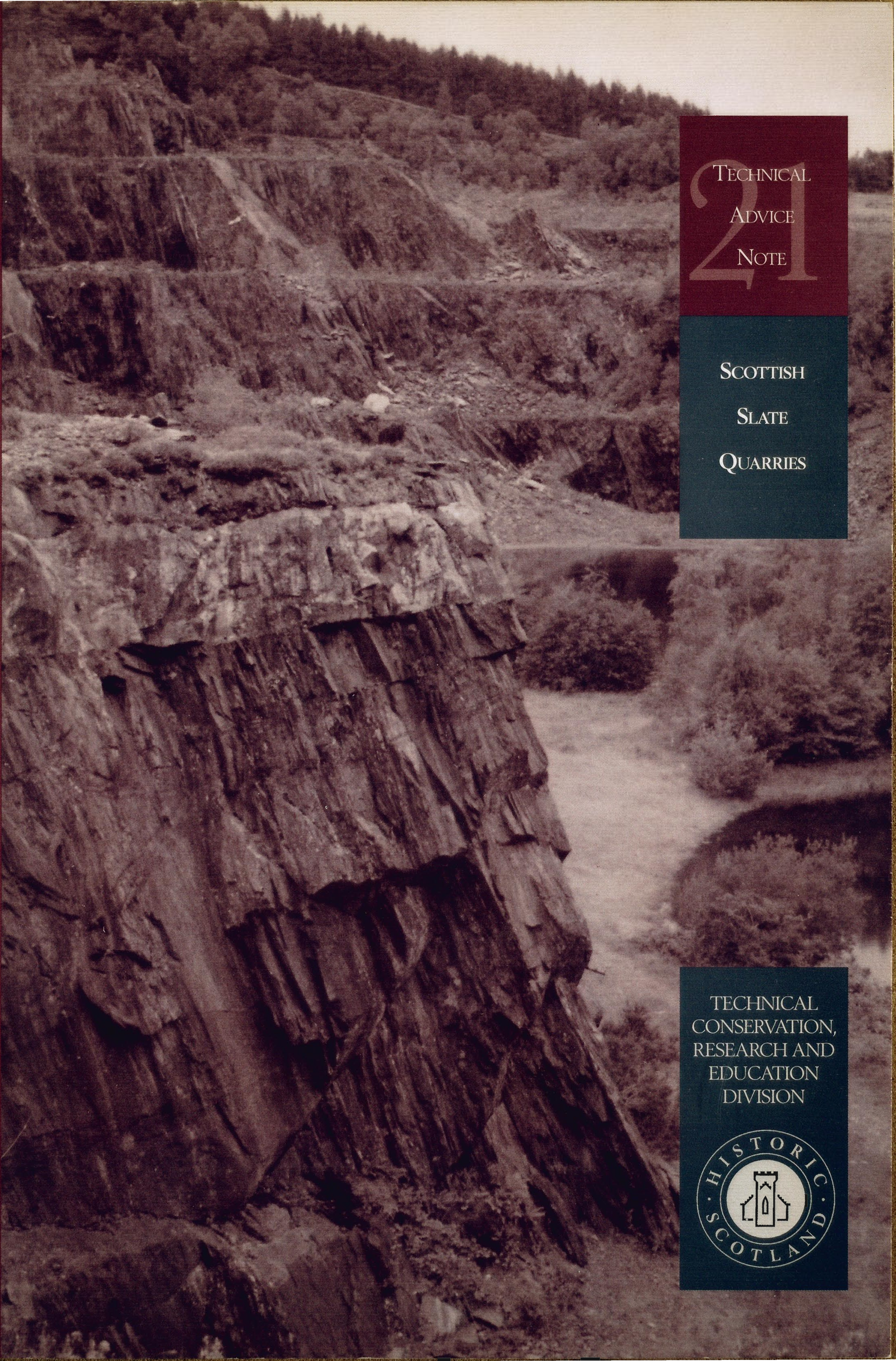
TAN 21

Scottish Slate Quarries



Technical Advice Note 21

Scottish Slate Quarries

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21 Technical Advice Note

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FOREWORD

Scottish slate was historically produced from four areas across the country: Ballachulish, Easdale, Highland Border and Macduff. Its unique and distinctive appearance is a direct consequence of its geological characteristics. Most important of these is slatey cleavage which determines how easily and how finely the material can be split. Because of its generally poorly defined slatey cleavage, Scottish slate is not capable of being split into the smooth, regular, finish of slates sourced from elsewhere. This feature was turned to economic advantage by the slate workers as they cut roofing slates from quarry blocks to whatever size could be produced, and laid the resulting variable sizes of slate in diminishing courses on the roof. Scottish roofscapes thus reflect the variety in the visual and performance characteristics of Scottish slate sourced from the four producing areas, and from different quarries within the areas. However, the last comprehensive survey of the quarry sources for Scottish slate was *Wartime Pamphlet 40: Scottish Slates,* published in 1944. The Scottish slate industry was in decline at the time this survey was carried out, and since the mid-1950s quarrying for slate has ceased entirely in Scotland.

Scottish slate roofs are a distinctive element of many buildings of traditional construction built until the early years of this century, and therefore make an important contribution to the integrity of the built environment. While Scottish slate is particularly well suited for use as a roofing material in Scotland and is of proven durability, some maintenance is required, involving tasks such as the replacement of lost or broken single slates or the re-roofing of a nail-sick roof. These repairs generate a demand for matching Scottish slate, a demand which must currently be met by recycled slate as newly-quarried slate is not available. This is an unsustainable situation, and erosion of the quality of Scotland's roofscapes is resulting.

Recognising the need to revive the Scottish slate industry, in 1995, Historic Scotland commissioned the University of Dundee to study the factors affecting the demand for Scottish slate. This research has now been completed and has been published as *Scottish slate: The potential for use in building repair and conservation area enhancement* Research Report. Also in 1995, the University of Glasgow were commissioned to investigate the performance of Scottish slate from all the quarries listed in *Wartime Pamphlet 40* for use as roofing slate and select those quarries that, from a geological point of view, are most suitable for re-opening. This work has been published in two volumes: a Research Report entitled *Methods of evaluating Slate and their application to the Scottish slate quarries* and this Technical Advice Note.

Historic Scotland has also been fortunate to be able to publish Gerald Emerton's Research Report *The Pattern of Scottish Roofing*. This report builds upon Mr Emerton's years of experience and his unique photographic archive of traditional roofs in Scotland. Sandstone, schist and true slate, pantile and other man-made roofing materials are all described in detail, as are the traditional techniques for their fixing on the roof. Released in conjunction with the Glasgow and Dundee studies, this volume ably complements them by illustrating the striking visual distinctiveness of traditional Scottish roofs.

This Technical Advice Note provides a comprehensive directory of the visual and performance characteristics of slate from all the quarries described in *Wartime Pamphlet 40*. Its publication will therefore facilitate the choice of appropriate materials for the repair of listed buildings, a condition applied to the receipt of grant aid for repairs to listed buildings by the Historic Buildings Council for Scotland (HBC) since 1953. However, as newly-quarried slate is not available, all matching Scottish slate currently used to repair historic buildings has been salvaged from other traditional buildings built pre-1950. To support the appropriate repair of Scottish historic buildings, the HBC has called for Scottish slate to be brought back into production. This TAN also serves as an initial scoping study for those in the stone industry who have expressed an interest in re-opening slate quarries in Scotland.

Inevitably, related issues have moved on since these research projects were commissioned. In particular, in May 2000, Rhona Brankin MSP, the Deputy Minister for Culture and Sport, launched the Scottish Stone

Liaison Group (SSLG). Membership of the group includes the Stone Federation GB, the British Geological Survey, the National Federation of Roofing Contractors, the Scottish Building Employers Federation, Scottish Environmental Protection Agency, the Royal Incorporation of Architects in Scotland and the Royal Institution of Chartered Surveyors in Scotland amongst others. This group was established to provide an appropriate industry-wide forum, to bring together all those with an interest in reviving the Scottish stone industry. One of its specific aims is:

'To address the question of the availability of indigenous materials (stone and slate) required for the maintenance of our built heritage ...'

This TAN, coupled with the related research reports from Glasgow and Dundee Universities and that of Gerald Emerton, will provide valuable data and evidence to assist in resolving this situation.

Ingval Maxwell
Director, Technical Conservation, Research and Education Division
Historic Scotland, Edinburgh
September 2000

SUMMARY

This Technical Advice Note (TAN) is one of the products of a Research Project initiated and funded by Historic Scotland with the objective of selecting appropriate Scottish quarries for further investigation with a view to reopening. It is hoped thereby to ensure the continued availability of this traditional roofing material of proven quality and durability and thus to maintain and restore the indigenous character of Scottish architecture. The principal product of the Project, referred to here as the Research Report, has been presented to the University of Glasgow for the degree of Doctor of Philosophy. It describes original research into methods of assessing the durability and other relevant qualities of slate as found in the quarry. This TAN describes the results of applying these methods to the various Scottish quarries, giving in each case an overall appraisal and an assessment of the prospects for reopening.

