodules, which contain well-crystallized, sometimes doubly terminated quartz crystals, along with a range of sulphides, including galena, sphalerite, chalcopyrite, pyrite and marcasite, as well as siegenite and millerite. Specimens of needle-like millerite sprays from South Wales Coalfield claystone–ironstone nodules are present in most major mineralogical museums. Academically the nodules are important because of the information that can be gained from studies of fluid inclusions in quartz and carbonate crystals, which permit modelling of fluid flow in the evolving basin (Alderton and Bevins, 1996; Alderton *et al.*, 2004). Unfortunately, because of the demise of the coal industry in Great Britain, accompanied by the large-scale removal of coal waste tips across the region, there are no sites suitable for conservation of the claystone–ironstone mineralization.

In latest Carboniferous times the major northwards thrusting and propagation in southern Britain culminated in the Variscan Orogeny, which was followed by the emplacement of a major intrusive body known as the 'Cornubian Batholith'. This occurred in the period 295–270 Ma, and was accompanied by major, long-lasting hydrothermal activity which generated the wide range of mineral deposits seen in the South-west England mineral province. A date of 269 ± 4 Ma has been proposed for the age of the main phase of mineralization. The evolution of this province has been reviewed and modelled by Alderton (1993), and more recently by Scrivener (2006).

Although carbonate-bearing rocks are relatively rare in the region, small-scale, localized skarns did develop as a result of contact metasomatism and metamorphism during emplacement of the batholith. The magnetite-hornblende deposits at the **Haytor Iron Mine** GCR site are an example of a skarn development of unusual nature for the mineral province. A site of international mineralogical interest is the **Red-a-Ven Mine** GCR site, lying at the north-west margin of the Dartmoor Granite, where Lower Carboniferous cherts, shales and minor limestones have been contact metamorphosed and metasomatized. It appears that an initial chalcopyrite-arsenopyrite-pyrrhotite skarn has been affected by later boron-rich fluids and further skarn development, leading to the presence of a range of rare mineral assemblages and skarns with anomalously high tin levels.

Pegmatites and aplites developed during the final stages of consolidation of the granite. The **Tremearne Par** GCR site provides an excellent demonstration of pegmatite-aplite relationships with the country rocks surrounding the Tregonning–Godolphin Granite, while the **Trevalour Downs Pegmatite** GCR site shows the development of large Li-rich micas. Of international importance is the **Meldon Aplite Quarries** GCR site for being a unique example in Great Britain of a sodium-potassium-lithium aplite, containing a wide range of rare minerals, although as noted below a degree of caution needs to be exercised with some of the previously published accounts describing mineral occurrences from this locality and a number of other localities described in this volume.

Greisens, sheeted-vein systems and stockworks are common in the province and have been considered to be relatively early features and accompany hydraulic fracturing of the host rock. Both granite-hosted (endogranitic) and sediment-hosted (exogranitic) greisens occur, the former being observable at the **Cameron Quarry** and **St Michael's Mount** GCR sites, while the **Mulberry Down Opencast** exposes an exogranitic greisen and a low-grade tin stockwork. Spectacular greisen-bordered tin and tungsten veins occur at the **Cligga Head** and the **Great Wheal Fortune** GCR sites. Tourmalinization is also widespread across the region, as at the **Nanjizal Cove** GCR site, while the **Priest's Cove** GCR site offers the opportunity to compare the genesis of magmatic tourmaline with mineralized tourmaline development of hydrothermal origin.

The main-stage mineralization is represented by steeply dipping fissure-veins which trend east–west in the eastern part of the province, north-east–south-west in the central area, and north-west–south-west in the west and whose thickness is highly variable but perhaps most typically in the range 1–2 m. Individual lode structures can sometimes be traced for a few kilometres; the **Devon Great Consols** GCR site is an exception, with the copper-bearing lode being worked over almost 4 km of continuous section. They are dominated by tin and copper, but also carry tungsten, arsenic, lead and zinc. There is evidence for both lateral and vertical zonation, especially in relation to tin and copper, as seen in relationships between main-stage tin-copper mineralization at the **Cligga Head**, **Trevaunance Cove**, **Cameron Quarry** and **Wheal Coates** GCR sites. Copper-tin-arsenic main-stage mineralization is well developed at the **Devon United Mine** GCR site, with the arsenic possibly being derived from underlying mafic igneous rocks.

