Geodiversity Audit of Active Aggregate Quarries

Quarries in Somerset

Project Overview Report

December 2004

DAVID ROCHE GeoConsulting

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Project undertaken in association with partners Somerset County Council, British Geological Survey, Mendip Quarry Producers and Mineral Industry Research Organisation.

Front Cover Photographs – clockwise from top left:

- ***A.*** ***Dulcote Quarry****, red-brown Mercia Mudstone with breccia unconformable on Carboniferous Limestone*
- ***B.*** ***Torr Quarry****, Haematite mineralization in Merehead fault zone*
- ***C.*** ***Gurney Slade Quarry****, flat bedding planes of Clifton Down Limestone dipping to the south east.*
- ***D.*** ***Colemans (Holwell) Quarry****, Mid-Jurassic Limestone unconformable on Carboniferous Limestone.*

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Important Note on Access and Safety

Publication of this report implies no right of access into any of the quarries.

Any access must be arranged with the quarry operator with full observance of the quarry safety requirements and procedures for visitors.

The cooperation and assistance given by the industry is gratefully acknowledged together with information supplied by their consultants who have contributed much to the knowledge base.

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PROJECT SUMMARY

Geodiversity encompasses the wide variety of geological features which make up the Earth and the processes which have formed these features throughout geological time.

Active quarries provide some of the best and most extensive geological exposures available and they offer a unique opportunity for three dimensional observation as the geology continues to be revealed by continuing operations. This detailed information can provide a valuable insight to the geology in areas where surface exposure may be poor and interpretation of the hidden geological structure from surface features alone can be difficult.

The project described continues the pilot study started in Devon in 2003 with the collection and recording of available information on the geodiversity revealed in seven active aggregate quarries in the East Mendip area of Somerset.

Geodiversity audit reports with photographic detail have been prepared as a record for each quarry and these are summarised here in the context of geological history.

The oldest rocks in Somerset are seen in aggregate quarries in the core of the Mendip ridge. They are volcanic andesite lavas with volcanic ashes and agglomerates and associated marine sediments containing fossils of the Silurian Period of geological time about 430 million years old. They were formed during a period of explosive volcanic activity in a shallow tropical sea. Little would be known about the early history of Mendip at this time if the rocks had not been exposed in the quarries.

Unconformable on the volcanic rocks, the Old Red Sandstone conglomerates, sandstones and shales were deposited in seasonal floods in a largely desert or semi-arid environment. These late-Devonian rocks grade upwards without any break into Lower Carboniferous marine shales and limestones

Some of the best continuous sections through the Carboniferous Limestone are seen in the large limestone aggregate quarries, some of which are amongst the biggest quarries in Europe. The full limestone succession is in the order of 1000m thick with many shell and coral fossils indicative of formation in shallow, clear water, tropical seas.

These older rocks were sharply folded and faulted by pressure of a continental collision from the south in the Variscan Orogeny at the end of the Carboniferous and early Permian about 300 million years ago.

The mountain terrain formed in the Variscan was then subject to intense erosion in the desert conditions of the Permian and Triassic in which the scree deposits of the ‘Dolomitic Conglomerate’ were formed around the edges of Mendip.

Traces of late Triassic and Jurassic sediments are also preserved around the edges of Mendip resting unconformably on the older rocks, and in fissures in the Carboniferous Limestone which can be seen in several of the active quarries. Vertebrate bones have occasionally been found in the fissures, including very rare bones of ancestral mammals about 250 million years old.

The main conclusion is that the geodiversity seen in active aggregate quarries constitutes a valuable educational and research resource of geological detail which can be integrated with the regional and global geological history.

Using the experience of this project as a stimulus, the wider education and training opportunities of many disciplines related to the minerals industry need to be developed in partnership with others to raise the career profile in this essential and varied industrial sector.

CONTENTS

1. INTRODUCTION

In partnership with the Mendip Quarry Producers representing nearly all the aggregate producers in the county, seven active quarries in East Mendip have been audited, these being the principal aggregate producing units in the area, listed alphabetically as follows:

	Quarry	Operator	Location and Grid Reference	General Geology
1.	Colemans	Aggregate Industries	Nunney, Frome ST 727 450	Carboniferous Limestone (Clifton Down, Vallis and Black Rock Formations) unconformably overlain by mid-Jurassic limestone and locally Triassic Dolomitic Conglomerate
2.	Dulcote	Foster Yeoman	Dulcote, Wells ST 566 442	Carboniferous Limestone (Clifton Down and Vallis Formations) unconformably overlain by red Triassic mudstones
3.	Gurney Slade	Morris and Perry	Gurney Slade, Shepton Mallet ST 626 492	Carboniferous Limestone (Hotwells and Clifton Down Formations) unconformably overlain by Jurassic limestone conglomerate
4.	Halecombe	Tarmac	Leigh upon Mendip, Frome, ST 702 474	Carboniferous Limestone (Clifton Down, Vallis, Black Rock and Lower Limestone Shale Formations).
5.	Moons Hill (includes Stoke Quarry)	Wainwright	Stoke St Michael, south of Radstock ST 665 462	Silurian volcanics (andesite tuffs and agglomerates) unconformably overlain by Upper Devonian sandstones of the Portishead Formation
6.	Torr	Foster Yeoman	East Cranmore, Shepton Mallet ST 692 438	Carboniferous Limestone (Clifton Down, Vallis and Black Rock Formations) unconformably overlain by mid-Jurassic limestone
7.	Whatley	Hanson	Whatley, Frome ST 732 479	Carboniferous Limestone (Clifton Down, Vallis and Black Rock Formations) unconformably overlain by mid-Jurassic limestone

TABLE 1

The project background and key objectives are described in ***Appendix A*** and a review of the project structure and feedback is presented in ***Appendix B***. Key references are listed in ***Appendix C*** and ***Appendix D***.

The key elements for each geodiversity audit are tabulated in summary at the beginning of each quarry report and these tables are reproduced in this report as ***Appendix E***.

The summary tables have been further summarised to a single table which has been used in the project publicity brochure.

Technical geological terms can not be avoided entirely and a ***Glossary*** is therefore included as ***Appendix F*** to help with explanation.

To geologists, a special importance of active quarries is that the working faces are continually moving and new geological information is continually being revealed.

For this reason, the main project record is largely photographic with locations of photographs and view directions recorded as accurately as possible using hand-held GPS positioning coupled with information from the quarry survey plan. This record is considered accurate to within 10m. The scale bar appearing in some photographs is marked in 10 cm intervals.

2. THE GEODIVERSITY RECORD

This Overview Report summarises some of the most significant Geodiversity features recognised in and around the seven active aggregate quarries in East Mendip. The individual quarry reports should be consulted for further detail and additional features. The record is discussed under Geodiversity headings, generally in the order considered in the quarry reports. However, in summarising the project, only a selection of features can be illustrated under each heading.

2.1 Stratigraphy

Stratigraphy is the study of the sequence of stratified rocks, particularly their evolution with time and changing environments and their classification in the order of the progression of time.

A generalised summary Table of Stratigraphy of the East Mendip area is as follows:

Formation name	Group	Geological Age	Thickness	Description
	Inferior Oolite Group	Mid Jurassic 175 M.yrs	up to 9m.	Pale yellow brown fossiliferous oolitic limestone.

UNCONFORMITY - Remnants of Triassic and Jurassic sediments are found as isolated outcrops ('dolomitic conglomerate) and within fissures ('neptunian dykes') in the underlying limestone

Quartzitic Sandstone Formation	Millstone Grit Group	Upper Carboniferous c. 310 M.yrs	45-65m.	Sandstone, quartzitic with subordinate mudstones
Hotwells Limestone Formation	Hotwells Group	Lower Carboniferous 350-320 M.yrs	c.150m.	Limestone, grey massive, fossiliferous, crinoidal and oolitic, bioclastic
Clifton Down Limestone Formation	Clifton Down Group		c.145m.	Limestone, mid grey, oolitic, crinoidal, overlain by well-bedded limestone
Burrington Oolite Formation			0 – c.55m.	Limestone, pale grey, oolitic and crinoidal
Vallis Limestone Formation			up to c.115m.	Limestone, pale grey, coarsely crinoidal
Black Rock Limestone Formation	Black Rock Group		c.300m.	Limestone, dark grey to black, fine grained, coarsely crinoidal, locally with chert
	Lower Limestone Shale Group		c.150m.	Mudstone, grey-green, dark grey and black, fissile, interbedded with limestone
Portishead Formation	Old Red Sandstone	Late Devonian c.360 M.yrs	up to 500m.	Red-brown sandstone with mudstone and conglomerate

UNCONFORMITY

Coalbrookdale Formation		Mid Silurian 425 M.yrs	c. 600m.	Andesite lavas with tuffs, agglomerates and mudstones

TABLE 2

The oldest rocks of Mendip are volcanic rocks of Silurian age which have been extensively quarried since the late 1800's for use mainly as building stone and roadstone. The outcrop is relatively small in area, only a few square kilometres in area at the core of the Beacon Hill Pericline which is the easternmost of the four main east-west folds of Mendip. The rocks are best seen in the quarries. Little would be known of this geological formation if the quarries had not been worked (Photos ***PO 5*** and ***PO 6***).

The Devonian Old Red Sandstone of the Portishead Formation (Upper Devonian) dips north and south on each side of the volcanic rocks in the core of the pericline. The strata can be seen at the edges of the quarried area, comprising red-brown sandstone beds for the most part with conglomerates and subordinate mudstones and siltstones (Photo ***PO 7***) transported and deposited in intermittent rivers in a desert or semi-arid environment.

The main source of quarried aggregate from Mendip is the Carboniferous Limestone of Lower Carboniferous age. The total Carboniferous Limestone sequence approaches 1000m in thickness divided into a series of formations with distinctive geological characteristics as summarised in ***Table 2*** above. Examples of all the formations are well seen in the quarries, although no single quarry exposes the complete sequence. Photo ***PO 1*** shows a typical limestone sequence in the steeply dipping beds of the northern limb of the Beacon Hill Pericline

Photo PO 1 Halecombe Quarry
Sequence in northward dipping Carboniferous Limestone. Black Rock Limestone right of centre, newly blasted pale-coloured Vallis Limestone left of centre.
Grid Ref approx. ST 696 475, c.136m AOD ***Facing East***

The Lower Carboniferous rocks are understood to be conformable with the underlying Old Red Sandstone demonstrating the transition from the continental conditions and the establishment of marine conditions with marine fossils in the Carboniferous Lower Limestone Shale. Corals and brachiopods thrived in the tropical conditions of the shallow limestone shelf seas with irregular lagoon and near-coastal areas lying to the north and deeper-water seas to the south.

Above the Hotwells Limestone, the Quartzitic Sandstone Formation at the base of the Upper Carboniferous is the thin equivalent of the much more massive sandstones and shales of the Millstone Grit Formation of Northern England. It is at the 'feather-edge' of the encroaching giant Upper Carboniferous delta formed by large rivers flowing from the north. The Upper Carboniferous is characterised by the cyclical, generally non-marine, sandstones and shales of the Coal Measures, well known in the now disused Somerset coalfield to the north of Mendip but not represented in the audit programme.

The youngest division in the geological sequence is the Inferior Oolite of mid-Jurassic age which is seen at several East Mendip quarries resting with spectacular unconformity on the underlying Carboniferous Limestone, as seen at Colemans Quarry, Photo ***PO 2*** below.

Photo PO 2   Colemans Quarry, Loc 09
Mid Jurassic Inferior Oolite unconformable on Carboniferous Limestone
Grid Ref ST 72583 44772, c136m. AOD   Photo ref CO-09b   Facing ESE

The Inferior Oolite in Mendip is a thin equivalent of some of the mid Jurassic limestones which have a much greater thickness in the Cotswolds. It's significance in Mendip however, is that it was deposited close to the shoreline of the mid-Jurassic sea of 175 million years ago when Mendip is believed to have been an archipelago of islands in a warm sub-tropical sea. At the surface of the unconformity, the flat erosion surface on the Carboniferous Limestone is generally seen to be covered with oyster shells and remains of other Jurassic bivalves some of which have bored down into the underlying limestone as seen in Photos ***PO 3*** and ***PO 4*** below.

Photo PO 3   Colemans Quarry
Sub-Jurassic erosion surface with fossil oyster beds
Photo ref CO-32a   Hand Specimen

Photo PO 4 Colemans Quarry
Jurassic marine borings in Carboniferous Limestone surface
Photo ref CO-32b ***Hand Specimen***

Detail of under-surface of above photo *CO-32a* showing abundant marine borings in Carboniferous Limestone.

Enlargement of top right corner, Jurassic mollusc bored in to Carboniferous Limestone

2.2 Petrography/Lithology

2.2.1 Silurian Volcanic Rocks

Of the active quarries in Mendip, the volcanic rocks are exposed only in Moons Hill Quarry and associated operations.

The restricted outcrop of volcanic rocks at the core of the Beacon Hill Pericline has been extensively quarried for many years because of its petrographic properties as a strong and durable construction aggregate, particularly valued for its main use as roadstone.

Commercially known under the trade group of 'basalt', the main rock type is strictly an andesite, a fine grained volcanic rock which is intermediate in mineral and chemical composition between basalt and rhyolite. Thick beds of the andesite lavas associated with tuffs and agglomerates occur at Moons Hill Quarry and at smaller satellite quarries such as Stoke Quarry nearby.

The lavas when fresh are typically grey and grey-green, fine grained, often with abundant amygdales which were originally steam and gas holes in the molten lava now filled with white calcite and other coloured minerals, Photo ***PO 5***.

Photo PO 5 Moons Hill Quarry, Loc 09
Silurian andesite with small calcite filled amygdales
Grid Ref ST 56702 44180, c169mAOD ***Photo re. MH09j*** ***Hand specimen***

Andesite lavas are generally characteristic of active mountain chains. The name andesite comes from the Andes of South America where present day volcanoes are generally explosive and produce large volumes of lavas, volcanic ashes, agglomerates and mud-flows, Photo ***PO 6***.

Photo PO 6 Moons Hill Quarry
Typical examples of weathered agglomerate and fresh tuff
Photo refs MH04j and MH08j Hand specimens


Silurian volcanic rocks are not common in Britain. However, it is probably significant that the mid-Silurian rocks of the Welsh Borderland contain thin, but frequently persistent, beds of mudstone which were originally composed of the clay mineral bentonite and these are generally believed to have been the product of intermittent volcanic ash falls.

2.2.2 Old Red Sandstone

The Old Red Sandstone is seen where it outcrops north and south of the workings at Moons Hill Quarry. These strata include variable red-brown, generally coarse sandstones with interbedded conglomerates and occasional shales, believed to be of fluvial origin, Photo ***PO 7***.

Photo PO 7 Moons Hill Quarry, Loc 13
Old Red Sandstone outcrop, sandstones and conglomerates with shale partings dipping steeply south
Grid Ref ST 66453 45575, c262mAOD Photo ref MH13e Facing SE

2.2.3 Lower Carboniferous

The Carboniferous Limestone formations of Mendip are all seen in the active quarries although no one quarry exposes the complete sequence.

The **Lower Limestone Shale** is the basal division of the Lower Carboniferous rocks which succeeds the Old Red Sandstone conformably and represents the gradual transgression of the sea over a period of several million years from the semi-arid continental conditions in the Devonian, to the wholly marine Lower Carboniferous. Only the upper part of the Lower Limestone Shale is seen in Halecombe Quarry where it grades upwards quite rapidly into the overlying Black Rock Limestone as shown in Photo ***PO 8***

Photo PO 8 Halecombe Quarry, Loc 06
Junction between Lower Limestone Shale to the right and Black Rock Limestone to the left.
Grid Ref ST70460 47223 c171mAOD Photo ref HA-06a Facing East

The Lower Limestone Shale comprises largely dark-grey shale and mudstone containing a predominance of land-derived clay minerals reflecting the proximity of the shoreline at the time of deposition. Higher in the division the proportion of limestone beds increases, reflecting the ongoing marine transgression as the shoreline advanced northwards.