An important aspect of the Project was to update the last appraisal of Scottish slate quarries, which was carried out in 1944 (Wartime Pamphlet No 40). There have been many changes in the subsequent 55 years, with some quarries being substantially altered due to continuing production. However, the last quarry ceased production in the 1960s and some no longer exist due to road building and landscaping. Those that remain are now considerably overgrown with gorse and heather making it difficult in many cases to assess them properly.

The approach taken in this TAN is to reassess all the quarries described in the Wartime Pamphlet and to update it in the light of both the physical changes in the locality and developments in the understanding of the geology of the region.

The quarries were grouped according to their location and in the order of their historical importance as follows:

1. Ballachulish
2. Slate Islands (Easdale)
3. Highland Border
4. Macduff (the Slate Hills of Buchan and Banff)

These are also the generic terms used and applied to all the quarries in the relevant group.

In assessing the quality of the slate in the various quarries reference is made to the Research Report and to the criteria which have been developed as follows:

• The minimum commercial thickness capable of being produced was estimated by comparison with the fabric of slates from producing quarries in Wales and Cumbria.

• The size of slates is controlled by the spacing and orientation of discontinuities such a joints within the quarry. However in most cases quarries are too overgrown to assess these properties and attention is drawn where possible to the historical sizes produced.

• The durability of slate is controlled by the relationship between crystallinity, mineralogy and water absorption. In general, low water absorption indicates high durability and when crystallinity is high, water absorption is often low. Furthermore, minerals are present in a crystalline form and hence are less susceptible to attack by water. However, in some cases fine grained slate with low crystallinity has low water absorption due to the grain size and is also durable. Finally, even if crystallinity is low and water absorption high, when mineralogy is good i.e. minerals are present in their oxidised form, the effect of high water absorption is substantially reduced. The slate is then durable even if water can penetrate it.

Quarry Appraisals

The results of the appraisals of the four main slate quarrying areas are given below in the order of their perceived potential for re-opening, including in each case a recommendation for further investigation with a view to reopening. Factors other than those directly related to geology, such as access, proximity to centres of population, environmental sensitivity etc., are also considered.

Ballachulish

The best Scottish slate was found at Ballachulish, and there are certainly sufficient resources still in the ground. However, this is a very scenic area with high tourism value and the principal quarry has now been made into a tourist amenity. Most of the remainder have severe limitations in terms of environmental sensitivity, but it has been possible to select one quarry in the area as meriting further investigation.

Macduff

There are large resources of slate on the north slopes of the Slate Hills, and the quality was found to be good and remarkably homogeneous from one hill to the next. Selecting a quarry for further investigation has depended on other factors such as access. In general, quarries having at least rudimentary vehicular access have been more extensively worked in the past and hence have the problem of large tips covering the working area. The splitting properties of the slate rock deteriorate to the south due to increasing proximity to the Insch igneous intrusion.

Highland Border

The Highland Border group comprises a number of quarries widely spaced between Arran and Dunkeld, whose only common factor is their overall geological similarity. The mineralogy of the slate, in particular the lack of pyrites, would suggest good potential as a roofing material. Other properties however, such as the degree of crystallinity, also control the durability of the slate and these vary considerably from quarry to quarry and for producing units within a quarry. Zones with poor crystallinity and low quartz content should be avoided.

Slate Islands

The slate from Easdale Island was once said to roof the world, and there is no question that it produced very durable slate, but resources on this small island are now exhausted. Resources are available elsewhere in the area but considerable work would need to be done to select a quarry suitable for further exploitation. Only limited information from fresh samples is available and assessment of the weathering properties of the slate from different quarries is based on the appearance of the slate in the quarries after 50 to 100 years of exposure. Many which were suitable in terms of their resources, location and access had badly weathered surfaces or complex geological features. Toberonochy slate appeared little weathered, but the confines of the present quarry are extensively worked and it is worth investigating only if the producing seam extends along strike. A more likely alternative is Breine Phort, even though the slate is badly weathered.

The brief for the Project calls for at least one quarry from each of the major areas to be recommended for further investigation. This is difficult in the case of the Slate Islands since all of the quarries have severe drawbacks. It is also difficult for Macduff for the opposite reason, that several quarries show good possibilities. Nevertheless, taking all the above factors into account, the following quarries are recommended for further investigation:

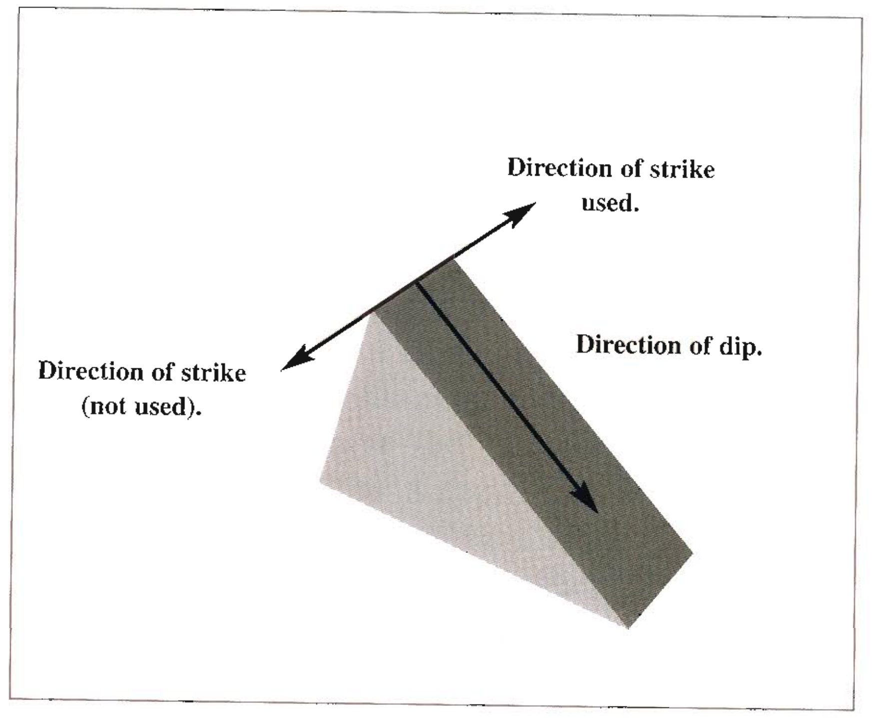
1	Ballachulish	Khartoum
2	Macduff	Kirkney
3	Highland Border	Logiealmond (Craiglea)
4	Highland Border	Aberfoyle
5	Slate Islands	Breine Phort

Convention used for describing the orientation of planes and lines.

The attitude of a plane such as bedding, joint or a cleavage plane is defined in terms of its strike and dip as follows:

strike/dip.

The strike, the direction along which the plane is horizontal is at right angles to the maximum dip direction which can be both 90° clockwise and 90° anticlockwise to this direction. The strike, which is 90° anticlockwise to the dip direction, is quoted throughout this Report. For example a plane 045°/60° refers to a plane dipping at 60° to the horizontal, towards the SE.



The attitude of a line is defined in terms of its **plunge** and **trend**,

plunge/trend

plunge is the angle between the line and the horizontal.

trend is the direction in which the line plunges.

Abbreviations

BGS	British Geological Survey
BRE	Building Research Establishment
BSE	Back scatter electron
BSI	British Standards Institution
CCUS	Centre for Conservation and Urban Studies
C of V	Coefficient of Variation
CD	Cleavage domains
FPS	Fabric Points Scheme
FWHM	Full Width at Half Magnitude
HS	Historic Scotland
IC	Illite crystallinity
LOI	Loss on Ignition
ML	Microlithon
SEM	Scanning Electron Microscope
St Dev	Standard deviation
W/D	Wetting and drying
XRD	X-ray Diffraction
XRF	X-ray Fluorescence
Z	Atomic number
μ	Attenuation coefficient