Some sites in the South-west England mineral province show evidence of multiple mineralizing episodes; for example at the **Penlee Quarry** GCR site four mineralizing events can be discerned, namely early pegmatites, contact metamorphism, main-stage tin-copper mineralization, and finally late cross-course mineralization (see below). It is the **Botallack Mine and Wheal Owles** GCR site that perhaps shows the greatest variety and representation of mineralization events in the province which makes it a site of international mineralogical importance, reflected by the extensive mining of the area's lodes and its inscription in 2006 on UNESCO's list of World Heritage Sites for the mining landscape. This site shows the development of skarn deposits, in the subhorizontal sheet-like tourmaline- and cassiterite-bearing 'floors', such as the 'Grylls Bunny', 'carbonas' (localized alteration associated with pipe-like bodies), main-stage tin-copper mineralization, and late cross-course mineralization containing lead, bismuth and uranium.

A suite of late veins, trending approximately north–south, are termed the 'cross-courses'.

They chiefly comprise lead and zinc, along with fluorite and barite. They occur away from the granite bodies and are considered to be low-temperature deposits. The cross-course mineralization bears a resemblance to MVT mineralization and it appears therefore that the origin of the fluids was most probably as a result of dewatering of adjacent Permo–Triassic red-bed sedimentary basins. The **Lockridge Mine** GCR site, near Bere Alston, shows a typical N–S-orientated cross-course lode, with quartz carrying galena and sphalerite, along with some sphalerite. The mine was important, however, for the argentiferous nature of the galena. The **Perran Beach to Holywell Bay** GCR site is a further example of cross-course mineralization, being well exposed in cliff sections, and comprising comby quartz, galena and fluorite, with some siderite. In the Porthleven area, the **Wheal Penrose** GCR site is related to three parallel N–S-trending cross-course lodes carrying quartz, galena, sphalerite, chalcopyrite and arsenopyrite. An example where there is a strong likelihood of host-rock influence on cross-course fluid composition is at the **South Terras Mine** GCR site, which contains uranium-bearing minerals. It is highly likely that the source of the uranium was the nearby St Austell Granite. Finally, at the **Devon United Mine** GCR site both main-stage and cross-course mineralization episodes can be discerned, the latter 'heaving', or displacing, the earlier mineralized structures.

The effects of the Variscan Orogeny led to dramatic changes in the palaeogeography and climate in early Permian times, combined with a steady northwards drift, away from the equatorial rainforest belt of the late Carboniferous period. The climate became more arid, and desert environments predominated. Critically, extension most probably linked to the onset of rifting of the proto-Atlantic led to the development of a series of isolated and interconnecting basins. By Late Permian times, a southwards transgression from the Arctic Sea had led to the development of the Zechstein Sea (in the North Sea region) and the Bakevellia Sea (in the Irish Sea region). Similar conditions persisted into Triassic times, when, however, connections to a sea were southwards, to the Tethys Ocean. Within and at the margins of these seas thick deposits of economically important evaporites developed, including gypsum, anhydrite, halite, K-rich salts (carnallite and sylvite) and celestine. The **Ben Knowle** and **Gipsy Lane Brick Pit** GCR sites are representative of evaporite development in Late Triassic times. Beds and nodules of gypsum occur in the Mercia Mudstone Group at **Gipsy Land Brick Pit**. At **Ben Knowle**, gypsum and anhydrite in beds of similar age were converted to celestine by the diagenetic addition of strontium from a Carboniferous source. The **Warren Quarry** GCR site is a unique location for the presence of the clay mineral palygorskite, which is thought to have precipitated at the junction between Caledonian hornblende tonalite and mudstones of the Mercia Mudstone Group as a result of weathering in an arid environment during late Triassic times.

Dinantian limestones in western and southern Cumbria, the Forest of Dean, South Wales and the Mendips contain important iron oxide (along with subordinate manganese) deposits, the age of which is still a matter of some debate. The most important economically were the hematite ores of the Cumbrian Orefield, which occur in a variety of forms, namely as veins along faults, stratiform replacement flats, and 'sops', which are dish-like dissolution hollows of karstic origin, and which are unique to southern Cumbria. It is currently considered that the source of the iron was as a result of convective leaching of Permo–Triassic red-bed successions in the Irish Sea Basin, with highly saline basinal brines being driven up-dip by convection. The timing has been placed anywhere between pre-Permian to post-Triassic. The **Florence Mine** GCR site in Cumbria provides the best example of replacement mineralization in the Cumbrian Orefield, as well as being the source of excellent museum-quality specimens, especially of 'kidney ore' hematite. The hematite mineralization also has an expression in the underlying Lower Palaeozoic strata, being seen as veins comprising 'kidney ore' hematite at the **Nab Gill Mine** GCR site.