A ‘ transition group’ has been recognised in some places at the top of the Lower Limestone Shale but at Halecombe the junction is relatively sharp. It is normal in such sedimentation conditions to expect such variations from place to place.

The **Black Rock Limestone** is the thickest of the limestone formations recognised in Mendip and it has a distinctive and characteristic appearance. It is seen in several of the active quarries (see ***Table 1***, list of quarries in Section 1 above) and it is easily recognised as a well bedded and relatively thinly bedded dark grey limestone, the dark colour indicative of a minor but significant clay mineral and/or bitumen content. When crushed during aggregate processing the limestone gives out a strong bituminous or sulphurous odour. Generally, the stone becomes lighter in colour the higher it is in the sequence. Photo ***PO 1*** in Section 2.1 above illustrates the appearance of the Black Rock Limestone at Halecombe Quarry.

Dolomitisation and Silicification are both common in the Black Rock Limestone, typically affecting distinct horizons in the formation at any one location, but not necessarily at the same horizon or to the same extent at different locations. Both of these processes come under the category of diagenesis, which includes all changes which occur in sediments after deposition, but not going so far as metamorphism by severe heat and/or pressure. Dolomitisation, for example, is the process of alteration of lime mud or limestone to the mineral dolomite by circulating water rich in magnesium and it can occur at any time in the history of the rock from immediately after deposition and/or much later. The dolomite commonly follows minor fractures and it is frequently selective, Photo ***PO 9.***

Photo PO 9 Whatley Quarry, Loc 03
Preferential dolomitisation of Black Rock Limestone matrix (buff and reddish colour) leaving coarser grains and fossil fragments undolomitised.
Grid Ref ST 72722 48206 c60 mAOD Photo ref WH03b Facing East

Silicification would appear to be a similar process but resulting from silica rich fluids. Fragments of fossils in the Black Rock Limestone are frequently silicified and, being hard and relatively insoluble, the fossils tend to weather out on the rock surface (see ***Section 2.5.3*** Palaeontology). As well as this, silica in the limestone occurs sometimes in the form of chert bands or nodules a few centimetres in thickness usually aligned along the bedding, Photo ***PO 10***.

Photo PO 10 Whatley Quarry, Loc 06
Chert Band parallel to bedding in limestone
Grid Ref ST 72642 48330 c51 mAOD Photo ref WH06d

Both these processes also feature in the other limestone formations, but generally to a lesser extent than in the Black Rock Limestone.

Another feature common in some horizons in the Black Rock Limestone, usually in the darker-coloured varieties, are roughly spherical ‘nodules’ of coarsely crystalline calcite. The ‘nodules’ are usually around fist sized and occasionally they are hollow in the centre, as is common at Halecombe, with crystal faces developed as cavity infill, see Photo ***PO 11*** below. Elsewhere, it is normal for there to be no hollow centre. The origin is obscure, but they appear commonly and prominently in the quarried faces.

Photo PO 11 Halecombe Quarry, Loc 12
Hollow calcite ‘nodule’ in Black Rock Limestone
Grid Ref ST72665 45763 c141 mAOD ***Photo ref HA-12e***

The **Vallis Limestone** is a much more pure limestone than the underlying Black Rock Limestone and it is generally a lighter grey colour. The normal gradation upwards as seen at Halecombe is illustrated on Photo ***PO 1*** above.

The Vallis Limestone comprises generally well bedded, pale to mid grey and pale brown, fine to medium grained, sparry, crinoidal, bioclastic limestone with occasional micritic zones.

The Burrington Oolite facies is rarely seen in the East Mendip Quarries, an exception being at Whatley Quarry where it is seen to contrast markedly with the nearby Black Rock Limestone. It has occasionally been recorded in some Company reports as a pale grey oolitic limestone. It appears that the Burrington Oolite is only weakly developed in East Mendip, but when seen it is very distinctive, especially when slightly weathered, Photo ***PO 12***.

Photo PO 12 Whatley Quarry, Loc 27
Burrington Oolite
Grid Ref ST 71922 48021, c123 mAOD Photo ref WH27dl

enlargement

The succeeding **Clifton Down Limestone** generally comprises flat-bedded, mid grey, fine grained, sparry, crinoidal and bioclastic limestone with occasional oolitic horizons see Front

Cover Photo ***PO C***. Some beds of dark grey limestones occur which appear similar to Black Rock Limestone, indicating intermittent return to the same conditions of formation, and along with this there are occasional occurrences of chert nodules and sometimes the unusual calcite 'nodules' described above. In places some beds are crowded with fossil compound corals, Photo ***PO 21***.

The **Hotwells Limestone** comprises generally well bedded, mid grey, fine grained, sparry, crinoidal and bioclastic limestone with occasional chert bands, and dolomitised zones. Large thick shelled brachiopods and large rolled solitary corals are abundant in some beds, Photos ***PO 22*** and ***PO 23***. Beds of spotted and mottled dark and pale limestone known as pseudobreccia also occur. As in the highest beds of the Carboniferous Limestone elsewhere in the country, the prominent bedding planes are often shaly with minor potholing beneath and probable fossil soils, indicative of emergence above sea level from time to time, Photo ***PO 13*** below.

Photo PO 13 Gurney Slade Quarry, Loc 02
Massively bedded Hotwells Limestone with prominent shaly bedding planes
Grid Ref ST 62793 49557, c196 mAOD   Photo ref GS02   Facing South

The Upper Carboniferous strata which succeed the Carboniferous Limestone, which include the Quartzitic Sandstone Group (the thin equivalent of the Millstone Grit) and the Coal Measures, are not seen in any of the active quarries.

2.2.4 Triassic Dolomitic Conglomerate

The so-named 'Dolomitic Conglomerate' (which is more normally a breccia and frequently not dolomitic) is a marginal facies of the Triassic Mercia Mudstone Group, Photo ***PO 14***. Formed as a scree deposit on and around the edges of the Triassic Mendip Hills during a period of intense weathering, it is a variable and diachronous series generally comprising ill-sorted red, brown and purple breccias, conglomerates and sandstones often overlain by, and passing laterally away from the hills into mudstones and siltstones of the normal Mercia Mudstone as seen resting unconformably on the Carboniferous Limestone at Dulcote Quarry, Photo ***PO A*** on front cover.

Photo PO 14 Gurney Slade Quarry, Loc 11
Detail of 'Dolomitic Conglomerate' with abundant angular clasts of Carboniferous Limestone in finer grained, typically reddish and yellowish-brown matrix.
Grid Ref ST 62700 49910, c222 mAOD   Photo ref GS11d

2.2.5 Jurassic Rocks

The mid-Jurassic **Inferior Oolite** resting unconformably on the Carboniferous Limestone at some quarries (Photo ***PO 2*** in Section 2.1 above) generally comprises well bedded, pale yellow-brown to buff, fine to coarse grained, fossiliferous, oolitic limestone. The limestone is often rubbly, friable, porous and weaker than the underlying Carboniferous Limestone.

A thin development of limestone conglomerate, believed to be the **Downside Beds** of early Jurassic age, is seen at only one location resting unconformably on the Carboniferous Limestone. It is a littoral facies (beach or intertidal deposit) of very pale-cream, calcareous, fine to coarse breccias and conglomerates.

Examples of shelly limestones of various Jurassic ages, together with Triassic red-brown clays are also seen in quarry exposures of fissure deposits, see Neptunian Dykes, ***Section 2.4*** below.

2.2.6 Mineralisation

Mineralisation is present to a variable extent throughout the limestones and in the 'dolomitic conglomerate' of the Mendips as a result of supergene (descending) fluids from above and hypogene (ascending) fluids from below. A complex interaction of both forms of mineralisation is recognised. Evidence from fluid inclusion studies (examination of traces of the original mineralising fluid preserved in the crystals) suggests that the rising fluids were hot and probably in excess of 85ºC. This type of mineralisation in limestone sequences is commonly known as Mississippi Valley-type mineralisation.

A range of minerals is found in many of the quarries including barite with some associated carbonate mineralisation and traces of (hypogene) metal sulphide mineralisation in the form of small, localised mineral veins, together with more common (supergene) iron, manganese and calcium based mineralisation that is typical of limestone host rocks.

Metalliferous lead and zinc mineralisation occurs in the Mendips as the result of hot, brine rich fluids moving throughout the limestone bodies via WNW – ENE fissures, faults and joints. The source of the metal was probably from sediments that incorporated marine organisms that had extracted and concentrated the metal elements (originally from the seawater) into their soft and skeletal body parts.

Lead, zinc and manganese ores have been worked (particularly in the west and central Mendip regions) since Roman times and more recently mainly in the 17th and 18th Centuries. It has been estimated that around 200 000 tonnes of lead ore and a similar tonnage of zinc have been worked. Mineral bearing veins extended in length for several hundreds of metres but rarely attained depths greater than 30 metres. All commercial mineral extraction in the Mendip region ceased many years ago and the orefield is regarded as fully worked out.

2.3 Geological Structure

2.3.1 Regional Structural Evolution

The main geological structure of the Mendip ridge consists of four main periclines, arranged *en-echelon* and trending generally east-west. The folds are asymmetrical with the bedding in the limestones being much steeper, almost overturned, on their northern limbs. Southward dipping thrust faults by which the strata on top have been pushed northwards for long distances are common. All this indicates that the main geological stress direction came from the south.

The cause of this complex geological structure of the older rocks of Mendip, the Palaeozoic rocks, was pressure of a colliding continent encroaching from the south and causing the mountain building episode known as the Variscan Orogeny. These powerful earth movements gradually advanced northwards across Europe and southwest England during the Devonian and Carboniferous geological periods and reached the Mendip area in the late Carboniferous and Permian which was some 300 million years ago. The 'Variscan Front' – the northernmost substantial influence of this period of earth movements – follows an east-west line only a few miles north of Mendip connecting Belgium and southwest Wales.

This collision of continents formed a giant mountain chain, much bigger and higher than Mendip is today. The mountains were of Alpine proportions extending eastwards into Central Europe and beyond, and westwards into North America. At that time the Atlantic Ocean did not exist.

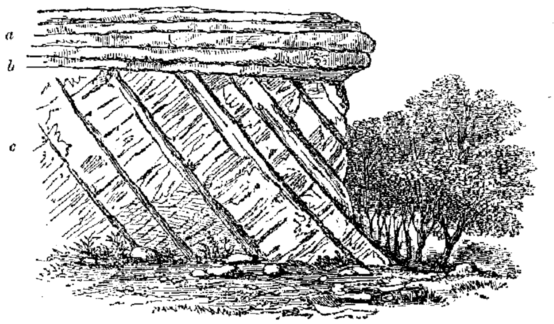
Earth movements of this kind proceed very slowly. A modern day equivalent of the Variscan is the collision of Northern Africa moving gradually, at about the speed that a fingernail grows, towards Southern Europe. This has been, and will continue to be, the cause of the earthquakes and volcanoes of the Mediterranean area and the creation of the present day Alpine mountain chain over the last 50 million years.

The East Mendip Quarries are within or close to the easternmost of the four main periclines, the Beacon Hill Pericline, situated between Wells and Frome.

Post-dating the Variscan Orogeny, the Mesozoic rocks which were deposited over the folded and then eroded Palaeozoic rocks are generally flat-lying and structurally much less disturbed. However, the distribution of the thickest basins of Mesozoic sediments away from the Mendip ridge, and the faults associated with them, are often seen to be strongly influenced by the older geological structures in the rocks beneath. The Upper Palaeozoic phase of intense compression by continental collision from the south was replaced in the Mesozoic by the opposite, a regime of tension in the rocks whereby the faulting was extensional, i.e. the earth's crust was stretched. The mineral and sediment filled fissures known as neptunian dykes, discussed separately in ***Section 2.4*** below, were formed at this time.

This structural contrast between the Palaeozoic and Mesozoic rocks of Mendip was first recognised at Vallis Vale by the pioneering work of Sir Henry Thomas de la Beche, first Director of the Geological Survey of Great Britain, in his survey work in Somerset in the early to mid 1800's.

The de la Beche Unconformity



a. Inferior Oolite.
b. Arenaceous parting.
c. Carboniferous Limestone.

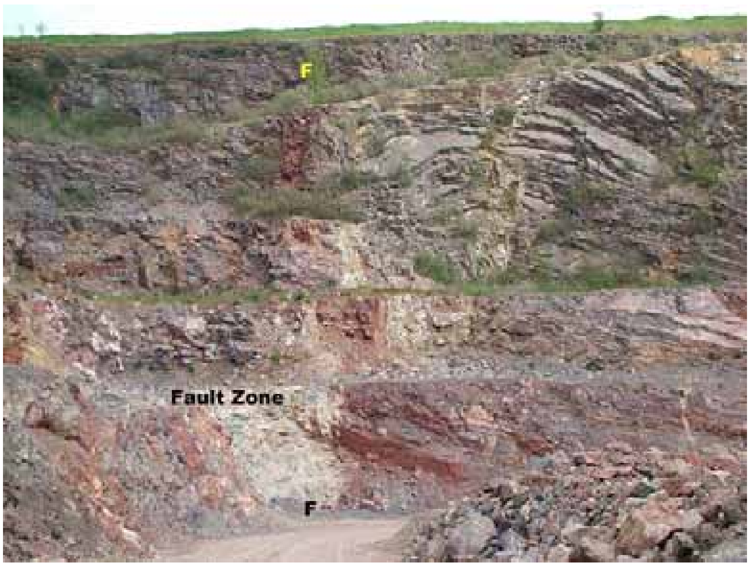
2.3.2 Geological structures seen in the quarries

De la Beche's unconformity can still be seen at the place where he sketched it at Vallis Vale (ST 758 485) and at nearby Tedbury Camp (ST 746 489). It is also intersected at several places in the active quarries at Whatley, Torr and Colemans (Holwell), illustrated as Photo ***PO D*** on the front cover of this report where the comparison with de la Beche's sketch above will be clear.

Colemans Quarry is on the southern (shallower) limb of the Beacon Hill pericline where the Vallis and Black Rock Formations of the Carboniferous Limestone dip southwards at angles averaging around 30^{o}.

Faulting In the quarry is complex and faults recognised in the quarry faces occur both as fault zones up to 25 metres in width, as well as discrete planar features. Typically, the fault zones generally are heavily stained red or have a pale bleached appearance and an abundance of clay, calcite growth, fault debris and associated calcite-cemented fault breccias, Photo ***PO 15***.

Photo PO 15 Colemans, Loc 11
Fault zone F-F in thinly bedded Black Rock Limestone dipping south
Grid Ref ST 72673 45460, c106 mAOD   Photo ref CO-11a   Facing NE



The faulting is commonly, though not necessarily, associated with the infilled fissures known as neptunian dykes described in the following ***Section 2.4***.

Similarly, **Torr Quarry** is also on the southerly limb of the Beacon Hill Pericline with a near complete sequence of the Carboniferous Limestone dipping south at angles varying from 24^{o} to 47^{o} at different locations in the quarry.

Several fault zones cross the quarry. Two large faults - the Downhead and Merehead Faults - run along the western margin and from southeast to northwest through the quarry respectively. An additional number of minor faults and thrusts may also be traced in the quarry. Faults recognised in the quarry faces occur as fault zones or as discrete planar features.