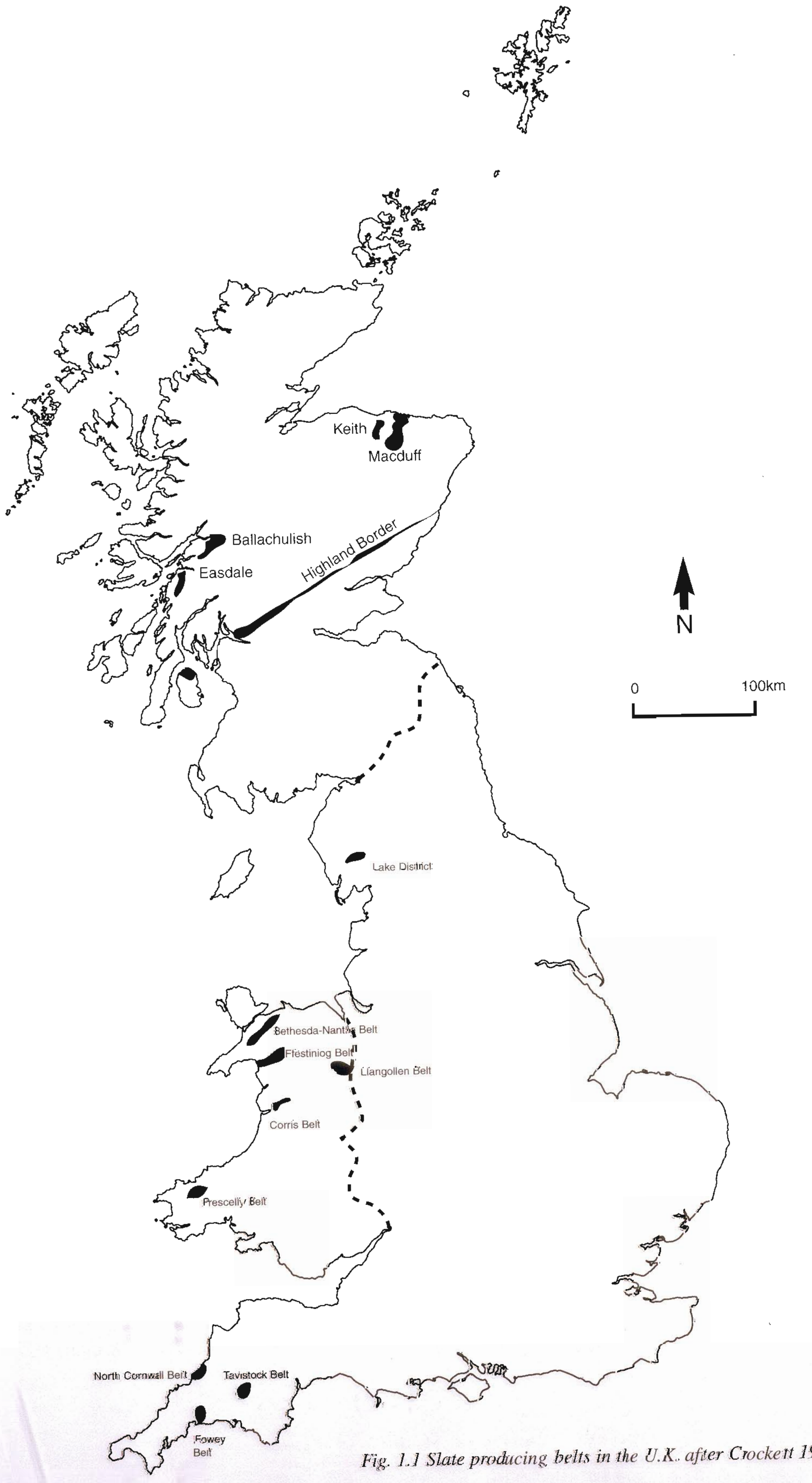


Fig. 1.1 Slate producing belts in the U.K. after Crockett 1975

1 SCOTTISH SLATE QUARRIES

1.1 Introduction

Slate and flagstone have been used as a roofing material since Roman times, but up until the time of the Industrial Revolution in the 19th century their use was limited to prestigious houses in areas where the material was available locally. The Industrial Revolution was a period of rising population, rapid growth of cities and improved transport facilities. The use of slate became more widespread, replacing thatch and other short lived roofing materials.

The main slate industry was centred in four areas in Britain, namely the Grampian Highlands of Scotland, Wales, Cumbria, and Cornwall and Devon. Because of the enormous growth of cities[1], the industry expanded rapidly during the 19th century reaching its zenith around 1900. However the beginning of the 20th century was marked by a depression in the building trade, compounded by a shortage of manpower during the World War I. The industry experienced a temporary revival between the wars but was affected by competition from cheaper tiles, which supplied most of the demand for roofing materials during this period. The industry continued its downward spiral throughout the World War II when it was again hit by a shortage of manpower. The possibility of revival of the industry post-war, as cities were being rebuilt, was hindered by government legislation controlling the price of slate thus preventing old quarries being re-equipped (Richards 1995). The competition from tiles continued as well as from slates imported from Spain and elsewhere. While the nucleus of the Welsh and English industries managed to survive with a few quarries staying in production, the effect in Scotland was total shut down in the 1960s. At its peak the Scottish industry had produced 25-30 million slates per annum, employing 1000-1500 men. This had reduced to 10 million slates and 370 men in 1937 and by 1945 output was negligible. Although resources of slate in Scotland are large, the geology is complex and its major markets are remote, both factors contributing to the shut down of the industry.

The balance between slate and clay tiles began to be redressed in the 1970s when soaring fuel prices increased the cost of kiln firing thus increasing the cost of producing tiles. In the 1980s government grants to restore old houses stimulated the demand for slate. Today, there is an appreciation of the durability of British slate and in contrast the durability of some cheaper imported slate is being questioned. Scottish slate, being smaller and thicker than its Welsh counterpart, is particularly suitable to the Scottish climate. This and an increasing awareness of its contribution to the architectural integrity of Scottish cities and towns are good pointers to the possible revival of the Scottish slate industry.

1.2 Geology of the Scottish Slate Areas

All the important slate areas in Scotland are to be found in the Grampian Highland Terrane. This is an area whose northern boundary is marked by the Great Glen Fault, a deep trench stretching from the Moray Firth to the Firth of Lorn. The southern boundary of the terrane is defined by the Highland Boundary Fault, a line stretching from Stonehaven in the north-east to Arran in the south-west - a notable topographical feature, where the low-lying Midland Valley gives way to the rugged and elevated hills of the Highlands (Fig. 1.2). Sediments laid down in the Precambrian were metamorphosed and deformed during the Caledonian Orogeny or mountain building event in the Early Palaeozoic Era. What is left today is the eroded root zone of this former mountain belt.

The Scottish slate industry was centred in four localities (Fig. 1.1):

i *Ballachulish* on the shores of Loch Leven close to the Great Glen Fault.

ii The islands of *Easdale*, Seil, Luing and Belnahua in a belt stretching from Oban to Jura.

iii In the Southern Highlands close to the *Highland Boundary Fault* in a series of quarries from Arran to Dunkeld.

iv The *Macduff* quarries near Huntly in Buchan and the Keith Quarries in Banff NE of Scotland.

1 Population		Glasgow	Edinburgh	Dundee	Aberdeen
Year	1841	275,000	164,000	65,000	60,000
"	1911	784,000	401,000	164,000	165,000

Source: Smout T.C. 1986

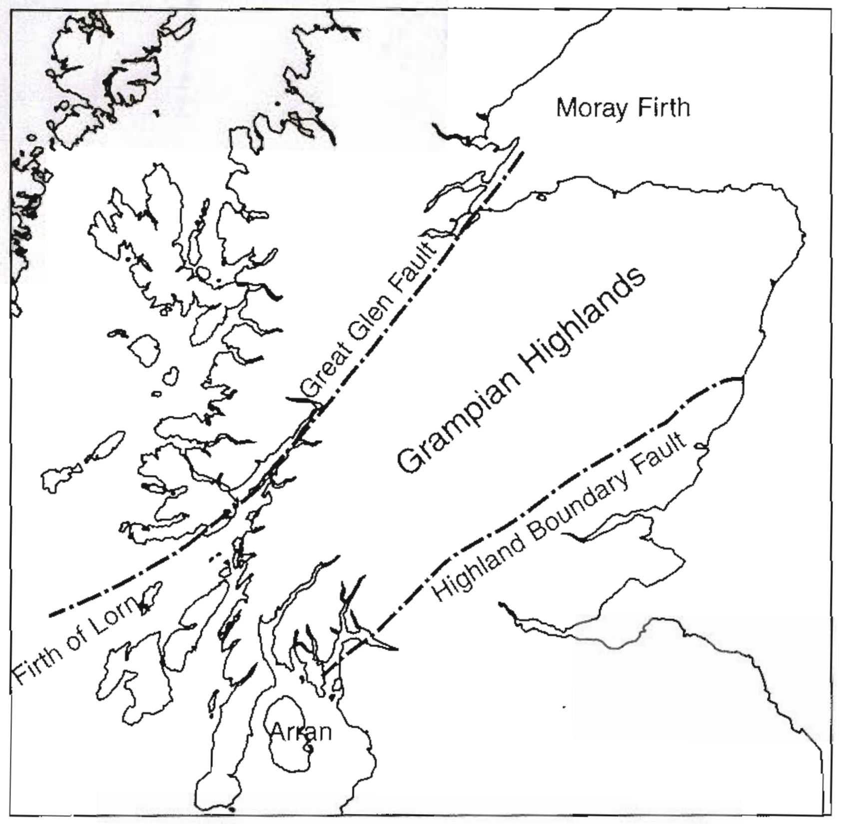


Fig. 1.2 The Grampian Highlands

Understanding how geological factors such as stratigraphy, geological structure and metamorphic grade affect the quality of slate resources is important in evaluating the quarries.