In South Wales, a series of hematite-goethite replacement deposits in Dinantian limestones were worked at a number of mines in the Llanharri area, the largest being the Llanharry Mine which closed as late as 1974. There is very little exposure remaining at any of the mined sites, although examples of the mineralization do occur at the **Mwyndy Mine** GCR site, with similar mineralization being seen in the Mendips area, at the **Compton Martin Ochre Mine**, the **Banwell Ochre Caves**, and the **Hartcliff Rocks Quarry** GCR sites. There has been considerable debate not only concerning the origin of this iron and manganese mineralization episode but also its age. Evidence from the **Ogmore Coast** GCR site has helped constrain the age as being pre-Jurassic, as syngenetic early Jurassic mineralization at that locality cuts limestones containing hematite veinlets and staining. On the basis of fluid-inclusion studies on samples from Llanharry Mine the fluids are currently considered to be related to mixing of low-temperature, highly saline iron-bearing ground-waters with warmer, dilute fluids driven out of the adjacent Coal Measure sequences. It is in fact considered that this episode of iron mineralization adjacent to the Permo–Triassic basins may be linked to crustal extension associated with the opening of the proto-Atlantic in late Triassic times.

In the Cheshire Basin, continental aeolian and fluvial sandstones of mainly Mid-Triassic age in the Sherwood Sandstone Group host a wide-spread barite mineralization and more localized occurrences of low-grade, Cu-dominated base-metal ores that are representative of the sediment-hosted, red-bed category of ore deposits. The latter are dominated by secondary species that result from alteration of primary sulphides and consist mainly of copper carbonates, with arsenates, oxides and hydroxides containing copper, lead, zinc, cobalt, nickel, vanadium and other elements. Mineralization is epigenetic and regarded as the result of the mixing of chloride-rich basinal brines and hydrocarbon fluids in the sandstones in structural traps beneath a seal formed by impermeable sediments of the over-lying Mercia Mudstone Group. Primary minerali-zation is regarded as having occurred either in Late Triassic to early Jurassic times or in the late Jurassic, with secondary alteration occurring in Tertiary times in both cases. The **Alderley Edge District** GCR site is the classic site for the examination of this style of mineralization in Great Britain and is uniquely accessible.

Evidence for a Mississippi Valley-type mineralizing episode is seen in the Mendip Hills and Bristol area, extending across into South Wales. It was veins associated with this event that led to the extraction of lead in these regions as early as Roman times. The age of mineraliza-tion has been the subject of considerable debate but there is now sufficient evidence to argue for an early Jurassic age. Critical evidence for this age is seen at the **Ogmore Coast** GCR site, where syngenetic MVT is present which indicates that fluids were exhaled into marginal Liassic sediments. Elsewhere in South Wales, this style of mineralization is seen exposed at the **Machen Quarry** GCR site. In the Mendips region, the **Charterhouse Lead Orefield**, **Banwell Caves** and **Clevedon Shore** GCR sites are representative of this mineralization episode. The **Wurt Pit** GCR site is a large karst collapse feature which exposes silicified lime-stones of early Jurassic age. The fluids responsible for the silicification are considered to be those responsible for the Mendip Hills MVT deposits. The fluids responsible for the mineralization in South Wales are thought to have been basinal brines expelled from the Bristol Channel Basin, while recent isotopic studies by Haggerty *et al.* (1996) have not only supported derivation of the Mendip Hills MVT fluids from basins of Mesozoic age but they conclude that a number of different basins were involved, including the Wessex Basin, the Central Somerset Basin, and again the Bristol Channel Basin.

An anomalous episode of mineralization, carrying many rare mineral species, is seen at the **Dolyhir Quarry** GCR site, in the Welsh Borderland. The nature of the mineralization and its association with carbonates suggest that it too might be an episode of MVT mineraliza-tion, possibly of the same age as the South Wales veins, with the fluids derived similarly from the Bristol Channel Basin. This requires further studies, however.