The most prominent fault, the Merehead fault, is a complex fault-zone up to 25 metres in width. It joins with the Downhead Fault in the northwest part of the quarry resulting in heavy fracturing and rotation of bedding in the adjacent face. This zone is generally heavily stained red and is associated with strong haematite mineralization, see Front Cover Photo ***PO B***. The Merehead fault zone also has a pale bleached area and an abundance of associated clay, calcite growth, fault debris and calcite cemented fault breccias that are typical of fault zones in the Mendips. Rounded boulders are incorporated into parts of the fault zone together with red marls that are typical of the Triassic Dolomitic Conglomerate, indicative of neptunian dyke characteristics, see following ***Section 2.4***. This is further supported by a number of identified Jurassic limestone blocks that are also incorporated into the fault zone. Other features associated with the Merehead fault zone are large rounded blocks of limestone that have undergone extensive solution. Examples of 'bedded' calcite-lined cavity infill are also noted, demonstrating free flow of water from time to time through the fault zone.

A number of low angle thrusts dipping to the south are seen in the faces at Torr, more or less concordant with the bedding. This has the effect of locally thickening the limestone deposit, see Photo ***PO 16***.

Photo PO 16 Torr, Loc 19
Minor thrust plane semi-concordant with bedding
Grid Ref ST 69106 44854, c98 mAOD Photo ref TO-19c Facing West

A larger thrust fault locally known as the Shute Farm Thrust marks the northern limit of quarrying activity at Torr.

Whatley Quarry and **Halecombe Quarry** are both on the northern limb of the Beacon Hill Pericline and both exhibit steeply northward dipping Carboniferous Limestone (see Photo ***PO 1*** in Section 2.1 above, Halecombe).

Dulcote Quarry is in an inlier of Carboniferous Limestone strata surrounded and overlain by breccia and mudstones of Triassic age, see Front Cover Photo ***PO A***. The Carboniferous limestones form a complex faulted and thrusted anticlinal fold structure known as the Dulcote Pericline situated south of a major thrust zone that separates the Dulcote Pericline from the major Beacon Hill Pericline.

Within the quarry area the beds are folded and in places near vertical and overturned with a general dip to the south. Numerous faults are seen in the quarry faces both as small fault zones as well as discrete planar features. The fault zones are generally heavily stained red and have an abundance of clay, calcite growth and associated calcite cemented fault breccias. Abundant low angle thrust faults dip to the south and slickensides occur on bedding plane surfaces indicating bedding plane slip and thrust movement that is coincident with the bedding.

Gurney Slade Quarry is situated in the northwest limb of the Binegar Syncline that divides the Pen Hill Pericline to the northwest and the Beacon Hill Pericline to the southeast. The quarry works a fairly simple series of beds in the Clifton Down and Hotwells Limestone Formations that dip consistently to the southeast, see Front Cover Photo ***PO C***.

At **Moons Hill** Quarry, the Silurian andesite volcanic lavas with beds of tuff in the core of the Beacon Hill Pericline are generally vertical, getting younger northwards. As such, this structure fits with the steep dipping strata seen in the quarries on the northern limb of the pericline. The contact with the relatively shallow dipping Old Red Sandstone on the southern limb of the pericline is not seen but it is believed to be faulted, probably a southward dipping thrust fault. There is no evidence that the Silurian rocks were significantly folded before the Old Red Sandstone was deposited on top. However, the junction is sharp and there is a substantial time gap in the geological succession at the contact, it is therefore an unconformity.

2.4 Fissure Veins and Neptunian Dykes

The relative abundance of fissure veins in the Carboniferous Limestone of East Mendip is a unique feature deserving special discussion. The fissure veins frequently contain Triassic and Jurassic sediments and fossils and they are known as ‘neptunian dykes’.

The nature of the neptunian dykes has been known for many years since they were first recognised in 1855 at Holwell, near the present workings of Colemans Quarry, and described by Moore, 1867 and later by Kuhne, 1946.

The fissures are considered to result from stretching of the Earth’s crust, the ‘extensional tectonics’ of the Mesozoic, which was a reversal of the ‘compressional tectonics’ of the Upper Palaeozoic Variscan continental collision - see ***Section 2.3.1*** above, Regional Structural Evolution.

Recent studies of the fissures by Wall and Jenkyns, 2004, have determined a total crustal extension during the Triassic and early Jurassic of about 4.7% N-S and about 0.6% E-W.

Extensional fissure veins with progressive infill of calcite crystals are seen in almost all of the active Carboniferous Limestone quarries in East Mendip. In areas where the sub-Mesozoic unconformity can be seen or is known to occur nearby, at Colemans and Torr Quarries for example, the fissures frequently contain Triassic and/or Jurassic sediments, Photos ***PO 17*** and ***PO 18***.

Photo PO 17 Colemans, Loc 13
Calcite lined fissure with neptunian dyke infill of red-brown clay, presumed Triassic. Width of fissure approx 0.5m.
Grid Ref ST 72801 45331, c98 mAOD Photo ref CO-13f Facing South

Photo PO 18 Colemans, Loc 23
Neptunian dyke with double outside veneer of calcite growth and centre infill of pink, coarse-grained, fossiliferous Jurassic limestone. Width of fissure about 1.70m.
Grid Ref ST 72457 45889, c115 mAOD Photo ref CO-23n Facing NW

2.5 Palaeontology

2.5.1 Silurian

The age of the volcanic andesites and tuffs at Moons Hill Quarry is proved by their association with shales containing fossil brachiopods of a shallow marine environment identified as Mid-Silurian (Wenlock) age. The shales are no longer exposed.

2.5.2 Old Red Sandstone

The Old Red Sandstone of Devonian age is reported occasionally to contain fragmentary remains of freshwater fish and plants but none have been identified from the Moons Hill area. It was in the Devonian Period that plants and animals first began to colonise the land.

2.5.3 Lower Carboniferous

The whole of the Lower Carboniferous succession, dominated by marine limestones, is highly fossiliferous. The various limestones (see ***Table 2***, Summary of Stratigraphy in Section 2.1) contain different assemblages of fossils characteristic of each formation. Examples are as follows:

No fossils were seen at the only exposure of the **Lower Limestone Shale** at Halecombe Quarry, but at other exposures it is reported to contain abundant debris of crinoid ossicles and the coral *Vaughania* (formerly called *Cleistopora*) which is characteristic of this lowest level in the sequence. The presence of corals and crinoids which are exclusively marine proves that the deposit was formed in the sea.

Above this, the **Black Rock Limestone,** worked at several of the quarries, is highly fossiliferous in places. Frequently, the fossil shells, corals and crinoids are silicified and, being insoluble, stand proud from the limestone matrix or weather out complete in the overburden, as shown in Photos ***PO 19*** and ***PO 20*** respectively, from Halecombe Quarry.

Photo PO 19 Halecombe Quarry, Loc 02
Abundant fossil brachiopods of the variety *Spirifer* preserved in silica.
Grid Ref ST7020 4725, c164mAOD ***Photo ref HA-02f***

Photo PO 20 Halecombe Quarry, Loc 08
Assemblage of fossil crinoid ossicles, corals and brachiopods preserved in silica. Found in overburden above Black Rock Limestone.
Grid Ref ST70482 47300, c164 mAOD   Photo ref HA-08d

Large solitary corals, for example, *Siphonophyllia* (formerly known as *Caninia*), occur frequently in the Black Rock Limestone especially in the higher levels of the formation.

Intact fossils are less common in the overlying **Vallis Limestone**, most traces of shells and crinoids being fragmentary and incorporated within the bioclastic limestones.

In the **Clifton Down Limestone**, intact corals and brachiopods become common again but in this case they are varieties which are different from those of the Black Rock Limestone, including varieties of the compound coral *Lithostrotion*, Photo ***PO 21,*** and large thick-shelled brachiopods.

Photo PO 21 Gurney Slade Quarry, Loc 23
Fossil compound coral *Lithostrotion martini* in Clifton Down Limestone. Some beds are crowded with this coral.
Grid Ref ST 62476 49785, c200 mAOD   Photo ref GS23c   Facing WNW

The **Hotwells Limestone** is highly fossiliferous with abundant large solitary corals such as *Palaeosmilia murchisoni,* Photo ***PO 22****,* and large thick shelled brachiopods. Photo ***PO 23****.*

Photo PO 22 Gurney Slade Quarry, Loc 10
Large solitary corals in Hotwells Limestone, *Palaeosmilia murchisoni*
Grid Ref ST 62609 49895 c221 mAOD   Photo ref. GS10n & GS10p

Photo PO 23 Gurney Slade Quarry, Loc 03
Examples of thick shelled fossil brachiopods in Hotwells Limestone.
Grid Ref ST 62809 49714, c193 mAOD   Photo ref. GS03k and GS03l

2.5.4 Triassic and Jurassic

Important late Triassic and Jurassic fossils have been found in the fissures (neptunian dykes) in the Carboniferous Limestone and they are well recorded in technical literature, but they are rare and no intact fossils were found during the audit, see ***Section 2.4*** above, Fissure Veins and Neptunian Dykes. However, several examples of fissures containing bioclastic limestone of Jurassic type, composed of fragmented shelly debris, was found in some of the fissures, Photo ***PO 18*** above.

A particular feature of the Neptunian dykes which adds to their uniqueness is the recorded presence in the fissure sediments of fossil vertebrate bones. The bones are rare and occur only in certain types of fissure sediment. Large volumes of the infill sediment have to be laboriously examined to yield small proportions of bones. They are mainly marine and most are bones of fish. However, in a small proportion of the residue are remains of terrestrial reptiles and an even smaller fraction of these are teeth of early mammal-like reptiles of late Triassic age, some of the earliest records of the evolution of mammals.

The Jurassic sediments which rest unconformably on the Carboniferous Limestone contain abundant fossils. At Colemans, Whatley and Torr Quarries, the Inferior Oolite contains typical mid Jurassic shells and fragments of echinoderms and the sub-Jurassic surface immediately beneath contains many trace fossils of organisms which lived on and bored and burrowed into the hard surface of the rock surface beneath, see Photos ***PO 2**, **PO 3*** and ***PO 4*** above.

At Gurney Slade Quarry, a beach deposit of early Jurassic breccias and conglomerates in a limestone matrix contains traces of calcareous algae.

2.6 Geotechnical

Stability of quarry faces, both at active and abandoned quarries, is an important safety issue which relates directly to geodiversity features. Particular features influencing stability are the discontinuities in rocks such as faults, fault zones, joints and bedding attitudes, their intersections with each other and with the cut faces and benches. Particular groups of strata are more susceptible to instability problems than others, for example, special care is needed when the Black Rock Limestone is encountered with its relatively thin bedding and shaly partings.

Detail of this can not be included in this overview, but active quarries are considered to provide valuable insight to this important aspect of applied geology and a valuable educational opportunity for student quarry visitors. The subject has been included in the geodiversity audit for this reason and a brief descriptive section is therefore included in each of the quarry audit reports.

2.7 Hydrogeology

Similarly, hydrogeology has been included in the geodiversity audit because active quarries can often demonstrate the practical issues involved in this specialist subject and as such can also provide a valuable educational opportunity for student visitors.

The Carboniferous Limestone of East Mendip is a major aquifer used extensively for water supply. Groundwater flow in the limestone is generally anisotropic and not constant in all directions. Flow is characterised by low primary porosity (intergranular flow) and moderate to locally high secondary porosity via bedding planes, joints and fissure flow, many of which have been enhanced by karst development and solution widening.

Hydrogeology is a subject which is generally difficult to demonstrate in the field but quarries working below the natural water table can provide a means of visualising hydrogeological principles and the relationship of groundwater to surface watercourses.

A great deal of specialist investigation and monitoring of hydrogeology has been carried out at the Mendip quarries, particularly relating to the actual and potential effects of quarry dewatering on the surrounding water environment both surface and underground.

2.8 Karst

Karst is a landscape characterised by caves, enlarged fissures and enhanced underground drainage caused by chemical solution of rocks and re-deposition. Karst is particularly characteristic of limestone areas, because limestone is the commonest rock that is readily water-soluble. Many spectacular karst locations in the UK are on or in the Carboniferous Limestone.

Mendip is well known for its karst features, some of which are important tourist attractions, e.g. Cheddar Gorge, Wookey Hole. Caving is an important recreational and scientific activity in Mendip. The karst of the area has therefore been extensively explored and well documented in various caving journals.

East Mendip is generally regarded as having less well developed karst than Central and West Mendip, but nevertheless it may be considered surprising that few significant karst features have been recognised in the quarry geodiversity audits. Intersections with caves are few. Most of the karst features seen are near surface solution features such as clay filled potholes and pinnacles of relatively low relief. Where it is, or recently has been present, the Inferior Oolite appears to have protected the top of the underlying Carboniferous Limestone from extensive solution effects.

This is not to say that quarries do not impinge upon the karst environment. Much of the hydrogeological investigation referred to in the preceding ***Section 2.7*** has been to determine the effects of quarrying on the surrounding groundwater regime in which water movement is largely in limestone fissures which have often been enlarged by solution.

2.9 Geomorphology and the Quaternary

The detailed landform of Mendip is dominated by the relatively recent karst development which probably followed the final stripping of the Mesozoic rock cover from the Carboniferous Limestone surface. This appears to have happened largely during the Quaternary with the climatic extremes of the alternating warm and cold periods of the ‘ice ages’.

In the big picture however, the larger Mendip landforms would appear closely to resemble the ancient Mesozoic hills, valleys and islands with remnants of Mesozoic piedmont and shoreline deposits along the margins. Especially in East Mendip, where the Jurassic limestones are only in process of being removed, the karst is immature and the landform only karstic in places.

The quarries generally give little clue to the relatively recent geological past. Mendip lay to the south of the most southerly extreme of Pleistocene ice sheets so it is not surprising that there is no evidence of glaciation, or any glacial surface deposits such as boulder clay or glacially transported erratic boulders.

However, the area was frequently close to the edge of the ice sheets so it must have been been subject to severe periglacial conditions of alternate freezing and thawing from time to time. Whilst ‘head’ and fan-gravel deposits of likely periglacial origin are recorded on the lower lying ground around Mendip, it is surprising that no evidence of periglacial conditions has been seen in the overburden at any of the quarry audits. Indeed the general absence of substantial superficial deposits forming overburden at any of the quarries is noted.

3. GEODIVERSITY CONTEXT

3.1 Background

The earth has been in existence for about 4.5 billion years. Primitive life is believed to have come into being about 3.5 billion years ago. About 500 million years ago in the Cambrian Period, animals developed hard shells and skeletons capable of being fossilised in the rocks. Much of the evidence for past conditions and climates comes from the study of the way rocks have been formed, the fossils within them and the way in which the animals and plants lived.

Unravelling the evolution of ancient climates can give clues to the way in which future climates and environments are likely to change.

It is now well known that the continents of the world move around its surface at a rate which is almost imperceptible by human timescales, but given the millions of years of geological time the continents can move, and have moved, thousands of miles.

The broad disposition of continents at different times during the last few hundred million years is now generally known from measurements of the magnetism preserved in certain types of rocks in relation to the magnetic poles of the earth at the time the rocks were formed. This geological concept has only been scientifically accepted within the last 50 years or so.

Any one location alone can not provide evidence sufficient to determine the ancient geography of the time. However, the geological features seen, taken together with evidence from many other locations, provide pieces contributing to reconstruction of the ‘geological jig-saw puzzle’.

Conversely, when considering detail at any one location, it is important to view this in light of the ‘big-picture’ of what is understood of the regional and global palaeogeography and palaeoenvironment.

Taken together, the Geodiversity Record in the active quarries, in particular the Stratigraphy, Sedimentary Petrology, Geological Structure and Palaeontology, considered along with other information of the same type from other places, provides valuable additional evidence for past environments and climates in which the rocks of Mendip were formed.

The sequence of strata recording the geological history of Mendip is summarised in ***Table 2***, Stratigraphy in East Mendip in Section 2.1. The Geological Timescale is outlined in the Table at the end of ***Appendix F, Glossary***.