1.2.1 Stratigraphy

Slate is derived from fine-grained clays or muds. In turbulent conditions such fine grained material stays in suspension; therefore the ideal conditions for deposition of potential slate are low energy environments such as deep seas or lagoons where fine-grained material can settle out. The Welsh Basin provided such conditions for millions of years and so accumulated a substantial thickness of muds, which were to become slate. In Scotland and the Lake District, slate deposits were also laid down by the slow accumulation of mud, but also by gravity driven *turbidites*. These are currents caused by increased density due to a suspended load of sediment in a fluid. This fluid is carried down slope, often at great speed, dropping its load of sediment as it fans out onto a more horizontal sea floor. The proximal deposits are coarser grained becoming finer grained in the more distal regions - the environment of potential slate deposits. Because the coarser grained material settles first, the deposits become progressively finer from the bottom upwards, which is the key to recognising turbidites in the field. Turbidites are associated with an unstable sea floor as found in a fault-bound subsiding basin.

Where deposition is close to the shore coarser grained material, often interpreted as storm deposits, produces bands of grit. Both coarse grained turbidites and storm deposits destroy the homogeneous nature of the ideal slate deposits.

This mud deposition provides the first important condition for slate formation.

The second important factor is the development of cleavage.

1.2.2 The Geological Structure

At elevated temperature and pressure, rocks respond to the shortening of the Earth's crust in a plastic manner by folding and developing cleavage. Folds in multilayered sequences are generally controlled in their distribution and wavelength by the stronger or more competent members of the sequence, while the weaker or more incompetent layers conform to the shape changes that are largely prescribed by the other stronger layers. In response to shortening during folding of the competent layers, the minerals of the incompetent layers deform and realign parallel to the direction of maximum stress. This is generally parallel to the axial plane of the fold. Slate is a relatively incompetent material and more readily deformed than quartz-rich grit bands, hence it is often found in the axes of the major folds as in the Highland Border slate quarries.

The most suitable cleavage for producing slates is the axial planar cleavage found in regular folds such as the large open folds found in the North Wales quarries. Scotland has experienced numerous phases of deformation and the refolded folds often give rise to distortion of the cleavage surfaces.

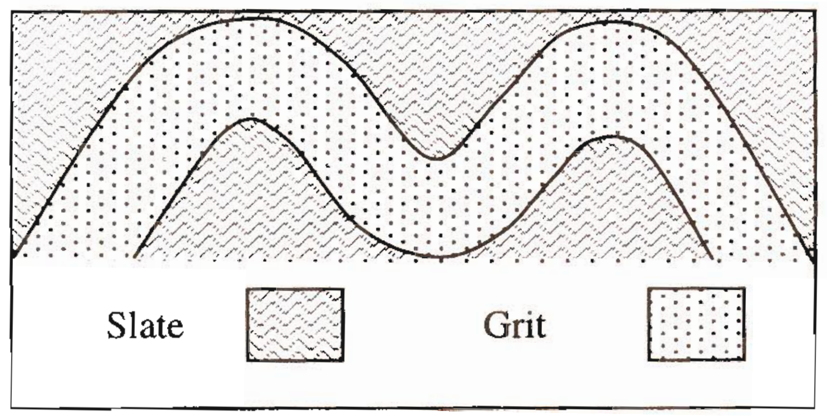


Fig. 1.3 Geometry of the fold is controlled by the competent layer such as grit, while the less competent rock such as slate conforms to the shape of the fold.

1.2.3 Metamorphic Grade

Slate is found in the greenschist facies or low grade of metamorphism on the fringes of the Grampian Terrane and in the Buchan area to the north east (Fig.1.4). In the rest of the area, the grade is too high and hence larger crystals have formed, resulting in a rock too coarse grained to yield good slate.

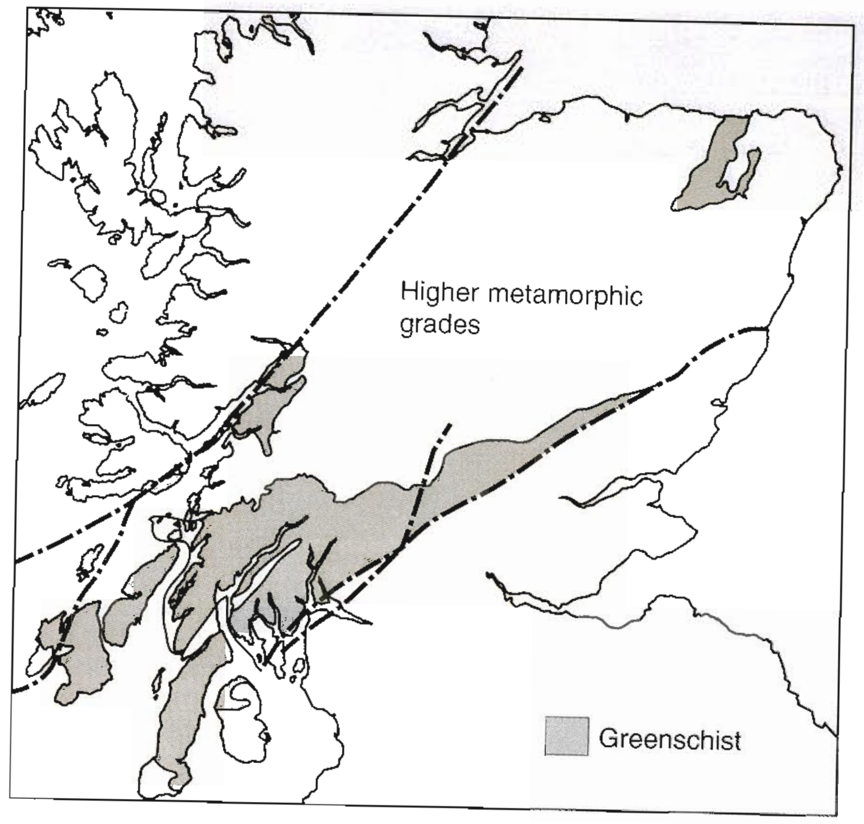


Fig. 1.4 The greenschist metamorphic zone of the Grampian Highlands after Fettes et al. (1985)

1.3 Properties of Scottish Slate

The properties of Scottish slate were compared with slate from Wales and Cumbria. However all Scottish slate has been weathered either on roofs or in the quarries, while samples of Welsh and Cumbrian slate were collected from working quarries and in most cases were unweathered. The following lists the important properties, which are seen to control the quality of the slate.

1.3.1 Mineralogy

The principal minerals of slate are quartz and platy minerals such as white mica, and chlorite. Estimates of the proportions of each mineral were determined (Research Report Chapter 2). In general the greater the amount of quartz, the greater the durability of a slate while the greater the amount of platy minerals the greater the ease of splitting the slate. The weathering properties of white mica and chlorite also differ, chlorite being much more vulnerable to attack. To estimate the original mineralogy of a slate, the ratio of the durable minerals quartz and white mica was used.

1.3.2 Accessory Minerals

Although present in small amounts (approximately 5%) the following minerals have a disproportionate effect on the properties of a slate, acting as reactants in weathering reactions.

Iron Ore Minerals

Iron ore minerals in slate are present as haematite, pyrite or pyrrhotite representing different oxidation states. Reduced iron (ferrous) is prone to oxidation, resulting in discoloration of the slates.

The presence of pyrite and/or haematite was determined by XRD analysis. The oxidation state of the ferric mineral is a function of the environment in which the original muds were deposited. The iron in haematite is a fully oxidised form and is general associated with turbidite deposits as found in the Highland Border Slate. The iron in pyrite is relatively reduced and is associated with deposits laid down in lagoons and restricted basins. This is the more usual form of iron mineral found in slate and that found in Ballachulish and Easdale slate. Pyrite is vulnerable to oxidation especially in its amorphous state. However, when found as crystals, it is resistant to oxidation even in an acidic polluted atmosphere. Occasionally pyrrhotite is found in slate; this mineral is often amorphous and is extremely vulnerable to weathering.

Carbonates

Although carbonates are present in large concentrations in some slates, it is included here as an accessory mineral. It is found in slate as dolomite, calcite or occasionally in magnesium rich rocks as magnesite. The relative stability of these forms of carbonate is as follows:

Dolomite > Calcite > Magnesite.

Similar to iron ore minerals, the degree of crystallinity is an important factor in determining their susceptibility to weathering.