Many mineral deposits in England and Wales have been subject to some form of weathering, especially the upper parts of the bodies, above the contemporary water-table, which have been affected by oxidation processes. The classic extreme end result of such processes is the leaching of most metals with the exception of iron, leading to the development of a gossan capping to the ore deposit. Such a gossan occurred at the **Parys Mountain** GCR site, which was particularly rich in fine specimens of the lead sulphate mineral anglesite and for which the site is the type locality. Remnants of gossanous horizons are found elsewhere in Wales, namely at the **Frongoch Mine** and the **Llechweddhelyg Mine** GCR sites, in the Central Wales Orefield, although it is likely that most gossan cappings were removed in this area by the effects of glaciation. In other cases metals leached from the metalliferous minerals in ore-bodies have been transported downwards in solution, to precipitate above the contemporary water-table as a variety of carbonates, sulphates, phosphates and arsenates. The **Machen Quarry** GCR site is renowned for the evidence of supergene alteration of lead-bearing veins which are now exposed by active quarrying. Spectacular anglesite crystals have been recovered from this locality. In the Lake District the **Red Gill Mine**, **Drygill Mine**, and **Roughtongill Mine** GCR sites are widely recognized for the museum-quality lead, copper and zinc carbonates, sulphates, phosphates and arsenates of supergene origin, while in South-west England the **Penberthy Croft Mine** GCR is of particular note for the extreme range of supergene minerals present and the **Wheal Alfred** GCR site is acknowledged as having yielded the finest pyromorphite specimens in the province. In the Northern Pennine Orefield supergene smithsonite was worked from a deposit unique in that area at the **Pikedaw Calamine and Copper Mines** (potential) GCR site, while the **Willyhole Mine** GCR site is of importance for the development of supergene greenockite derived from the alteration of sphalerite. A unique mineral deposit of supergene copper mineralization is developed at the **Turf Copper Mine** GCR site in North Wales, where in post-glacial times copper has been leached from the largely hidden Coed y Brenin porphyry copper deposit and precipitated as native copper replacing organic matter in a developing peat bog.

If copper-bearing solutions descend below the contemporary water-table and interact with primary copper sulphides secondary enrichment can occur, leading to the generation of minerals such as bornite and djurleite, as seen at the **Birk Fell Hawse Mine**, **Seathwaite Copper Mines** and **Dale Head North and South Veins** GCR sites in the Lake District, and the **Alderley Edge District** GCR site in Cheshire. Similar enrichment processes are indicated to have occurred at the **Newhurst Quarry** GCR site in Leicestershire, where remnants of a chalcocite-bornite supergene paragenesis is almost totally obliterated by a later oxidized association of copper salts.

It is clear that some of the supergene mineral development is of post-mining age; in other cases the age of the mineralization is equivocal. It has been suggested that some of the supergene alteration in the Lake District occurred in Jurassic times, while the manganese mineralization at the **Mynydd Nodol Mine** GCR site in North Wales is thought to have developed from the leaching of Ordovician volcanic rocks in Tertiary times. Two sites of mineralogical interest in Derbyshire have a part of their history linked to processes operating as recently as Pliocene–Pleistocene times. At the **Portway Gravel Pits** GCR site a solution-related collapse feature on a mineralized vein, thought to have developed in Pleistocene times, is filled with blocks of limestone and a distinctive quartz rock. At the **Kirkham's Silica Sandpits** GCR site, the Miocene–Pliocene Brassington Formation comprises silica sands and kaolinitic clays of commercial value, and the site is noted for the presence of the clay mineral metahallyosite, although its exact origin is not currently understood.

Finally, and very unfortunately, caution must be exercised in relation to the recording of mineral provenance, which has been highlighted by the deception that has been uncovered in relation to specimens from the collection of the late Arthur Kingsbury, now housed in the Natural History Museum. It has come to light that Kingsbury falsified the provenance of a significant number of his specimens, a situation which has only really come to light in the last 10 years or so, following the detailed investigations of the late George Ryback and curatorial staff at the Natural History Museum (Ryback *et al.*, 1998, 2001). Tindle (2008) has recently provided the most detailed information relating to the scale of the fraud. What is relevant to this volume is that caution is required whenever site accounts describe mineral occurrences which are based on published reports by Kingsbury. Some ten GCR mineral sites are in some way implicated to a greater or lesser degree in this unfortunate situation, namely **South Terras Mine**, **Carrock Mine–Brandy Gill**, **Meldon Aplite Quarries**, **Tynebottom Mine**, **Hingston Down Quarry and Hingston Down Consols**, **Cligga Head**, **Red-a-Ven Mine**, **Alderley Edge District**, **Roughtongill Mine** and **High Down Quarry**. In addition, of course, there have been subsequent studies which have been based on Kingsbury specimens, some of which now carry suspect results, and finally Kingsbury donated specimens to others and so there may be fraudulent details in other mineral collections.