3.2 Palaeoenvironment and Palaeogeography

3.2.1 Silurian (450 to 420 million years)

The earliest rocks in Mendip are the shales and volcanic rocks of the mid-Silurian Period about 430 million years old. At that time, most of the continental areas of the world as we now know them were grouped together as two large supercontinents:

Laurentia, spanning the equator, took in the main part of North America together with Scandinavia, the Baltic countries and parts of Russia.

Gondwana, largely in the southern hemisphere, was made up of Africa, South America, Antarctica, India and Australia.

The Southern part of Britain was then situated on a separate ‘micro-continent’ known as *Avalonia* which had separated from Gondwana and had moved across the intervening ocean. Avalonia collided with the southern part of Laurentia in the early Silurian and joined with it forming the Caledonian mountain chain, the remains of which we still see today in the highlands extending from Norway through Northern Britain to the Appalachian mountains of eastern North America.

In the Silurian, the southern part of England and Wales was on a relatively stable part of Avalonia on the edge of Laurentia close to the equator.

Generally, the Silurian Period in Southern Britain was a relatively quiet time, so the existence of explosive volcanoes in the area of Mendip in the midst of a shallow shelf sea appears to be an anomaly which is difficult to fit into the general pattern. The volcanic rocks are well seen at Moons Hill Quarry, Photos ***PO 5*** and ***PO 6***.

Towards the end of the Silurian, about 420 million years ago, the land rose relative to sea level with the onset of the continental semi-arid deposits of the Old Red Sandstone.

3.2.2 Devonian (420 to 350 million years)

As appears to have happened often throughout geological time, following a major continental collision and formation of a mountain range much of the new land became desert. The Old Red Sandstone is the name given to the red-brown rocks of much of Devonian Britain, mainly sandstones, conglomerates and mudstones which were formed by flash floods of intermittent but powerful rivers in the piedmont (mountain foot) and lower-lying continental area of the Devonian Period. Probably the best known Old Red Sandstone deposits in southern Britain are those forming the high mountains of the Brecon Beacons.

It was in the Devonian Period that the first land animals (primitive fish and amphibians) and land plants in any significant numbers are believed to have evolved. Fragmentary fossils of freshwater fish and plant remains are found in some Old Red Sandstone deposits.

A deep sea basin lay at the southern edge of Britain where the marine Devonian sediments of south Cornwall and Devon were formed. Farther to the south, but probably no great distance away, was the edge of the continent of Gondwana advancing northwards, already influencing the structure of the rocks of Cornwall and Devon and heralding the approach of the later Variscan continental collision.

In Mendip, Upper Silurian and the Lower and Middle Old Red Sandstone rocks are missing, either they were not deposited or, more likely, any sediments deposited were removed later by erosion.

The Upper Old Red Sandstone rocks (Portishead Beds) seen at Moons Hill Quarry, Photo ***PO 7***, are typical river deposited red-brown sandstones, conglomerates and mudstones.

There is therefore a long time gap of about 70 million years in which there is no direct evidence of Mendip environmental conditions between the formation of the mid-Silurian shales and volcanics and the Old Red Sandstone of late Devonian age. However, evidence from earlier Old Red Sandstone rocks elsewhere in Britain suggests that semi-arid desert conditions generally prevailed throughout and during this time the mountain ranges were eroded to a relatively flat plain which allowed the early Carboniferous sea easily to transgress the land with only a slight change in relative sea level.

3.2.3 Carboniferous (350 to 290 million years)

The marine transgression at the base of the Carboniferous in Mendip is seen to be continuous, evidently with no break, from the desert continental environment of the Devonian to the shallow muddy coastal sea in which the Lower Limestone Shale was deposited, Photo ***PO 8***, Halecombe Quarry.

The early muddy sediment was derived from the adjacent land but gradually the water cleared sufficiently to allow relatively pure limestones to form with abundant fossil remains such as crinoids (known today as ‘sea lilies’, not plants but animals related to starfish), corals and brachiopods, for example, Photos ***PO19*** to ***PO 23***. The proportion of land derived sediment in the limestones is negligible.

Around 1000 metres of Carboniferous Limestone was deposited altogether and the evidence of the fossils and the limestone sediments indicates that most would have formed in relatively shallow water, probably within the range of wave base.

The land was therefore subsiding and sediment accumulation was keeping pace with it. It is believed that the Carboniferous Limestone of Mendip took around 30 million years to accumulate.

This is equivalent to about 1mm depth of accumulation every 30 years. Geological processes are slow, but can achieve a lot, given time enough.

The environment is considered to have been comparable to the Bahamas or the Maldives today and during the Carboniferous period the area of Mendip was close to the equator.

The various formations of the Carboniferous Limestone of Mendip can be correlated readily with their counterparts elsewhere in the country, for example, in the Pennine areas, North Wales and Cumbria, using the characteristic fossils such as corals and brachiopods which evolved significantly during the 30 million years of formation. The environments of formation appear to have been closely similar over a wide area.

The highest formation of the Carboniferous Limestone in Mendip, the Hotwells Limestone, is of particular interest, Photo ***PO 13***, at Gurney Slade Quarry. The limestone beds are distinctive from beds in the other formations in having distinct thin shale beds between and thin fossil soils known as palaeosols have been recorded. The alternating limestone and shale is suggestive of rhythmic cycles. Closely similar strata are recognised in Northern England and the abundant fossil corals and brachiopods are of the same species'. Elsewhere there are records that the limestone strata pass laterally into sandy limestones and sandstones with thin coal seams. This indicates an overall shallowing of the sea and emergence of the sea floor above sea level from time to time.

These features of the formation of the Hotwells Limestone would seem to be precursors of a giant Upper Carboniferous delta which grew from the north and eventually covered most of the country. The many sedimentary alternations of sandstone, shale and coal seams of the Upper Carboniferous Coal Measures almost certainly result from cyclical rising and falling of sea level and the consequences of this on the nearby land.

This was a time of hot and humid tropical conditions, somewhat similar to tropical rain forest conditions today in deltas at the ends of major rivers in parts of equatorial Africa and South America.

This was also a time of one of the great glacial ice-ages of the world, not in Britain which was then close to the equator, but far to the south in the other continent of Gondwana where glacial sediments of this age are known from South America, South Africa and Australia, believed then to have been close to the South Pole.

Modern understanding is that the Gondwanan glacial cycles of freezing and melting resulted in rises and falls of sea level in the order of several tens of metres worldwide and this caused the fluctuating sedimentary conditions of the Upper Carboniferous in Northern Europe.

The Hotwells Limestone of Mendip is overlain sharply by the Quartzitic Sandstone Formation (the southerly extension of the well known Upper Carboniferous Millstone Grit of Pennine areas) which is overlain in turn by the Coal Measures of the Bristol coalfield.

None of these Upper Carboniferous strata are exposed in the active aggregate quarries but it is mentioned here as an important part of the evolution of Mendip geology.

The Bristol coalfield is no longer worked because the complexities of geological structure caused by the Variscan earth movements meant that modern mining technology was impractical and uneconomic.

3.2.4 Variscan (380 to 280 million years)

The Variscan is not a distinct Geological Period but it is a term applied to the 'orogeny' or mountain building episode in the late Palaeozoic whereby northern parts of Gondwana collided with the southern part of Laurasia (Laurussia as it is often known at this stage) to play its part in forming the supercontinent of Pangaea in which nearly all the continents of the world came together in what appears to have been a single landmass.

The whole process appears to have taken about 100 million years from the late Devonian through the Carboniferous to the early Permian, but it affected different areas at different times. For instance, in France and Cornwall the deformation appears to have started in the Devonian whereas in Mendip near the northern limit of the Variscan Front there was little obvious effect until the late Carboniferous when the major asymmetric folding, faulting and thrusting of the Palaeozoic rocks of Mendip took place.

The result of the Variscan orogeny was a giant mountain chain of Alpine proportions stretching from Eastern Europe, through Germany, France and Southern Britain to the eastern seaboard of North America (the Atlantic Ocean did not exist at that time) as far as Central America.

3.2.5 Permian (290 to 250 million years)

Another outcome of the Variscan was that much of the land became largely desert again. Britain was landlocked in mid Pangaea at the beginning of the Permian some 280 million years ago and at the same time the steady northward drift of the continents had brought the area into the arid climate belt, equivalent in latitude to the Sahara desert today.

The high mountains underwent active erosion in the extreme climate with temporary deposits of coarse scree breccias in the piedmont areas. Wind blown sands and thick beds of river sand and gravel were deposited on the lower lying ground, along with mudstones formed in intermittent seasonal lakes some of which became highly saline. The arid or semi-arid conditions were punctuated by short periods of intense rainfall with flash floods.

So far as is known there are no Permian deposits in Mendip. The evidence for the Permian environment of Mendip is derived from deposits of this age in nearby areas, for example parts of Devon, the Midlands and the North, and the awareness that the erosion of the folded mountain range must have occurred during this period.

Many deposits of the Permian of Britain are red-brown in colour, descriptively called 'red beds', and together with the Triassic deposits they are known as the New Red Sandstone (see, for comparison, ***Section 3.2.2*** above, the Old Red Sandstone).

The time around the end of the Permian about 250 million years ago is marked globally by the greatest mass extinction in geological history. Approaching 50% of all orders and families of species may have perished. Evidence in Britain is meagre because fossils are rare in the New Red Sandstone. The causes of the extinction event are unknown, but it is worth noting here because climate change relating to Pangaea has been suggested as a possible influence.

3.2.6 Triassic (250 to 200 million years)

Triassic deposits are important in Mendip. The 'Dolomitic Conglomerate' rests unconformably on Carboniferous rocks and it has a widespread but irregular outcrop throughout the upland area and in valleys radiating outwards. The present day upland Mendip landform is believed closely to resemble the topography of the Triassic, modified only to a minor extent by subsequent events. The valleys are features created by Permo-Triassic erosion and the deposits are understood to be remnants of screes and flash-flood deposits representing late stages of the severe erosion of the mountains which started in the early Permian.

The deposit grades outwards away from edges of the Mendip upland into the lowland Triassic deposits of the Mercia Mudstone, a red-brown silty clay, which was deposited at the same time in lowland temporary lakes, known in the desert environment as 'playa lakes'.

An example of typical Dolomitic Conglomerate is shown in Photo ***PO 14*** at Gurney Slade. Less typical but particularly interesting is the 'wadi-fill' deposit of the Dolomitic Conglomerate exposed in abandoned workings at Colemans Quarry and notified as an SSSI. The term 'wadi' denotes a steep-sided valley formed by flash floods in desert climatic conditions.

The Front Cover Photo ***PO A*** shows Triassic red-beds comprising red-brown, yellow and purple breccias, mudstones and siltstones overlying Carboniferous Limestone at Dulcote Quarry. At this location, siliceous geodes in the Triassic rocks, which used to be extracted for ornamental use, are believed from their shape and structure to have originated as nodules of anhydrite, a mineral formed by evaporation in temporary lakes in the desert environment.

In places, some of the fissures caused by tectonic stretching in the underlying Carboniferous Limestone (see ***Section 2.4***, Fissure Veins and Neptunian Dykes) became filled with red-beds sediment percolating down from the Triassic landscape, Photo ***PO 17***.

Towards the end of the Triassic, the land was again inundated by a steady marine transgression caused by a worldwide gradual rise in sea level coincident with what appears to be the end of the southern hemisphere glacial episodes. This overall rise continued with numerous smaller fluctuations through the Jurassic and into the Cretaceous coincident with the break up of Pangaea and the beginnings of the split of the Atlantic Ocean.

3.2.7 Jurassic (200 to 140 million years)

Mendip about 200 million years ago in the early Jurassic is often visualised as an archipelago of numerous islands formed by the higher ground protruding above the slowly advancing sea level. The evidence for this comes from isolated exposures of early Jurassic beach deposits formed by the advancing sea around the flanks of the islands. At Gurney Slade Quarry, remnants of a beach deposit of early Jurassic breccias and conglomerates are embedded in a limestone matrix which contains traces of corals and calcareous algae.

As with the Triassic, some of the fissures in the underlying Carboniferous Limestone resulting from tectonic stretching (see ***Section 2.4***, Fissure Veins and Neptunian Dykes) contain sediments of early and mid Jurassic age, Photo ***PO 18***, providing tantalising glimpses into the life and conditions at the time.

Mid Jurassic limestones of the Inferior Oolite about 170 million years old, resting unconformably on the Carboniferous Limestone, are seen at several locations and in some of the active quarries, for example Photos ***PO 2*** to ***PO 4*** at Colemans Quarry, providing evidence of a more extensive and longer-lasting advance of the sea. Although only small thicknesses of these limestones remain in Mendip, a greater thickness of the same limestones can be seen no great distance away in the Cotswolds. These are generally coarse grained oolitic and bioclastic limestones. The fossil content includes shells and sea urchins characteristic of shallow, clear, coastal seas in a warm temperate climate, evidently in Mediterranean latitudes. The general northward drift of the continents continued.

There are no later Mesozoic deposits of Jurassic or Cretaceous age in Mendip so the palaeoenvoronmental conditions at that time must be deduced from geological evidence elsewhere in Southern Britain.

3.2.8 Cretaceous (140 to 65 million years)

In general terms, shallow near-coastal marine conditions in Mendip probably continued with some fluctuations of sea levels through the late Jurassic into the Cretaceous. The Mendip Hills probably continued as 'islands' in the early Cretaceous, but it is not known if any sediments were deposited and later removed by erosion, or if they were never deposited.

The Cretaceous is generally regarded as a 'greenhouse world'. There is no evidence anywhere of any polar ice caps and sea levels worldwide were generally high. The proportion of carbon dioxide in the Cretaceous atmosphere was probably greater than at any other time in the previous 500 million years. This can be measured by analysis of CO_2 in calcium carbonate fossil shells.

By late Cretaceous times when the well known Chalk of Southern England and large areas of Continental Europe was deposited, there is powerful regional evidence that the Chalk seas extended over all but the highest of the pre-existing land areas. For example it is believed that the upland areas of Brittany, Devon and Cornwall (known as the Cornubian Massif) were fully submerged.

Land areas were generally arid and low relief. There is little evidence for land derived sediment in the Chalk. It is therefore almost certain that Mendip was also submerged during the late Cretaceous. However, no remnants of the Chalk are known to have been found on Mendip, even though thick Chalk deposits are present only a few tens of kilometres east of Mendip in Wiltshire.

3.2.9 Tertiary (65 to 1.8 million years)

In Britain the unconformity between the Reading Beds of the lowest Tertiary and the underlying Chalk is dramatic. The Cretaceous-Tertiary boundary represents globally one of the most striking environmental changes in geological history about 65 million years ago. It was the time when the dinosaurs and many other forms of life became extinct. However, in Britain the time gap between the latest Cretaceous Chalk and the earliest Tertiary clays and gravels is about 15 million years so the evidence is missing. In that time interval the environmental conditions of Southern England appear to have changed from the widespread warm clear sea of the Chalk to a continental regime, largely non-marine, with rivers draining from the west into shallow muddy seas at the eastern end of Southern England and the Low Countries.

Exactly what happened in Mendip at that time is conjectural. However, it is known from evidence elsewhere that climate change in the early Tertiary introduced a phase of extreme environmental stress. If the Chalk were deposited over the top of Mendip it is likely that this was the time when it was eroded away completely over a period of about 10 million years by a combination of intensive chemical and mechanical weathering in tropical climatic conditions. However, direct evidence for this is meagre. No evidence has been seen in the active quarries.

This period of extreme weathering conditions is given support in Southwest England by the evidence for the generation of kaolinite ball clays in the early Tertiary by tropical weathering processes and the presence of deep laterite soils on basic igneous rocks in Devon.