Graphite

Graphite is associated with deposits laid down in reducing conditions. It inhibits the growth of minerals and hence is associated with slates with low crystallinity. It also acts as a catalyst in weathering reactions.

1.3.3 Crystallinity

The crystallinity of a rock increases with increasing metamorphic grade. The sharpness of an XRD peak (FWHM full width at half magnitude) is the usual method of determining the metamorphic grade. However, this method was found insensitive at the range of values observed in slate, so an alternative method was devised (Research Report Chapter 3) using the intensity of peaks of an XRD profile. The range of crystallinities were graded loosely as follows:

Crystallinity Grade	Value
Very low	<250
Low	250-500
Medium	501-750
High	751-1000
Very High	>1000

Table 1.1 Classification of crystallinity based on intensities of XRD peaks

1.3.4 Fabric

The ability to split the slate rock is an important criterion in assessing the property of a slate. The fabric of Scottish slate was compared to that from Welsh and Cumbrian quarries to get an estimate of the potential minimum commercial thickness of the slate. Slate was examined under the microscope and classified according to several parameters.

The fabric of a slate is made up of zones of aligned platy minerals separated by zones of more equant minerals such as quartz. The former are called the *cleavage domains* and the latter are called the *microlithons*. The ability to split a slate is dependent on the ratio of cleavage domains to microlithons and the shape of these zones. A more detailed description of the classification system is given in the Research Report Chapter 3.

1.4 Resources and Reserves

The *resource* is the overall volume of the slate deposit and *reserves* is the amount of slate which can be exploited and hence is dependent on many factors: geological, economic and environmental etc. However since not all of these factors have been explored in this Study no figure can be put to the reserves. In this Report therefore, any estimates, based solely on geological factors, of the proportion of useable rock are referred to as *usable slate*.

In giving quantitative estimates of *usable slate* the following points have to be evaluated:

- Resource i.e. the volume of the available outcrop.
- Depth of workable slate.
- Proportion of rock suitable as slate.

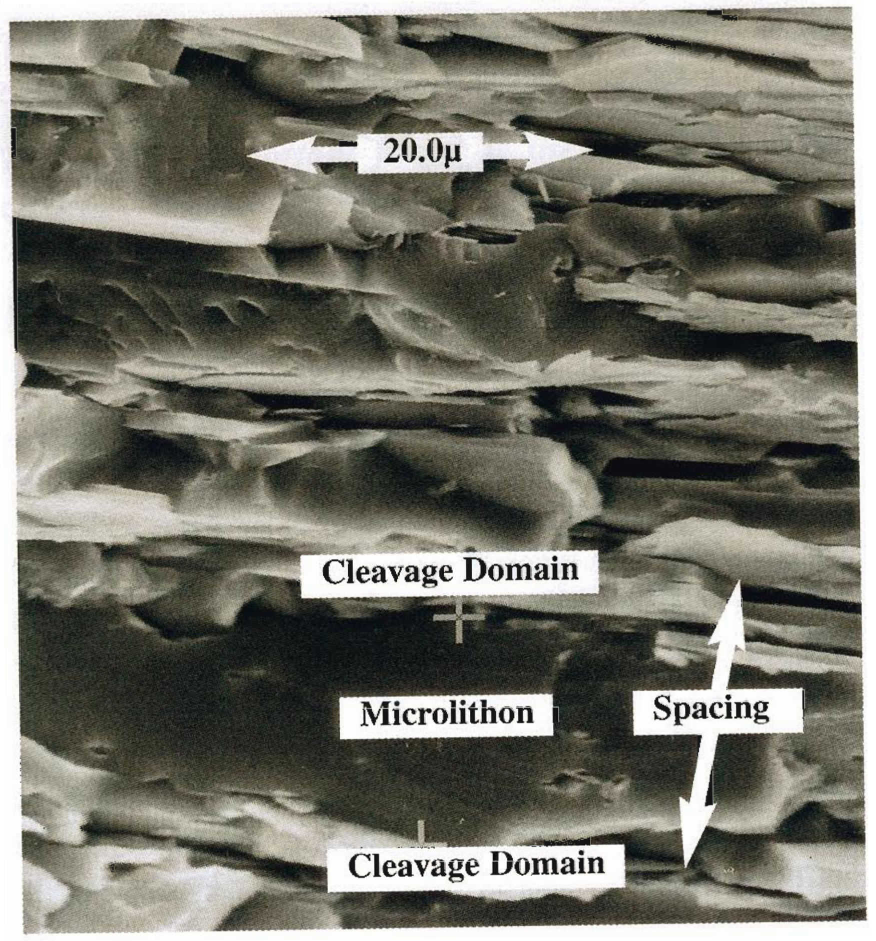


Fig. 1.5 Slaty cleavage, showing the domainal nature of a fabric of a slate whereby zones of aligned platy minerals in the cleavage domains are separated by zones rich in quartz in the microlithons.

1.4.1 Resources

The *resource* is the area of the outcrop times the depth.

Area of the outcrop

The area of the outcrop can refer to the area in the immediate confines of the quarry or the limit of the slate outcrop in the surrounding areas. In some cases the limits of the quarry are clearly defined such as on Easdale Island or Belnahua, but more often this is not the case. Except in one or two cases (which are clearly mentioned in individual quarry reports) the total area of outcrop is usually on so large a scale that it is not seen as a limiting factor. No allowance is made in this Report for the availability of land for slate quarrying.

Depth of Outcrop

Without borehole information the depth of outcrop can only be inferred from geological maps. In general the depth of outcrop is not seen as a limiting factor.

1.4.2 Depth of Workable Slate

The depth to which a quarry can be economically worked is variable. It is generally noted that the quality of a slate improves with depth but the deeper the quarry the higher the cost of extraction. The limit of the *usable slate* is dictated by the engineering factors such as the need to pump out groundwater etc. For a quarry

situated on high ground, the depth to which it can be worked is considerably more than for a quarry on low ground, especially if close to the sea. Yet several Easdale quarries were worked to a depth of greater than 50m, as the quality of the slate was good, but with dire consequences (see Ellenabeich Section 3.5.2). For historical reasons none of the Macduff quarries was worked to much more than 10m depth, making their further exploitation feasible.

1.4.3 Exploitable Proportion of Slate Rock

Within a quarry the slate is often found interspersed with quartz veins, igneous bodies and other types of rock. Where there is a high concentration of such irregularities the amount of *useable slate* is low.

Slate quarries are generally worked along strike, following the line of a productive unit or *seam*. For this reason the possibility of extending the seam is given in individual quarry reports. For example at Toberonochy (Section 3.5.5), the seam in the quarry is of good quality but the resources within the confines of the quarry are limited, so the possibility of looking for an extension of the useable slate along strike is suggested.

Exploitation of *useable slate* in the surrounding area but outwith the immediate confines of the quarry would need much exploratory work such as boreholes etc. to determine the quality and extent of the slate.

In this preliminary study of all the Scottish slate quarries, it is possible in some cases to estimate the resource. Based on these estimates, quarries are described in this report in the following terms: (These are the terms used in individual quarry reports and Research Report Section 6.5)

Resource (x100,000m³)	
<10	Exhausted
10 - 100	Limited
100-1000	Medium
1000-10,000	Large
>10,000	Very large

Table 1.2 Classification of resources based on estimated volume of deposit

For those quarries which appear to have substantial resources, the usable slate can then be estimated based on the size of the seam and other observations in the quarry.

To make a more accurate assessment of the useable slate of a selected quarry would involve firstly surveying the area surrounding it to determine the extent of the available resources, and then a more detailed mapping inside the quarry to determine the ratio of useable slate to the total rock. This is beyond the scope of this Research Report.

1.4.4 Joints and Recovery

Having located a good seam of slate, the size of the blocks extracted is strongly influenced by the pattern of joints in the rock.

Joints are classified as systematic and irregular:

Systematic jointing consists of planar fractures, whose form and orientation are related to the deformation history of the rock and subsequent de-stressing associated with erosion. Superimposed on Scottish slate is *irregular jointing* associated with over 50 years of weathering, so that it is not often possible to determine the original systematic fractures. The type of joints most often identified are parallel to the cleavage surface J_0 and subvertically dipping joints normal to the cleavage surface J_1. It was not always possible to determine the orientation of the grain of the slate and hence the pillaring line, however in general the steeply dipping joints J_1 are parallel to the pillaring surface (Fig1.6). Occasionally other fractures, such as diagonal joints, form a pattern which is considered as characteristic of the original rock J_2 (The terms J_0, J_1 etc. are those used in the individual quarry reports).