This may relate to the deep weathering in the upper layers of the Silurian volcanic rocks of Mendip recognised at Moons Hill but further study is required to confirm this.

The world's climate cooled progressively over the 50 million years or so through the remainder of the Tertiary. The Antarctic ice sheets started forming about 30 million years ago and must have begun to influence worldwide sea levels and climates from about that time.

3.2.10 Quaternary (1.8 million years to the present)

Glacial conditions returned to northern continents about 2 million years ago and have persisted since then through the Quaternary on a broadly oscillating cycle of about 100,000 years, advance and retreat, glacial and interglacial, sea level fall and rise. Much of the evidence for this comes from study of drill cores in undersea sediments.

At present we are in an interglacial period. It appears certain that the oscillation pattern will be followed in future and that glacial conditions will return, subject to modification in the short term (by geological time standards) by the climatic consequences of human activity.

Mendip has not been glaciated. The greatest extent of the north polar ice sheets stopped short of the present line of the M4, as shown by the absence of glacial features and sediments south of this line. However, during periods of advance of the ice sheets Mendip must have been subject to extremely cold periglacial conditions. Melting of the ice sheets at the end of each cycle must have led to powerful floods on the lower ground around Mendip. Evidence for oscillations of sea level is known locally from sediments and buried valley systems beneath the Somerset Levels.

Evidence in the active quarries again is meagre. Such evidence would normally be expected in the higher layers of quarry overburden, but very little of this relatively recent overburden is seen at any of the quarries.

The main solution features in the limestones of Mendip are believed to have formed in the Quaternary. The subject is discussed in ***Section 2.8*** and ***Section 2.9*** above. However, in confirmation of the variability of the Quaternary climate, fossil finds in caves demonstrate wide temperature ranges. In some interglacial periods the climate must have been warmer than today, supporting animals such as hippo, elephant and rhino. In other instances representing different times, the animal bones found are various forms of deer, brown bear, fox, and various rodents indicative of cold periods.

Large volumes of water were locked up as ice during the glacial periods and during these times the sea level would have been low, evidently more than 100m below present day sea level. England and France would have been joined at such times and this allowed free movement of animals between the two, including humans and stone-age cultures. The human remains found on Mendip in caves at Cheddar have been dated at around 9,000 years old but flint artefacts indicate human occupation in southwest England for at least the last 200 000 years.

4. PRINCIPAL CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

- The audit project has successfully reported on the geodiversity to be seen in the active aggregate quarries in the East Mendip area of Somerset.
- Active aggregate quarries offer a valuable geodiversity resource which is continually developing.
- Annotated digital photography with location and view direction accurately recorded is confirmed as the most useful tool for recording and disseminating this type of information.
- The educational opportunity presented by integrating the local geological detail in the quarries with the regional and global geological history is demonstrated.
- Use of CD-ROM is confirmed as a valuable, practical and low-cost means of recording and disseminating the new information.
- Only small numbers of printed copies of the reports need be prepared and issued.
- Use of the Somerset County web-site linked with the MIRO website is a useful, cost effective and convenient way of widely publicising useful information at county level and providing an opportunity for updating.
- A summary brochure has been published for widespread distribution and publicity.
- Much useful exploration and survey information has been made available by the quarry operators, both as records and in discussion, and this has been assimilated into the reports.
- The project audit reports in turn are considered valuable to the greater geological understanding of the quarry operators, particularly as this relates to quarry visits by educational and other interested groups.
- The project partnership has been a valuable communication experience between separate and varied organisations aiming towards a common goal.
- Broader educational opportunities of the results remain to be considered in detail with educational authorities and schools, colleges and universities.
- The requirement for extra investigation time has been demonstrated and this has implications for additional costs in extending the project elsewhere.
- Opportunities for compensatory cost savings would appear to be few without sacrificing quality.
- The success of this project has demonstrated by example the opportunity for cooperation between the aggregates industry and the wider community.

4.2 Recommendations

- Similar geodiversity audits carried out by partnership teams should be promoted in other counties and further afield.
- Digital photography is recommended as the principal recording and reporting tool.

- The positive geodiversity opportunity resulting from active aggregate quarrying needs to be properly recognised in the minerals planning process.

- Within Somerset (and Devon), broad educational opportunities relating to wider aspects of Geodiversity should be developed, related at least in part to this project. A related project specially aimed at developing the educational opportunity at all levels is recommended.

- The availability of support from the Aggregates Levy Sustainability Fund provides opportunities for the development of other educational and research projects connected with the aggregates industry.

- Using the experience of this project as a stimulus, the wider education and training opportunities of many disciplines related to the minerals industry need to be developed in partnership with others to raise the career profile in this essential and varied industrial sector.

APPENDICES

APPENDIX A: Project Background and Key Objectives

PROJECT BACKGROUND

This Project Overview Report summarises a series of quarry reports prepared during this project which audits the Geodiversity in Active Aggregate Quarries in Somerset. The Somerset project is an extension to the pilot study carried out in 2003/04 in Devon.

The project is supported by funding from the Aggregates Levy Sustainability Fund (ALSF) through a grant awarded to David Roche GeoConsulting (DRG) of Exeter by the Mineral Industry Sustainable Technology Programme (MIST). MIST has been established by the Department for the Environment, Food and Rural Affairs (DEFRA) and the Mineral Industry Research Organisation (MIRO) under the terms of reference of ALSF. The funding from ALSF to enable this project is gratefully acknowledged.

Project Partners working with David Roche GeoConsulting to deliver this project are the Mendip Quarry Producers, Somerset County Council (SCC), British Geological Survey (BGS) and MIRO. The various contributions to this project from these principal partners, and also from others, are gratefully acknowledged.

Geodiversity encompasses all the variety of rocks, minerals, landforms and other geological features together with the processes that have formed these features throughout geological time. Working quarries provide some of the best rock exposures in areas where surface outcrops may be poor and understanding the underlying geology from natural surface features alone can be notoriously difficult. Working quarries are also continually revealing new geodiversity features.

KEY OBJECTIVES

The main objectives of the project have been to produce a Geodiversity Report for each of the active working quarries in Somerset, recording the key geological features in relation to the regional geological setting in a readily understood format which can be used as an educational tool, and provide useful information for quarry managers and for quarry visitors. Information sources include: reports and records made available by quarry operators and by others, observation and recording of features which can be seen in the quarries at present; BGS maps and other maps, publications and records.

This Project Overview Report provides a separate overview of the project including additional detail on the background and concepts, and the deliverables and uses and it summarises the main findings and recommendations.

Dissemination of the project findings are key objectives and it is intended to prepare the information in electronic form for issue on CD-ROM and, in part, by website. Further dissemination of results will be through a summary brochure and a regional Geodiversity Seminar in 2005 to disseminate the findings to a wide audience.

In this report following the main descriptive text there are further appendices including Summaries of Geodiversity Audit at each quarry, references and glossary.

REPORT AUTHORSHIP

The author of this Overview Report is project leader Dr Clive Nicholas, a chartered geologist with minerals experience in UK and overseas, and notably in SW England; he was previously Chief Geologist with Aggregate Industries (formerly ECC Quarries). The overview report incorporates information from the audit reports for the individual quarries compiled by authors David Allen and Stephen Parkhouse. The skills of these authors in geological observation and interpretation, in recording by digital photography during audit fieldwork, and in compiling this report on the findings, are gratefully acknowledged.

APPENDIX B: Project Structure and Review

1. General

This Overview Report on Quarries in Somerset is intended to be a ‘stand-alone’ report with minimal reference to the earlier Devon report of 2003. However, in consideration of the general principles of the project, the technical and practical requirements and the resources required to carry out the work, these were established following the Devon project in 2003 and reference to it is unavoidable. This further project in Somerset has been regarded as an extension of the Devon Pilot Study to test and confirm detailed requirements and methodology.

The level of funding has not allowed all of the Somerset quarries to be audited at this stage, only the seven East Mendip quarries. The remaining three quarries in the western part of the county remain to be audited. However, this Overview Report is intended to be applicable to all ten of the county’s active aggregate quarries.

2. Partnerships

A fundamental part of a project of this type is the formation of appropriate partnerships. The important advantage which this provides is the opportunity for networking, additional expertise and mutual generation of new ideas. The partners in the project team are listed on page 2 at the beginning of this report.

In addition, the enthusiasm and support of the Somerset Geology Group, particularly Hugh Prudden who has provided valuable local information, is gratefully acknowledged.

3. Project Management

The project was proposed by and has been managed and executed by the lead partner David Roche GeoConsulting Limited, Exeter.

Mr David Roche, Director, has been responsible for overall financial management and resourcing along with senior technical input and review.

Dr Clive Nicholas, Consultant in Minerals Geology and Project Leader has been responsible for management and coordination, interface with partners and ensuring that expected results are achieved and properly reported.

Audit investigation work and reporting has been carried out by Mr David Allen, Consultant and by Mr Stephen Parkhouse, GeoServe, acting as consultant to David Roche GeoConsulting.

4. Project Plan

4.1. Work Plan and Key Tasks

The Work Plan closely followed that adopted in the Devon project:

1. *Preparation and submission of the proposal, communication with partners*
2. *Detail of the Project Plan*
3. *Carrying out the investigation and audit work*
    - *i First Stage to select two quarries to trial methods and procedures*
    - *ii Main Stage to complete all quarries to final draft report stage*
4. *Reporting and disseminating the results*
    - *i Finalise all quarry reports and overview report*
    - *ii Prepare CD-ROM and web-site*
    - *iii Prepare summary brochure*
    - *iv Project Seminar*

4.2. Timescales

The deadline for the project to be fully complete was set by the MIST requirement for project completion by the end of March and by the Project Seminar date of 22nd February 2005, as determined early in the project planning stage.

The average of 6 days investigating and reporting time allocated for the audit of each quarry in the Devon project turned out to be inadequate. An important lesson learned in Devon was that substantially more time than this was required.

It was recognised that most of the Somerset quarries are much larger than those in Devon, requiring more preparation time, more time on-site to cover the necessary ground and generally more information was available at each quarry to be examined and discussed.

Furthermore, from health and safety considerations in such large and busy quarries it was decided that the site work should normally be carried out in pairs. This was confirmed by most of the operators not permitting lone working.

Overall, substantially more time was required and the allocated time per site was increased to 15 person-days, as follows:

• *Preparation/desk study*	*2 days*
• *Preliminary site inspection*	*1 day*
• *Obtain and consider operators and other information*	*1 day*
• *Audit quarry inspections*	*2 days*
• *Supplementary quarry visits*	*2 days*
• *Data, maps, photos sorting and collation*	*1 day*
• *Reporting*	*3 days*
• *Report review*	*2 days*
• *Report editing and finalisation*	*1 day*

In practice, fewer days than allocated were required on site, but they were long days because of travelling time and the large scale of the quarries. More time was required for adequate consideration of information, sorting and organising of photos and plans, and preparation of reports. Also, more time than allocated was needed for final editing in readiness for printing and electronic media dissemination.

As previously, quarterly team meetings were held on pre-planned dates to provide regular progress reports to make sure that the project remained on schedule. Key deadlines were identified in advance along with the tasks, timescales and resources required to achieve them.

5. Investigations

As in Devon, the investigation was proposed as an audit taking account of available information rather than researching new information or interpretation. An audit normally considers selections or samples of information and can not normally be fully comprehensive, but again the intention was to consider as many geodiversity features as possible.

The audit check list developed in the Devon Project, designed to deal with as many points as possible in the time allocated, was found not to require much modification. Where appropriate, consideration was given to:

- *Regional geological setting*
- *Geological history*
- *Stratigraphy*
- *Palaeontology*
- *Geological structure*
- *Petrography*
- *Mineralogy*

- *Chemistry*
- *Hydrogeology*
- *Geotechnical aspects*
- *Weathering*
- *Solution*
- *Geomorphology*
- *Palaeogeography*
- *Palaeoenvironment*

The check list did not operate rigidly, frequently because of limiting time constraints and sometimes because information on a particular aspect was not relevant or not available. However, a check list is an essential tool, although every quarry is different.

Information sources targeted were as follows:

- *Features to be seen in the quarry at present*
- *Information from the quarry operator*
- *Discussions with company staff*
- *Discussions with others*
- *BGS maps and other Survey records*
- *Other scientific publications*
- *Records of other organisations*

The site inspections and the discussions with both the geological and operational staff of the operating companies provided invaluable information, much of it hitherto unrecorded in the public domain.

6. Health and Safety

Particular attention was paid to Health & Safety issues for quarry inspections. The general Health & Safety Risk Assessment prepared for the quarry inspections in Devon was modified slightly to take account of experience. The Risk Assessment identifying tasks, hazards and actions required to eliminate or minimise risk is reproduced in this report as Appendix G.

Each quarry has special Health & Safety requirements. Availability of the above general risk assessment is valuable but it is insufficient in itself because there are always local conditions to consider and it is essential to obtain a local induction, properly documented, from the Quarry Manager or designated Deputy before starting work.

Health & Safety management and risk assessment are therefore highlighted as important to the audit work, in particular because quarries are inherently hazardous and individuals may be working alone at times. Key components in the project Health & Safety management system are:

- *Risk assessment - generic hazard identification and mitigation*
- *Specific site safety induction as set by quarry managers*
- *Awareness by individual auditors of general/local issues, by briefing and discussion*
- *Compliance with safe working procedures*
- *Feedback reporting by auditors with review discussion*

7. Recording and Reporting

Recording and reporting followed closely the Devon experience which confirmed that digital photography provides the best tool for rapid and accurate recording of site features. A combination of hand held GPS, compass and quarry plan was used to record the national grid location, elevation, and facing direction of each photograph, this being considered especially important for future reference when the location may eventually be quarried away.

Conservation of geodiversity in active quarries is not considered normally to be a satisfactory solution, only in occasional or exceptional circumstances. Sometimes conservation can be planned into the working scheme. Mostly however, the need for preservation of a feature is far outweighed by the advantage of continued working revealing more and better geodiversity. This reinforces the need for proper recording as working progresses, regardless of any conservation opportunity later.

A well organised photo labelling system accompanied by site notes is essential. An effective 3-part labelling system which has been used is, by way of example:

TO 19a

- where 'TO' is the reference for the quarry, the first two letters of the name.
- where '19' is the number of the locality of the photo in the quarry, as recorded in the notebook and plan.
- and 'a' is the photo suffix label for the photo taken at that location, increasing …b,c,d,e, etc according to the number of photos.

Having 'trialled' different reporting styles in the Devon project, the style relating closest to the audit check list, and therefore easiest to adapt to a database structure, was considered to be the most appropriate to follow. The separation of the photos from the text is not so 'friendly' in printed versions but this is outweighed by the convenience of doing so and the linking of photos to the text in electronic versions overcomes this disadvantage.

The 'photo-essay' style of reporting has not been pursued for the site reports in this study but this overview report combines text and photos in a more narrative style since it is considered more appropriate in this case.

As in Devon, a brief desk study report was provided from available records by the British Geological Survey summarising the geology of each quarry and its immediate environment, together with key references, to ensure completeness and adoption of correct current nomenclature.

The CD-ROM prepared by the Mineral Industry Research Organisation (MIRO) incorporates all the quarry reports and this overview report in a single concise package. A summary brochure and publicity information for the Seminar in February 2005 has also been prepared by MIRO.

Summary report information is available on the Somerset County Council website.

Principal Conclusions and Recommendations from the project are summarised in Section 4 at the end of the main part of this report.

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BRITISH GEOLOGICAL SURVEY, www.bgs.ac.uk

DEVON COUNTY COUNCIL 2001. *Educational Register of Geological Sites in Devon.* www.devon.gov.uk/geology/site_index.pdf

DEVON COUNTY COUNCIL 2004. *Geodiversity Audit of Active Aggregate Quarries: Quarries in Devon.* www.devon.gov.uk/geology/site_index.pdf

ENGLISH NATURE, www.english-nature.org.uk

GEOLOGICAL SOCIETY OF LONDON, www.geolsoc.org.uk

SOMERSET COUNTY COUNCIL, www.somerset.gov.uk

APPENDIX E: Geodiversity Audit Summaries for Each Quarry

SUMMARY OF GEODIVERSITY AUDIT

Quarry name	**Colemans Quarry** (previously known as Holwell Quarry)
County	Somerset
Location:	At Holwell, Near Nunney, Frome, East Mendips,
Output:	About 0.6M tonnes per year for general purpose construction aggregates
O.S. Grid Ref:	ST 727 450 (quarry office)
O.S. Map No:	1:50 000 Landranger Sheet 183 1:25 000 Explorer sheet 142
BGS Map No:	1:50 000 Sheet 281
Operated by:	Bardon Aggregates, subsidiary of Aggregate Industries UK
Quarry workings:	The quarry has developed as several separate working areas divided by public roads.
Scientific Status:	Important geological SSSI for late Triassic and early to mid Jurassic fissure deposits containing fish remains and early mammalian teeth.
Main Rock Type	Carboniferous Limestone.
Geological Age	Lower Carboniferous, about 350-320 million years old
Geological Formations	Pale coloured Clifton Down and Vallis Limestones grading down (northwards) into very dark grey Black Rock Limestone
Geological Structure	Beds dip generally to the south. Occasional near-vertical faults and joints.
Sedimentology	Well-bedded Lower Carboniferous Limestone with thin shale partings, especially in the Black Rock Limestone Formation.
Palaeontology	Abundant shelly fossils and corals. Very rare Triassic early mammalian teeth and fish remains in fissures in limestone.
Mineralogy	Vein deposits with abundant calcite crystals and traces of metalliferous mineralisation.
Other Rock Types	Jurassic oolitic limestone about 170 million years old overlying older Carboniferous Limestone with sharp flat erosion surface forming angular unconformity. Ancient seabed with abundant oyster shells. Coarse Triassic conglomerate locally overlying limestone in SSSI area
Hydrogeology	Limestone has low primary permeability and high secondary permeability in joints and fissures. Valuable water supply aquifer in the vicinity. Water table generally at about 120 metres AOD.
Geotechnical	Black Rock Limestone is known for occasional wedge failures along dipping shale partings and bounded by intersecting near-vertical joints.
Geomorphology	Mendips form ancient Island chain and shoreline along southern margin
Weathering, Erosion	Solution widening of joints and fissures. High level cave and cavity formation.
Geodiversity Highlights	• Pale to dark grey well-bedded Carboniferous Limestone dipping consistently southwards with overlying horizontally bedded buff-coloured Jurassic oolitic limestone forming an angular unconformity. • Ancient Jurassic erosion surface at the unconformity with oyster shells and abundant marine borings in the top of the Carboniferous Limestone. • Abundant near-vertical fissures and joints in the limestone with varying amounts of calcite mineralization. A few of these have been found to contain rare Upper Triassic and Jurassic vertebrate remains.
Geodiversity Context	• Late Devonian desert conditions ended about 350 million years ago with advance of the shallow clear-water tropical sea in which the thick Carboniferous limestones accumulated. Land was to the north, deep water to the south. The Mendip area was probably near the equator. • The limestones were deeply buried, folded, faulted and lifted above the sea by pressure of continental collision from the south in the Variscan mountain building when the main structure of Mendip was formed. • Desert conditions returned in the Permian and Triassic when Mendip was a mountain area with deep and narrow valleys around its flanks. • The sea encroached again about 180 million years ago in the Jurassic. Mendip was an island and oolitic carbonate sediments were formed in shallow clear-water seas along its southern shoreline.

SUMMARY OF GEODIVERSITY AUDIT

Quarry name	**Dulcote Quarry**
County	Somerset
Location:	At Dulcote nr Wells, East Mendips,
Output:	About 0.25M tonnes per year for general purpose construction aggregates
O.S. Grid Ref:	ST 56621 44158 (quarry entrance)
O.S. Map No:	1:50 000 Landranger Sheet 183 1:25 000 Explorer sheet 141
BGS Map No:	1:50 000 Sheet 280 Wells
Operated by:	Foster Yeoman Ltd.
Quarry workings:	The quarry has developed as one large pit that measures around 600 m from W to E and around 350 m from N to S.
Scientific Status:	
Main Rock Type	Carboniferous Limestone.
Geological Age	Lower Carboniferous. About 330 million years old.
Geological Formations	An outlier of Clifton Down Limestone in faulted contact with Burrington Oolite.
Geological Structure	Strata folded and overturned with general variable dip to the south. Several near-vertical faults, major thrust zones, minor thrusts and joints.
Sedimentology	Well-bedded Lower Carboniferous limestones with minor shale partings.
Palaeontology	Occasional shelly fossils, crinoids and corals.
Mineralogy	Vein deposits with abundant calcite crystals and minor traces of metalliferous mineralisation. Replacement silica mineralisation associated with overlying Triassic sediments.
Other Rock Types	Triassic Mercia Mudstone facies about 240 million years old comprising breccias, sandstones, siltstones and mudstones in top of north-eastern end of quarry forming angular unconformity with underlying Carboniferous Limestone.
Hydrogeology	Limestone has low primary permeability and high secondary permeability in joints and fissures. Quarry pond at natural groundwater level (60 m AOD).
Geotechnical	Occasional bedding plane failures along dipping beds bounded by intersecting joints and thrusts particularly in top northern faces.
Geomorphology	Present Mendip landforms closely resemble ancient Mesozoic hills, valleys and Islands with shoreline deposits along southern margin
Weathering, Erosion	Limestone solution widening along joints and fissures. Surface karst with minor weathered gullies and minor cave/cavity formation.
Geodiversity Highlights	• Pale to dark grey moderately well bedded folded Carboniferous Limestone dipping mainly to the south with small area of overlying red and purple-coloured Triassic breccias forming an angular unconformity. • Large recumbent fold in north and west faces with vertical and overturned bedding in west face. • Abundant vertical and curved sediment infilled fissures and joints (Neptunian Dykes) • Varying amounts of calcite mineralization. • Siliceous mineral replacement in Triassic sediments forming geodes.
Geodiversity Context	• Late Devonian desert conditions ended about 350 million years ago with advance of the shallow clear-water tropical sea in which the thick Carboniferous limestones accumulated. Land was to the north, deep water to the south. The Mendip area was probably near the equator. • The limestones were deeply buried, folded, faulted and lifted above the sea by pressure of continental collision from the south in the Variscan mountain building when the main structure of Mendip was formed. • Desert conditions returned in the Permian & Triassic when the Mendips were a mountain range with breccias, wadi filled debris flows and scree material deposited around its flanks

SUMMARY OF GEODIVERSITY AUDIT

Quarry name	**Gurney Slade Quarry**
County	Somerset
Location:	At Gurney Slade, Nr Radstock
Output:	About 0.5M tonnes per year for general purpose construction aggregates
O.S. Grid Ref:	ST 62562 49248 (quarry entrance)
O.S. Map No:	1:50 000 Landranger Sheet 183 1:25 000 Explorer sheet 142
BGS Map No:	1:50 000 Sheet 280 Wells
Operated by:	Morris and Perry Ltd.
Quarry workings:	The quarry has developed as one large pit that measures around 700 m in either direction.
Scientific Status:	
Main Rock Type	Carboniferous Limestone.
Geological Age	Lower Carboniferous. About 350-320 million years old.
Geological Formations	A dipping succession of Carboniferous Limestone including the Hotwells and Clifton Down Limestone Formations.
Geological Structure	Strata folded with a general dip to the southeast. Several near-vertical faults and sub parallel joints.
Sedimentology	Well-bedded Lower Carboniferous limestones with shale partings especially in the Hotwells Limestone.
Palaeontology	Varied including abundant Carboniferous thick-shelled brachiopods, corals, and crinoids and Jurassic belemnites, ammonites, brachiopods and crinoids
Mineralogy	Vein deposits with abundant calcite crystals and minor traces of metalliferous mineralisation. Barite associated with overlying Jurassic rocks
Other Rock Types	Triassic Mercia Mudstone facies about 240 million years old comprising breccias, and mudstones. Lower Jurassic conglomerate and breccias forming angular unconformity with underlying Carboniferous Limestone. Lower and Middle Jurassic limestones infilling neptunian dykes.
Hydrogeology	Limestone has low primary permeability and high secondary permeability in joints and fissures. Quarry pond at pumped groundwater level (179 m AOD)
Geotechnical	Occasional minor bedding plane failures along dipping beds bounded by intersecting joints and faults.
Geomorphology	Mendips form ancient Islands with shoreline along southern margin
Weathering, Erosion	Limestone solution widening along joints and fissures. Surface karst with minor weathered gullies and minor cave/cavity formation.
Geodiversity Highlights	• Pale to very dark grey well bedded folded Carboniferous Limestone dipping to the southeast overlain by red and purple-coloured Triassic breccias and marls in the northeast. • Small faulted block of overlying Lower Jurassic breccias forming an angular unconformity with the Carboniferous Limestone. • Abundant vertical sediment infilled fissures and joints (Neptunian Dykes) • Varying amounts of calcite mineralization. • Common fossil material associated with the Carboniferous and Jurassic limestones.
Geodiversity Context	• Late Devonian desert conditions ended about 350 million years ago with advance of the shallow clear-water tropical sea in which the thick Carboniferous limestones accumulated. Land was to the north, deep water to the south. The Mendip area was probably near the equator. • The limestones were deeply buried, folded, faulted and lifted above the sea by pressure of continental collision from the south in the Variscan mountain building period when the main structure of Mendip was formed. • Desert conditions returned in the Permian & Triassic when the Mendips were a mountain range with breccias, wadi filled debris flows and scree material deposited around its flanks • Mendips flanked by Lower and Middle Jurassic sub littoral seas.

SUMMARY OF GEODIVERSITY AUDIT

Quarry name	**Halecombe Quarry**
County	Somerset
Location:	At Leigh upon Mendip, Frome, East Mendips,
Output:	About 1.0M tonnes per year for general purpose construction aggregates
O.S. Grid Ref:	ST 702 475 (quarry office)
O.S. Map No:	1:50 000 Landranger Sheet 183
BGS Map No:	1:50 000 Sheet 281
Operated by:	Tarmac Southern Ltd, part of Anglo American plc
Quarry workings:	The quarry has developed as a single large pit.
Scientific Status:	
Main Rock Type	Carboniferous Limestone
Geological Age	Lower Carboniferous, about 350-320 million years old
Geological Formations	Pale coloured Clifton Down & Vallis Limestones grading down (southwards) into very dark grey Black Rock Limestone and Lower Limestone Shale.
Geological Structure	Strata dip generally to the north. Occasional near-vertical faults and joints.
Sedimentology	Well-bedded Lower Carboniferous limestones with thin shale partings, especially in the Black Rock Limestone Formation and Lower Limestone Shale.
Palaeontology	Abundant shelly fossils and corals.
Mineralogy	Vein deposits with abundant calcite and traces of metalliferous minerals
Other Rock Types	None
Hydrogeology	Limestone has low primary permeability and high secondary permeability in joints and fissures. Valuable water supply aquifer in the vicinity. Water table generally at about 120 metres AOD.
Geotechnical	Black Rock Limestone is known for occasional wedge failures along dipping shale partings and bounded by intersecting near-vertical joints.
Geomorphology	Present Mendip landforms closely resemble ancient Mesozoic hills, valleys and islands.
Weathering, Erosion	Limestone solution widening of joints and fissures. Small cavity formation near rockhead.
Geodiversity Highlights	• Pale to dark grey well-bedded Carboniferous Limestone dipping steeply and consistently northwards. • Numerous “fist-sized” calcite inclusions within the limestones both solid and hollow with internal calcite crystal growth. • Abundant near-vertical fissures and joints in the limestone with varying amounts of calcite mineralization. • Tufa growth around groundwater seepages
Geodiversity Context	• Late Devonian desert conditions ended about 350 million years ago with advance of the shallow clear-water tropical sea in which the thick Carboniferous limestones accumulated. Land was to the north, deep water to the south. The Mendip area was probably near the equator. • The limestones were deeply buried, folded, faulted and lifted above the sea by pressure of continental collision from the south in the Variscan mountain building when the main structure of Mendip was formed. • Desert conditions returned in the Permian and Triassic when Mendip was a mountain area with deep and narrow valleys around its flanks. • The sea encroached again about 180 million years ago in the Jurassic. Mendip was an island and oolitic carbonate sediments were formed in shallow clear-water seas along its southern shoreline (not visible at Halecombe Quarry).

SUMMARY OF GEODIVERSITY AUDIT

Quarry name	**Moons Hill Quarry**
County	Somerset
Location:	At Stoke St Michael, Near Shepton Mallet, East Mendips,
Output:	About 0.5M tonnes per year for general purpose construction aggregates
O.S. Grid Ref:	ST 665 462 (quarry office)
O.S. Map No:	1:50 000 Landranger Sheet 183
BGS Map No:	1:50 000 Sheet 281
Operated by:	John Wainwright & Co Limited
Quarry workings:	The quarry has developed as two large pits, Moons Hill and Stoke Quarries.
Scientific Status:	One area designated as a SSSI
Main Rock Type	Silurian Volcanics, andesite lava, tuff and agglomerate
Geological Age	Silurian, Wenlock Series, about 440 million years old
Geological Formations	Generally dark grey volcanic rocks with interbedded mudstones of the Coalbrookdale Formation overlain unconformably by red brown sandstones of the Portishead Formation of Devonian age.
Geological Structure	Strata generally dip very steeply to the north, with near-vertical faults.
Sedimentology	Thinly bedded mudstones as interbeds within the volcanic sequence.
Palaeontology	Shelly fossils within the mudstones and tuffs.
Mineralogy	None
Other Rock Types	None
Hydrogeology	The volcanic rocks have low primary permeability and high secondary permeability in joints and fissures. Water table generally at about 200mAOD
Geotechnical	The lavas and tuffs in particular are known for occasional wedge failures where blocks are bounded by intersecting near-vertical joints.
Geomorphology	Present Mendip landforms closely resemble ancient Mesozoic hills, valleys and islands.
Weathering, Erosion	Weathering of the volcanic rocks to significant depth with particular decomposition of the matrix within tuffs and agglomerates and exfoliation of boulders within the latter.
Geodiversity Highlights	• Dark grey amygdaloidal andesite lavas • Interbedded tuffs and mudstones • Ancient volcanic neck represented by vent agglomerate deposit • Abundant fractures and joints in the volcanic succession • Angular unconformity with the overlying Old Red Sandstone
Geodiversity Context	• During the Silurian period, some 440 million years ago, vulcanism deposited lavas, tuffs and agglomerates in shallow seas. • A period of uplift and folding which produced a major mountain chain across northern Britain – the Caledonian Orogeny, reached a climax in late Silurian times. • In the Devonian, desert conditions prevailed until about 350 million years ago. A shallow tropical sea then advanced across the land and the thick Carboniferous limestones were deposited. Land was to the north, deep water to the south. The Mendip area was probably near the equator. • The Palaeozoic rocks were deeply buried, folded, faulted and lifted above the sea by pressure of continental collision from the south in the Variscan mountain building when the main structure of Mendip was formed. The Silurian rocks were brought close to the surface. • Desert conditions returned in the Permian and Triassic when Mendip was a mountain area with deep and narrow valleys around its flanks and the Silurian rocks were raised close to the surface. • Advance of tropical seas in late Triassic/Jurassic times (not seen at Moons Hill Quarry). At this time Mendip was a group of islands.