Size of Slates

The spacing of joints and the angle (pitch) at which they cut the cleavage surface controls the dimensions of a slab produced in the quarry (Fig. 1.6). This in turn affects the size of slate produced (Section 2.3.4 for sizes of Ballachulish slates). Welsh quarries generally report around 5-10% recovery, yet Bailey *et al.* (1916) when describing the Ballachulish quarries reports *'6000 tons annually of finished material representing 30,000 to 35,000 tons of quarried rock'*, which equates to 15% recovery. Blaikie (1834) mentions 20% recovery when discussing Macduff slate. These figures reflect the difference in roofing practice between Scotland and the rest of the U.K. whereby the former makes use of different sizes of slate and is prepared to use even the smallest *peggies* (228x 150mm).

The relationship between size of slate and percentage recovery was calculated (Research Report Section 6.4.4) for different pitches of joints and for varying perpendicular spacing between them (Fig. 1.6). This shows how the use of smaller sizes increases the rate of recovery where jointing is fairly closely spaced (Fig. 1.7), especially at higher angles of pitch (Fig. 1.7b).

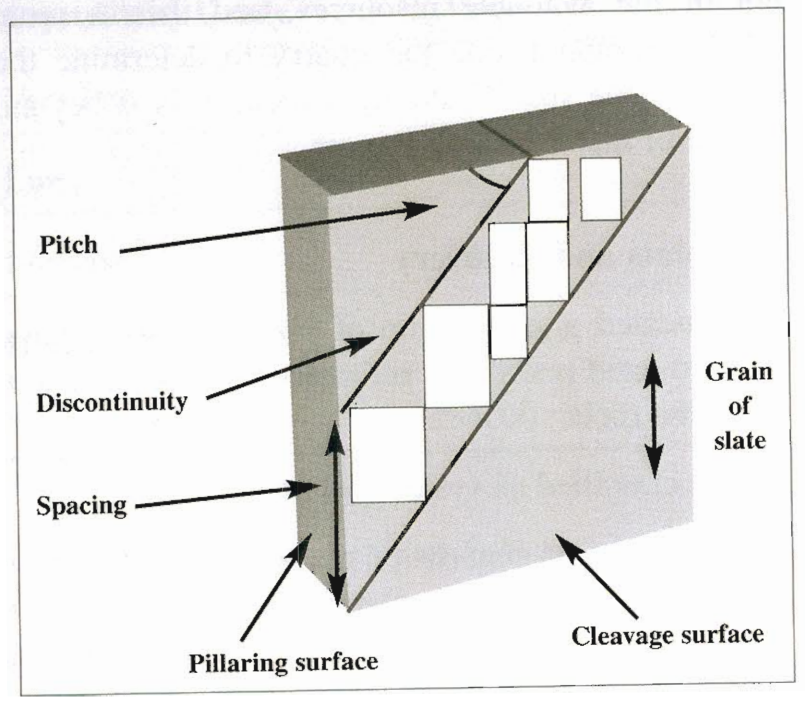
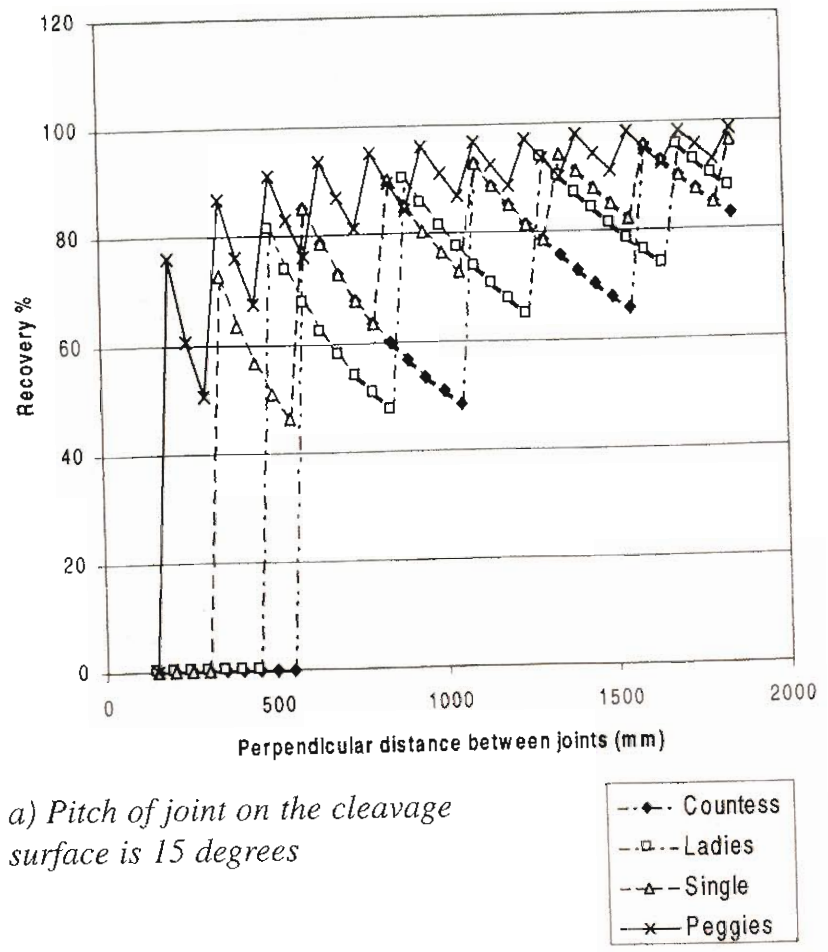
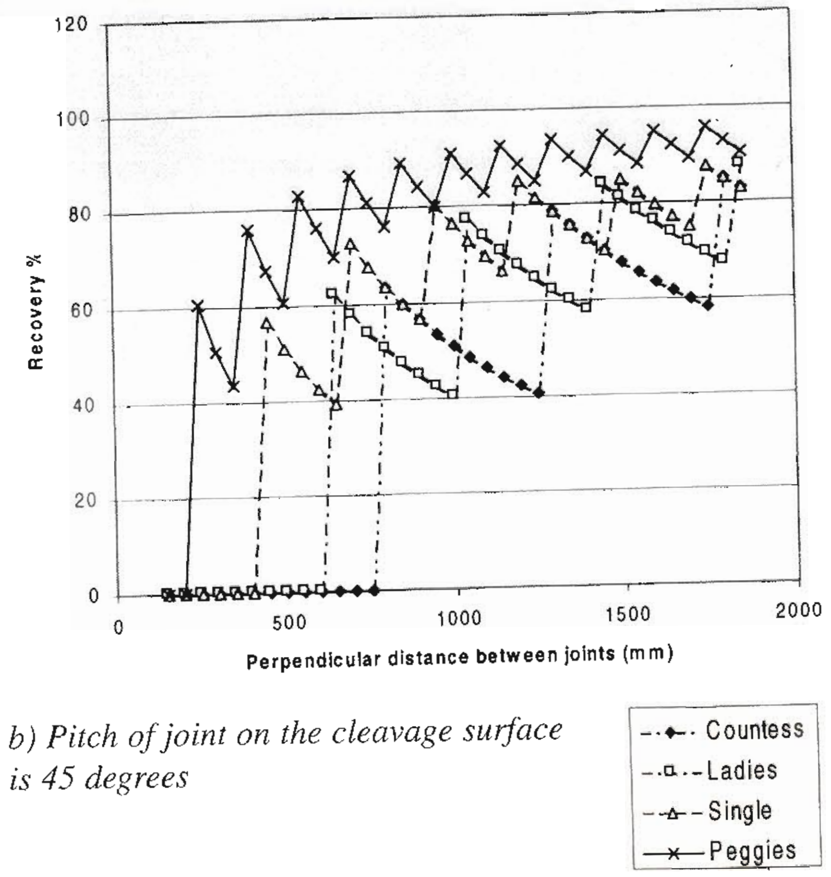


Fig 1.6 Orientation of joints relative to the cleavage surface. Slates are cut along the pillaring line, which is the perpendicular line shown. The recovery is affected by the distance between joints and the angle or pitch of the joints.



a) Pitch of joint on the cleavage surface is 15 degrees



b) Pitch of joint on the cleavage surface is 45 degrees

Fig. 1.7 Relationship between the rate of recovery and the size of slate. Note: The sizes in mm of the named slate sizes referred to above are:

Countess	*510 x 260 mm*
Ladies	*405 x 200 mm*
Single	*255 x 180 mm*
Peggies	*228 x 150 mm*

1.5 Weathering of Quarry Faces

It should be borne in mind in considering the individual quarry reports which follow that all the faces of present day Scottish quarries have been exposed for at least 50 and in some cases more than 100 years. The effect of this exposure in terms of weathering is to some extent indicative of the likely durability of the slate. Weathering of the slate at the quarry faces has been assessed subjectively by reference to the extent of rusty staining, the softness of the surface rock etc.

2 BALLACHULISH SLATE QUARRIES

2.1 Introduction

Ballachulish is the best known of all Scottish slate both in terms of quality and quantity. Its quality is considered to be the best in Scotland; it can be readily split and is extremely durable, lasting well over a hundred years and often outliving the life of a building before being re-used. Production started in the 1693 just one year after the infamous Glencoe Massacre (Bremmer 1869), and rose to a peak in the late 19th century when 15 million slates were produced annually

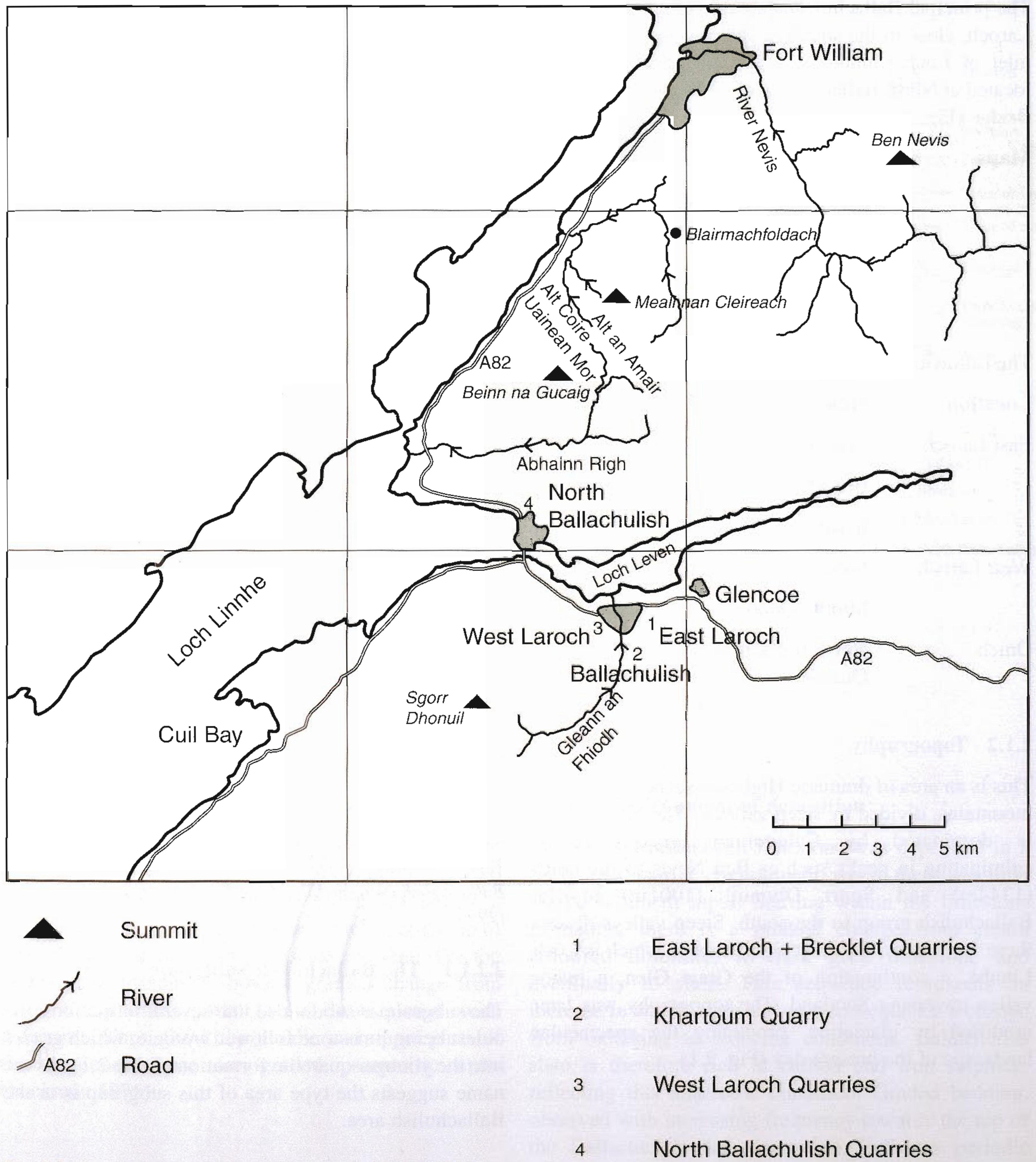


Fig. 2.1 Location map of the Ballachulish slate quarries

(Tucker 1977). From the beginning of the 20th century levels of production declined, until finally in 1955 the quarries closed (Fairweather 1994). One of the factors leading to this decline was competition from cheaper but less durable synthetic materials.

However, in recent time an increasing awareness of the properties of Ballachulish slate has led to this re-evaluation of the resources and the viability of some of the quarries. Resources in the Ballachulish area are still plentiful, but individual quarries have their particular limitations in terms of recovery rates, accessibility etc.

2.1.1 Location

The principal Ballachulish slate quarries are located in Laroch, close to the southern shore of Loch Leven, an inlet of Loch Linnhe. Less extensive workings are located at North Ballachulish, close to the Ballachulish Bridge (Fig. 2.1).

Maps	OS	1:50000 Landranger Series Sheet 41
		1:10000 NN 05 NE
		1:10000 NN 06 SW
	BGS	1:63360 Sheet 53

The following quarries are described below:

Location	Quarry	Grid Reference
East Laroch	Main quarries	NN085582
	Brecklet	NN085579
	Khartoum	NN084572
West Laroch	West Quarry	NN073582
	Middle Quarry	NN075582
Onich	North Ballachulish Quarries	NN049611

2.1.2 Topography

This is an area of dramatic Highland scenery with high mountains, divided by steep valleys. The high ground is dominated by Caledonian igneous rocks, culminating in peaks such as Ben Nevis to the north (1344m) and Sgorr Dhonuil (1001m) in the Ballachulish group to the south. Steep valleys dissect these mountains, the most significant of which is Loch Linnhe, a continuation of the Great Glen, a major valley traversing Scotland. The topography was later modified by glaciation, producing the spectacular landscape of the present day (Fig. 2.1).

Slate outcrops occupy relatively low ground, forming the grassy hills of Beinn na Gucaig (616m) and Meall nan Cleireach (535m) to the east of Loch Linnhe (Plate 12). Slate is also exposed on the west side of Gleann an Fhiodh.

2.2 Geology

The Ballachulish area is composed of metasedimentary rocks of the Appin Group (>650Ma) one of the lower stratigraphical levels of the Dalradian Supergroup (Gibbons & Harris 1994). The geological structure is characterised by recumbent isoclinal folds, facing NW (Bailey 1934, 1960, Bowes & Wright 1973). These rocks are cut by younger igneous intrusions such as the Ballachulish Granite and the Ben Nevis Granite (406Ma) and associated swarms of NNE trending dykes (Stephenson and Gould 1995).

2.2.1 Stratigraphy of the Appin Group

The Appin Group consists mainly of shelf sediments, made up of pelites, semipelites quartzites and calc-silicate rocks (Wright 1988). Marker horizons within the Dalradian outcrop can be matched over large distances from Connemara in the west of Ireland to Moray in the NE of Scotland. The group has been divided into three sub-groups: Lochaber, Ballachulish and Blair Atholl.

Group	Subgroup	Formation
Appin	Blair Atholl	Lismore Limestone
		Cuil Bay Slate
	Ballachulish	Appin Phyllite and Limestone
		Appin Quartzite
		Appin Transition Series
		Ballachulish Slate
		Ballachulish Limestone
	Lochaber	Leven Schist

Table 2.1 Stratigraphy of the Appin rocks of the Ballachulish area modified from Stephenson and Gould (1995)

2.2.1.1 The Ballachulish Subgroup

The subgroup is subdivided into several formations; the oldest being limestone followed by slate, which grades into the younger quartzite formation (Table 2.1). As the name suggests the type area of this subgroup is in the Ballachulish area.