SUMMARY OF GEODIVERSITY AUDIT

Quarry name	**Torr Quarry**
County	Somerset
Location:	At East Cranmore, nr Shepton Mallet, East Mendips,
Output:	About 0.6M tonnes per year for general purpose construction aggregates
O.S. Grid Ref:	ST 692 438 (quarry office)
O.S. Map No:	1:50 000 Landranger Sheet 183 1:25 000 Explorer sheet 142
BGS Map No:	1:50 000 Sheet 281
Operated by:	Foster Yeoman Ltd
Quarry workings:	The quarry has developed as one large pit that extends more than 1.9km from N to S and is around 1.4km from E to W.
Scientific Status:	
Main Rock Type	Carboniferous Limestone
Geological Age	Lower Carboniferous. About 350-320 million years old.
Geological Formations	Hotwells Limestone, Clifton Down Limestone, Vallis Limestone grading down (northwards) into dark-grey Black Rock Limestone.
Geological Structure	Strata generally dip to the south and south-southeast at 24º to 47º. Several near-vertical faults, major fault zones, minor thrusts and joints.
Sedimentology	Well-bedded Lower Carboniferous limestones with minor shale partings, in dark-grey Black Rock Limestone.
Palaeontology	Abundant shelly fossils, crinoids and corals.
Mineralogy	Vein deposits with abundant calcite crystals and traces of metalliferous mineralisation. Rare minerals above water table now wholly worked out.
Other Rock Types	Mid Jurassic oolitic limestone about 170 million years old in top layers of eastern end of quarry forming angular unconformity with underlying Carboniferous Limestone.
Hydrogeology	Limestone has low primary permeability and high secondary permeability in joints and fissures. Quarry pond at de-watered level of (131 m AOD)
Geotechnical	Black Rock Limestone is known for occasional wedge failures along dipping shale partings and bounded by intersecting near-vertical joints. Quarry faces formed to enhance natural stability.
Geomorphology	Present Mendip landforms closely resemble ancient Mesozoic hills, valleys and Islands with shoreline deposits along southern margin.
Weathering, Erosion	Limestone solution widening along joints and fissures. Surface karst weathering with minor pinnacle formation and weathered gullies.
Geodiversity Highlights	• Pale to dark grey well bedded Carboniferous Limestone dipping consistently southwards with small area of overlying horizontally bedded buff-coloured Jurassic oolitic limestone forming an angular unconformity. • Ancient Jurassic seabed at the unconformity with oyster shells and marine borings in the top of the Carboniferous Limestone. • Dolomitisation & chert formation within Black Rock Limestone • Abundant near-vertical fissures with sediment infill (Neptunian Dykes) • Varying amounts of calcite and metaliferous mineralization.
Geodiversity Context	• Late Devonian desert conditions ended about 350 million years ago with advance of the shallow clear-water tropical sea in which the thick Carboniferous limestones accumulated. Land was to the north, deep water to the south. The Mendip area was probably near the equator. • The limestones were deeply buried, folded, faulted and lifted above the sea by pressure of continental collision from the south in the Variscan mountain building when the main structure of Mendip was formed. • Desert conditions returned in the Permian and Triassic when Mendip was a mountain area with deep and narrow valleys around its flanks. • The sea encroached again about 180 million years ago in the Jurassic. Mendip was an island and oolitic carbonate sediments were formed in shallow clear-water seas along its southern shoreline.

SUMMARY OF GEODIVERSITY AUDIT

Quarry name	**Whatley Quarry**
County	Somerset
Location:	At Whatley, nr Frome, East Mendips,
Output:	About 5M tonnes per year for general purpose construction aggregates
O.S. Grid Ref:	ST 732 479 (quarry office)
O.S. Map No:	1:50 000 Landranger Sheet 183 1:25 000 Explorer sheet 142
BGS Map No:	1:50 000 Sheet 281
Operated by:	Hanson Aggregates, subsidiary of Hanson plc
Quarry workings:	The quarry has developed as one large pit around 1.5Km WSW to ENE and 0.6Km in width.
Scientific Status:	
Main Rock Type	Carboniferous Limestone
Geological Age	Lower Carboniferous. About 350-320 million years old.
Geological Formations	Pale coloured Clifton Down, Burrington Oolite and Vallis Limestones grading down (southwards) into dark-grey Black Rock Limestone
Geological Structure	Strata generally dip steeply to the north-northwest at 65º. Occasional near-vertical faults and joints.
Sedimentology	Well bedded Lower Carboniferous limestones with prominent shale partings, in dark-grey Black Rock Limestone. Dolomitised near top.
Palaeontology	Abundant shelly fossils and corals.
Mineralogy	Vein deposits with abundant calcite crystals and traces of metalliferous mineralisation.
Other Rock Types	Mid Jurassic oolitic limestone about 170 million years old in top of eastern end of quarry forming angular unconformity with underlying Carboniferous Limestone.
Hydrogeology	Limestone has low primary permeability and high secondary permeability in joints and fissures. Valuable water supply aquifer in the vicinity. Quarry water catchment pond holds about 500 Mega litres and stands at de-watered level of 50 m AOD.
Geotechnical	South faces cut at bedding dip angles promoting face stability. Remedial works to stabilise deep karst features adjacent to large fault zone.
Geomorphology	Mendips form ancient island chain with shoreline along southern margin.
Weathering, Erosion	Limestone solution widening along joints and fissures. Surface karst weathering with minor pinnacle formation and weathered gullies to 5 metres
Geodiversity Highlights	• Pale to dark grey well bedded Carboniferous Limestone dipping consistently northwards with small area of overlying horizontally bedded buff-coloured Jurassic oolitic limestone forming an angular unconformity. • Extensive dolomitisation of top of the Black Rock Limestone • Abundant near-vertical fissures and joints near top of limestone with karst weathering and minor pinnacle formation.
Geodiversity Context	• Late Devonian desert conditions ended about 350 million years ago with advance of the shallow clear-water tropical sea in which the thick Carboniferous limestones accumulated. Land was to the north, deep water to the south. The Mendip area was probably near the equator. • The limestones were deeply buried, folded, faulted and lifted above the sea by pressure of continental collision from the south in the Variscan mountain building when the main structure of Mendip was formed. • Desert conditions returned in the Permian and Triassic when Mendip was a mountain area with deep and narrow valleys around its flanks. • The sea encroached again about 180 million years ago in the Jurassic. Mendip was an island and oolitic carbonate sediments were formed in shallow clear-water seas along its southern shoreline.

APPENDIX F: Glossary of Geological Terms and Summary Timescale

These definitions apply to geological terms used in context of this project, Quarries in Somerset; other definitions may apply in different contexts. Words appearing in italics are defined elsewhere in this Glossary.

Acknowledgement is made for some of these definitions to the Glossary in *Educational Register of Geological Sites in Devon*, www.devon.gov.uk/geology/. Some other geological definitions may also be found at this site.

Other definitions are found in various Dictionaries of Geology, such as published by Collins and Penguin.

Acid Rock *Igneous rock* with relatively high *silica* content, usually containing free silica in the form of *quartz*, e.g. granite, rhyolite
Aeolian Wind dominated environment and related *sedimentary* deposits that have been eroded, transported and deposited by wind; characteristic of a desert.
Alluvium *Sediment* which may be *gravel, sand, silt* and/or *mud* transported and deposited by a river.
Ammonite A (usually) coiled marine free-swimming shellfish related to the squid and useful in detailed identification of strata of different ages in *Jurassic* and *Cretaceous* rocks. Now extinct.
Amygdale Steam hole in volcanic rock filled with secondary minerals introduced by percolating fluids
Andesite Named after the Andes of South America, a *volcanic rock* characteristic of active *volcanic* margins of continents, intermediate in *mineral* and chemical composition between *basalt* and rhyolite*.*
Anisotropic Having different characteristics in different directions
Anticline An arch-shaped *fold* in layered *rock*.
Arenaceous Applicable to s*ediment* or *sedimentary rock* such as sand or *sandstone* composed of *sand*-sized particles, irrespective of *mineral* composition.
Argillaceous Applicable to **f**ine-grained **s**ediment or *sedimentary rock* such as mud, *shale* or *mudstone* composed of *silt* or *mud* particles of any mineral composition, but usually with *clay minerals* predominant.
Armour stone Large heavy *boulder* of *rock* specially selected at a quarry for use in flood defences.
Arid Very dry environment characteristic of a desert.
Assemblage As applied to *fossils*, a community of different varieties characteristic of a particular stratigraphic group.
Axial plane cleavage Set of *cleavage* planes generally parallel or sub-parallel to the axial plane of a *fold* and related to the formation and geometry of the *fold*.
Basalt Fine grained dark-coloured *basic igneous rock*, usually *volcanic*, with relatively low *silica* content, rich in iron-magnesium minerals and without free *silica* such as *quartz.*
Basic rock *Igneous rock* with relatively low *silica* content, rich in iron-magnesium minerals and usually no free *silica* in the form of *quartz*.
Bed/bedding A layer or layering in *sedimentary rock*.
Bedding plane Surface between *beds*.
Bentonite A clay mineral usually found as seams produced as an alteration product of volcanic ash.
Boulder Lump of *rock* more than 0.25m diameter.
Bioclastic Refers to *sedimentary rock* composed mainly of broken remains of organisms such as shells.
Brachiopod Marine bivalve shell similar to a cockle but unrelated, usually attached to sea-floor when living. A common fossil which can be used for dating sedimentary rocks if species can be determined.
Breccia *Rock* formed mainly of angular fragments of pre-existing *rock* usually set in a finer *matrix*.
Calcarenite *Limestone* formed mainly of *sand*-sized particles, grain-size 0.06mm-2mm.
Calcite The most common *carbonate* mineral, the principal component of *limestone*.

Calcrete Layers or *concretions* of *carbonate* formed in desert sub-soils by water evaporation from the surface and precipitation of *mineral* in *arid* conditions.
Carbonaceous *Rock* or *sediment* containing some carbon, frequently fossil remains of plants.
Carbonate 1. A *mineral* type containing *carbonate* (CO_3). *Calcite* and aragonite (both $CaCO_3$) and *dolomite* ($Ca,Mg(CO_3)_2$) are three examples of *carbonate minerals*.
2. *Sediment* composed wholly or largely of *carbonate minerals*, e.g. *limestone*, d*olomite*.
Carboniferous Geological system or time period about 350 to 290 million years ago. So named because of the important coal deposits in Upper Carboniferous *strata*.
Chalk Specifically, when used with capital 'C', refers to the well-known fine-grained white *limestone* of Upper Cretaceous age in Southern Britain and elsewhere in Europe.
Chert (or flint) Dense microcrystalline silica occurring as layers or nodules within *sedimentary rocks* such as the *Chalk* (where it is known as *flint*). Frequently found as derived *pebbles* or *cobbles* in younger *gravels*.
Clast A fragment of *rock* derived from pre-existing *rock*.
Cobble A *rock* fragment between 64 and 256 mm diameter. Larger than a *pebble,* smaller than a *boulder*.
Coral *Marine* animal related to jellyfish which constructs a *calcium carbonate* skeleton common in many *limestones*. Often with complex inner structure identifying species and used for relative dating of *rocks*.
Clay minerals A group of generally fine grained *minerals* of variable composition, predominantly *silicates* of alumina and iron. Important constituents of many *rocks*.
Cleavage Tendency for some rocks and minerals to split along distinct 'cleavage planes', for example, *slate*, *mica*. Coarse cleavage cutting across bedding is often seen in *limestones* and *sandstones*
Concretion Similar to a *nodule,* usually with concentric internal structure.
Conglomerate A *sedimentary rock* formed of rounded *pebbles* and *cobbles* derived from earlier rocks and usually set in a finer textured *matrix* of *sand* or *silt*.
Conodonts Microscopic tooth-like microfossils ranging in time from Cambrian to *Jurassic*. Used for detailed *stratigraphic* division of the *Devonian* and *Carboniferous.*
Contemporaneous Formed at the same time as…. (other *rocks* or features referred to).
Continental Formed or generated on land, or in lakes or rivers on land, as opposed to *marine* (in the sea).
Correlate Comparison of rocks of the same age at different places.
Cretaceous Geological system or time period about 145 to 65 million years ago.
Crinoid/crinoidal A class of *echinoderms* (animal kingdom) commonly called sea lily since they resemble plants often attached to the sea floor. They are composed of *calcite* parts (*ossicles*) which often form the main constituent of some *limestones*, then called *crinoidal*.
Cross bedding A series of *bedding planes* inclined to normal bedding and related to water-flow direction or wind-direction, angle of rest, and/or rate of sediment supply.
Deformation A geological process whereby rocks are deformed by application of force .
Detrital Rocks or particles derived by erosion of pre-existing rocks.
Devonian Geological system or time *period* about 420 to 350 million years ago. Named after Devon where the rocks were first recognised and now used in reference to similar age rocks worldwide.
Diachronous Applies to a *bed* or formation produced by shift of *sedimentary* conditions with time. Results in *rock*s of similar appearance having a different age which can often be determined by *fossil* content.
Diagenesis All processes and changes affecting a *sediment* after its formation, but excluding *tectonics*, *metamorphism* and *weathering*.
Dip The angle of a *bedding plane*, or other planar or linear geological feature such as a *fault* or *mineral vein*, measured from horizontal.
Discordant A term used to describe an *igneous rock* or other geological feature cutting across other features or structures.
Dolomite A *carbonate rock* commonly known as magnesian *limestone.* Also applied to the *mineral* dolomite which is a carbonate of calcium and magnesium, Ca,Mg $(CO_3)_2$.
Downfaulted Rocks on the downthrown side of a *fault* are described as downfaulted.
Downthrow The side of a *fault* appearing to have moved downward relative to the other side.
Dyke A steeply inclined, or near vertical wall-like intrusion of *igneous rock*.

Echinoderm A group of entirely marine animals having a skeleton made up of calcite plates or *ossicles*, the best known examples being sea urchins and crinoids.
Facies A geological unit with characteristics and conditions of formation different from other units of the same age.
Fault A fracture in rocks along which movement on either side has taken place
Fault plane The fracture surface along which fault movement has occurred.
Fault zone Applies where a distinct or single fault plane can not be determined
Feldspar *Silicate* mineral, numerous varieties which are frequently major components of *igneous rocks*.
Ferruginous Containing iron.
Fissile Applies to a rock such as a *slat*e or *shale* which splits along narrow *bedding* or *cleavage* planes.
Fissure A cleft or open crack in rock.
Flint Variety of *chert* specifically occurring as nodules in the *Chalk* or in gravels derived from the *Chalk.*
Flowstone A chemical precipitate deposited by water flowing over the walls or floor of a cave.
Fluvial/fluviatile Process or environment whereby material is eroded, transported and/or deposited by rivers. See also *alluvium*
Fold A deformation or bend in layered rocks.
Foliation A layer structure in rocks which is not obviously bedding.
Formation A geological unit having distinct features which can be useful as a geological mapping unit. Frequently named after a locality where it can be well seen or where it was originally recognised.
Fossil Remains or traces of an ancient organism.
Geodiversity The variety of rocks, minerals and landforms and the processes which have formed these features throughout geological time.
Geology Study of the solid earth and its history.
Geological time The period of time since the Earth was formed about 4.5 billion years ago. Divided into numerous named *Periods*, e.g. *Carboniferous, Jurassic*.
Geomorphology Study of the form of the ground and processes that shape it.
Geotechnical Geology as it relates to engineering, for example in ground stability.
Glacial. Associated with ice, often referring to cold periods in earth history when 'ice-age' conditions were prevalent. Many glacial periods have been recognised throughout *geological time*.
Glaciation A cold event in earth history when glaciers advanced and *glacial* ice sheets covered large parts of the earth's surface.
Graben *Downthrown* block between two parallel *faults.*
Granite Coarse-grained *acid igneous rock* containing light-coloured *quartz and feldspar* as major constituents, together usually with some mica or other dark coloured mineral.
Gravel Coarse mineral or rock particles predominantly in the range above 2mm (4mm commercially).
Groundmass Similar to matrix, often used where the mineral content of a matrix is indeterminate.
Groundwater All water beneath ground level but often refers specifically to water beneath the *water table.*
Holocene The last 10,000 years. Sometimes known as the Recent.
Horizon A particular level within a group of strata.
Horst Block of ground uplifted between two *faults*.
Hydrogeology Geology of underground water.
Hypersaline Very concentrated salty water.
Igneous Rock Formed by solidification from a hot molten state. Sometimes known as 'primary' rock.
Intrusion A body of *igneous* rock which has been has been forced when molten (as *magma*) into pre-existing rock.
Joint/Jointing Planar fracture which can occur in any type of rock, distinguished from a fault in having no significant displacement.
Jurassic Geological system or time period about 205 to 145 million years ago.
Kaolinite A variety of clay mineral of economic importance formed by alteration of other rocks.
Karst Landscape characterised by caves and enhanced underground drainage caused by chemical solution of rocks and redeposition. Particularly characteristic of limestone areas.

Karstic Weakly developed karst features.
Laminae/lamination Fine, discrete layers of rock, 0.005 - 1.00 mm thick.
Lapilli *Gravel* sized *volcanic* fragments ejected from a volcano.
Laterite Red soil residue of clay minerals and iron oxide formed in tropical climate conditions.
Lava Molten *rock* at the land surface.
Lens/lenticular Applies to an ore or *rock* body that is thick in the middle and thin at the edges.
Limestone A *rock* comprising almost entirely of calcium *carbonate*.
Lineation A general term for any *rock* feature showing a linear structure, frequently resulting from intersection of two planes such as *bedding* and *cleavage*.
Lithology Rock type described on the basis of observed properties such as colour, grain-size and composition.
Lithic Applies to a *tuff* containing mainly *rock* fragments
Littoral related to shoreline, beach.
Magma Molten rock.
Marine Pertaining to the sea
Massive Having great bulk or having homogenous structure or texture.
Matrix Finer grained material enveloping larger or coarser bodies or structures within a *rock*.
Member A minor stratigraphic unit comprising part of a larger *Formation*.
Micrite/micritic An abbreviation of microcrystalline *calcite*; very fine grained carbonate frequently occurring as a distinct rock or as the *matrix* in *limestones.*
Mineral Generally, a naturally occurring element or compound usually (but not exclusively) of non-biological origin.
Mineralogy Study of minerals.
Mud Very fine-grained sediment of any *mineral* composition.
Mudstone (or Mudrock) A *sedimentary rock* composed essentially of very fine grained particles.
Neptunian Dyke A crack or fissure in rock which contains sediment or mineral of a later age.
New Red Sandstone Continental sediments formed in desert/semi-desert conditions in the Permo-Trias
Nodule Rounded lump of *mineral* or rock embedded in different *mineral* or *rock matrix*.
Old Red Sandstone Continental sediments formed in desert/ semi-desert conditions in the Devonian.
Oolite *Sedimentary rock*, usually a limestone, composed mainly of *sand*-sized particles known as ooliths having a concentric and/or radial internal structure.
Orogeny A major phase of deformation, *folding* and *metamorphism* of the earth’s crust associated with continental collision, formation of mountains and igneous activity.
Ossicle Constituent part of a *crinoid* (sea lily) or echinoid (sea urchin). Formed of a single *Calcite* crystal*.*
Outcrop Area of rock at the land surface.
Palaeoenvironment Ancient environment.
Palaeogeography Ancient geography.
Palaeontology Study of ancient life by means of fossils.
Pangaea A supercontinent of about 300 to 200 million years ago, formed partly by the *Variscan orogeny*
Pebble A *rounded rock* fragment of 4 - 64 mm in diameter.
Pericline Anticline *plunging* in all directions away from a centre, commonly having a ‘whaleback’ form.
Period A major unit of *geological time* measured on a scale of several million years, e.g. *Jurassic*
Periglacial Relating to locations, conditions, processes and *geomorphologica*l features characteristic of a cold climate close to borders of a *glacial* area or ice sheet.
Permian Geological system or time period about 290 to 250 million years ago.
Petrography The systematic description of rocks.
Piedmont Region, area or feature situated at the foot of a mountain or mountain range.
Pleistocene Geological time period of the last Ice Age, about 2 million to 10,000 years ago.
Plunge Angle and/or direction of inclination of a fold axis or other linear geological feature.
Post-depositional Structures in *sedimentary rock* formed after the *rock* was deposited.
Pyroclastic Fragmental rock materials formed by volcanic explosion.
Quaternary Most recent geological period encompassing the Pleistocene and the Holocene.
Quartz Crystalline silica, SiO_2, hard translucent or white mineral which is an essential constituent of *granite* and it is also a major component of most *sandstones* and siltstones.

Ripple marks Small scale ridges and troughs formed by flow of wind or water over loose sandy sediment.
Rounded Referring to a rock fragment having its corners and edges rounded but not necessarily spherical.
Rock An aggregate of one or more minerals.
Saccharoidal Granular texture resembling that of sugar.
Scree A heap of rock debris at the base of a cliff resulting from weathering.
Sand Mineral or rock particles in the range 0.06 to 2mm (4mm commercially).
Sandstone A *sedimentary rock* composed essentially of *sand*-sized grains.
Sediment Solid material that has settled from suspension in a fluid.
Sedimentary Rock Formed by consolidation of *sediment*. Sometimes known as 'secondary' rock.
Sedimentology The scientific study of *sedimentary rocks* and processes responsible for their formation.
Seismic Pertaining to earthquakes or earth vibration.
Shale Fine grained *sedimentary rock,* usually *laminated*, formed by consolidation of mud, clay, and/or *silt.*
Shear Fracture in rock on any scale whereby one part of the rock has been made to slide past the other.
Silica Silicon dioxide, SiO_2, occurring as *quartz* and other forms of free silica and also as a chemical constituent of *silicate* minerals.
Silicate Any of numerous, often complex, mineral compounds that contain silicon and oxygen. This is the largest class of *minerals*.
Silicification Process by which minerals, rocks, cavities or fossils of other mineral composition are replaced by silica.
Silt Fine sediment of particle size between *sand* and *mud*.
Silurian Geological system or time *period* about 450 to 420 million years ago.
Slickenside A polished, usually striated, surface caused by movement on a *fault plane* and indicative of movement direction.
Solifluction Downhill movement of soil or scree cover during freezing and thawing.
Spar Crystalline non-metallic *mineral*.
Sparite *Limestone* composed mainly of visibly crystalline calcite.
Spring A point where water flows from underground.
Strata Beds or layers of *sedimentary rocks.*
Stratigraphy The study of stratified rocks, particularly their evolution with time and changing environments and their classification in the order of time.
Strike Intersection of a planar geological feature such as a *fault* or *bedding-plane* with the horizontal.
Stylolite Solution feature of obscure origin believed to have formed under pressure and seen frequently in limestone. Often having a zig-zag cross section appearance with insoluble mineral accumulation.
Syn-depositional Structures in *sedimentary rock* formed at the same time as the *rock* was being deposited.
System Named unit of *stratigraphy* classification equating to time *Periods, e.g. Carboniferous, Jurassic.*
Superficial Surface or near-surface deposits which are relatively recent in geological age.
Syncline A U-shaped *fold* in layered *rock.*
Tectonic Relating to major earth forces and movements producing large scale geological structures.
Tertiary A geological period of time from 65 million years to about 2 million years ago.
Thin section Slice of rock prepared to a thickness of about 0.003mm for microscopic mineral examination.
Thrust (Thrust Fault) A low-angle *fault* which can be on a very large scale with large displacement associated with mountain building and *orogeny*.
Transgression Spread of the sea over the land.
Triassic Geological system or time period about 250 to 205 million years ago
Tufa Deposit of *calcium carbonate* precipitated by water evaporation around a spring or along a stream.
Tuff Rock composed mainly of volcanic ash.
Unconformity A break in a sequence of strata representing a significant time gap.

Vadose water Water in the unsaturated zone between the ground surface and the *water table*.
Variscan The major period of earth movements (*orogen*y) across central Europe and the eastern USA during *Devonian* and *Carboniferous* times caused by continental collision following the closure of an ancient ocean.
Vein A sheet-like or tabular body of one or more *minerals* formed by infilling of a fracture within a rock.
Vesicles Small spherical cavities in a volcanic rock produced by bubbles of gas trapped during solidification. Vesicles are frequently infilled with *mineral*.
Volcanic Relating to a volcano, a vent in the earth's surface by which molten *rock* (*magma*), fluids and gases are erupted.
Water table The level beneath the ground under which all cavities and fissures are saturated with water.
Weathering Natural processes by which rocks are altered by the weather.

Summary Geological Timescale

ERA	PERIOD	BEGINNING (MILLION YEARS)	NOTES
QUATERNARY	HOLOCENE	0.01	The last 10 000 years
	PLEISTOCENE	1.8	'Ice ages', periodic glacial conditions
TERTIARY	PLIOCENE	5.3	
	MIOCENE	23.8	General cooling of climate
	OLIGOCENE	33.7	
	EOCENE	54.8	Severe tropical weathering and erosion
	PALAEOCENE	65.0	Dinosaurs extinct, ammonites extinct
MESOZOIC	CRETACEOUS	144	The 'Chalk' (in Upper Cretaceous)
	JURASSIC	206	Oolitic limestones, east Mendip, Cotswolds
	TRIASSIC	248	New Red Sandstone, desert conditions
PALAEOZOIC	PERMIAN	290	Variscan orogeny, Carboniferous-Permian
	CARBONIFEROUS	354	Carboniferous Limestone and Coal Measures
	DEVONIAN	417	Old Red Sandstone, desert conditions
	SILURIAN	443	Oldest rocks in Mendip, largely volcanic
	ORDOVICIAN	490	
	CAMBRIAN	543	'Explosion' of life
PROTEROZOIC	PRE CAMBRIAN	2 500	Scarce fossils of soft bodied creatures
ARCHAEAN		3 800	Ancient rocks, traces of primitive life
PRE ARCHAEAN		4 600	Formation of the earth. No rock record

APPENDIX G: General Health & Safety Risk Assessment

David Roche Geo Consulting
Geodiversity Audit of Active Aggregate Quarries
Health & Safety Assessment

Summary

The Job: Visit and record geological features of interest at Active Quarries in Somerset.

Main Tasks: Walk each site observing, examining and recording geological features, making notes, taking measurements, photographs and small (hand-size) samples. 1 to 2 days anticipated at each site.

Principal Hazards arising from: Lone working; difficult ground; mobile plant; water and waterlogged areas.

Risk Assessment

Task	**Hazard**	**Actions**
Planning:		Determine good methodology and order of working.
		Only competent and experienced persons involved.
		Arrange visit date and time beforehand
Site Arrival:		Contact Manager (or designated Deputy) immediately on arrival. Log in and remember to log out on departure. Check local vehicle rules for parking, reversing, etc. Consider this Risk Assessment with the Manager, modify if necessary. **Get clear information and instructions about quarry-specific conditions and act accordingly.**
General:		Personal Protection Equipment such as high visibility jacket or waistcoat, safety helmet and safety footwear to be worn at all times on site. Eye and ear protectors to be carried and used if dusty or noisy conditions are encountered. Gloves to be carried and used where appropriate. Be aware of the adverse effects of fatigue; do not work long hours without a break; carry a water bottle and some food.
Lone working: (Note – paired working to be undertaken where possible)	Out of direct contact with others.	Agree route and timing with Manager and stick to it. Make sure to return to office at agreed time. Carry an accurate watch. Make contact with Manager by mobile phone if unexpectedly delayed. Agree with Manager to search if late. Acknowledge other operators at all opportunities to ensure they are aware of your presence. Carry fully charged mobile phone, keep it switched on, use it sparingly, only if necessary and only when safe to do so. Ensure that you have contact number(s) for Quarry Manager and others and that they have your number.

		Determine other procedures if mobile phone doesn't work. Carry a whistle in an easily reached pocket and use it in emergency if phone signal not available.
	Mobile Plant	Mobile plant such as dumpers, loaders and other vehicles present a serious hazard. Only competent and experienced 'quarry aware' persons can operate in areas where mobile plant may be encountered unless accompanied by another suitably competent person. Whenever possible keep away from areas where mobile plant is operating. Drivers of large vehicles may have difficulty seeing smaller vehicles and/or pedestrians. In all cases, assume that a driver of a large vehicle is unaware of your presence unless you are sure that you have been seen. Keep well away from large vehicles, whether moving or stationery, be sure to give moving vehicles a wide berth. If inadvertently caught in a place where close approach of a large vehicle is unavoidable, stand still in a safe position, make eye-contact with the driver if possible to be sure that your presence is known. If being passed on a roadway by a large vehicle, stand still in a safe place to avoid any risk of slipping or stumbling into its path. Acknowledge all drivers as soon as possible and at every opportunity to ensure that your presence in the area is known. Be continually aware of your immediate environment.
	Blasting	Ensure that you are aware if blasting is to be carried out and at what time (and ensure that the Manager or person in charge knows that you are aware). Keep away from the area or areas being prepared for blasting. However, acknowledge persons preparing the blast or otherwise ensure that they are aware of your presence in the quarry. Return to the quarry office, or proceed to another safe area designated by the Manager or person in charge, no less than 30 minutes before the scheduled time for the blast. Ensure that the Manager is in no doubt that you are out of the quarry or in a safe area. Do not re-enter the quarry area until instructed that it is safe to do so. Do not go near a blast pile unless the Manager or person in charge has indicated that it is safe to do so.
Operating, i.e: walking, inspecting, observing, recording, photographing, measuring, etc:	Difficult ground underfoot; risk of stumbling, tripping or falling.	Wear proper, good quality, safety footwear. Take great care when moving around at all times. Avoid areas of difficulty. Find a safe place to write, draw, photograph, etc, Do not move around whilst doing so. Be continually aware of your immediate environment.
	Quarry faces; risk of falling rock	Do not approach within 5m of the toe of a face **UNLESS**: -the face has been inspected by the Manager or his deputy and proposed actions adjudged safe, **AND**, -accompanied by another competent person acting as look-out to observe and give warning of any potential rock fall or other hazard, **AND**,

		- a minimum time is spent at the face to allow actions such as brief inspection and/or placement or retrieval of a scale bar for photography.
	Quarry faces; risk of falling over	Do not approach within 5m of the crest of a face **UNLESS**: -a secure fence or safety barrier is in place such as at an observation point or survey station, **OR,** -an approved harness is worn, **AND**, -accompanied by another competent person.
	Water areas	Do not go near such areas **UNLESS**: -the location has been inspected by the Manager or his deputy and proposed actions adjudged safe**, OR**, -accompanied by another competent person, **AND**, -appropriate water rescue equipment such as lifebelt and rope is immediately available
	Areas of soft waterlogged ground	Be aware of the possibility of such areas and avoid them. If inadvertently such areas are encountered, retreat immediately or, if bogged down and this is not possible, call for help.
Collecting hand samples:	Hammering	If hammering is involved, proper eye protection, such as a helmet visor or safety goggles, is essential. Gloves must be worn.
Working in bad weather:	Adverse conditions	Awareness of adverse effects of inclement weather is important and enhanced vigilance is necessary on all matters in conditions which may be wet, windy, cold, hot, or combinations of these. In some conditions the work may need to be postponed for safety reasons.

CN 15/04/04

APPENDIX H: Plan of Somerset Showing Locations of Active Quarries