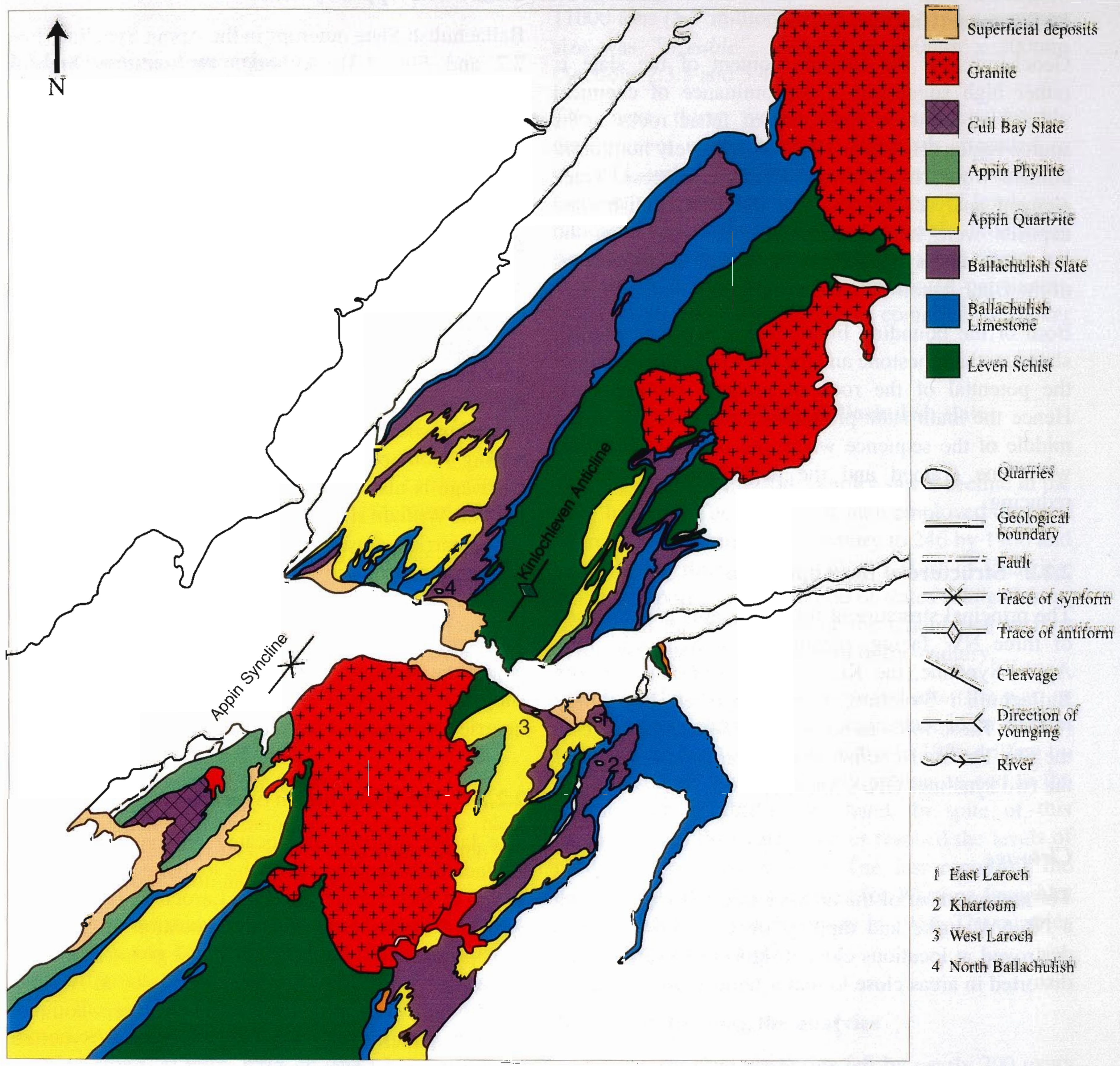


Fig. 2.2 Map of the Geology of the Ballachulish area, based on the BGS Sheet 53

2.2.1.2 Ballachulish Slate Formation

This formation is pyritiferous black slate, approximately 400m thick (Stephenson and Gould 1995). The lower part of the formation shows a transition from limestone to slate, which is made up of intercalations of dark grey carbonate and slate. The top of the slate formation shows a gradual change from slate to quartzite, with slate intercalated with psammite. Throughout the middle and upper parts of the sequence there are graded psammitic units (Hickman 1975).

2.2.1.3 Environment of deposition

The lower Ballachulish limestone was deposited in a fairly open marine environment, where there was little clastic sediment input. Starting within the limestone formation, there is a gradual change from cream coloured dolomite, to dark grey limestone and eventually to slate. This sequence represents an increase in water depth and as a consequence a change from oxidising to reducing conditions. Ballachulish slate is therefore rich in carbon and iron sulphide, reflecting this anaerobic condition. Graded bedding, observed with increasing frequency towards the top of the Ballachulish slate formation, indicates periodic influxes of distal turbidites in an otherwise stagnant environment (Hickman 1975).

Geochemically, the alumina content of the slate is rather high suggesting a predominance of chemical weathering products, probably of felsic rocks in its source region (Hickman 1975). A relatively hot humid climate would have favoured such a process. Trace element analyses suggest that the Ballachulish slate deposits were laid down in deeper water than the younger Cuil Bay slate deposits, one of the formations of the Blair Atholl Subgroup (Table 2.1).

Both of the bounding lithologies of the Ballachulish slate, i.e. the limestone and the turbidites, greatly affect the potential of the rock to produce roofing slate. Hence the main slate producing rock is found in the middle of the sequence where the original sediments were fine grained and the depositional conditions reducing.

2.2.2 Structure of the Appin area

The principal structure of the Appin area is comprised of three NW facing, recumbent isoclinal folds, the Appin Syncline, the Kinlochleven Anticline and the Ballachulish Syncline, first recognised by Bailey (1934). These folds trend NNE – SSW and plunge to the SE. The Ballachulish slate outcrops in the core of the two synclines (BGS Sheet 53).

Cleavage

Throughout most of the area, cleavage is regular, with a NE-SW strike and dipping steeply. However it is destroyed at locations close to igneous intrusions and distorted in areas close to major faults (called slides).

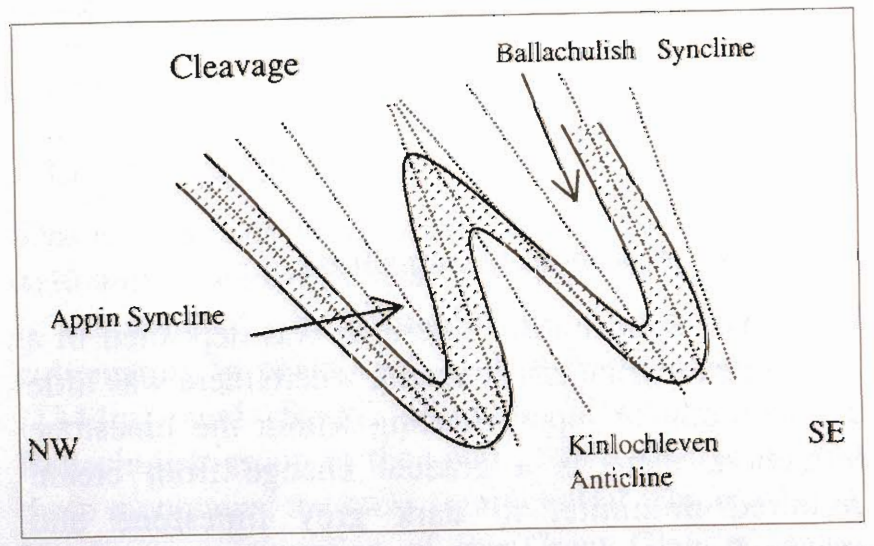


Fig. 2.3 Cartoon of a simplified cross section of the geological structure in the Ballachulish area.

2.2.2.1 The Appin Syncline

Ballachulish Slate outcrops in the Appin Syncline (Fig. 2.2 and Fig. 2.3). Although the western limb is attenuated by the Fort William slide, the outcrop is extensive. Slate is exposed on the north shores of Loch Leven and forms grassy hills extending for 12km to the north east towards Glen Nevis (Fig. 2.1).

Cleavage

To the north of the outcrop, cleavage is destroyed by the proximity of the Ben Nevis Granite Complex, e.g. the slate is brittle and spotted with the mineral cordierite (Bailey 1934). In the south of the outcrop, the slate is affected by the Ballachulish Granite Complex; here pyrites were converted to pyrrhotite during contact metamorphism (Neumann 1950). Cleavage is also distorted in the Onich area, close to the Fort William slide (NN015616). North Ballachulish slate quarries, close to the north side of the narrows at the entrance to Loch Leven are located in the eastern limb of the Appin Syncline (Location 4, Fig. 2.2).

The syncline continues to the south of Loch Leven, where the younger Cuil Bay slate of the Blair Atholl subgroup is exposed in its core at Cuil Bay. No slate quarries are reported from this locality (Table 2.1).

2.2.2.2 The Ballachulish Syncline

The larger quarries are located on the limbs of the Ballachulish Syncline along the southern shore of Loch Leven at West Laroch and East Laroch on the west and east limb respectively Fig. 2.2 Location 1, 2 and 3). This primary fold has been re-folded giving rise to the secondary Stob Ban Synform (Roberts & Treagus 1977). This has produced a much more complex outcrop pattern than that of the Appin Syncline. Similar to the Appin Syncline, the lower limb of the fold is attenuated by a thrust fault called the Ballachulish Slide.

The outcrop at West Laroch is less extensive than on the east limb, extending approximately 2km in a narrow band to the south. The outcrop at East Laroch extends for about 6km NNE-SSW along the east side of Glen Fhiodh. The cleavage at the southern end of the outcrop is destroyed by the effect of the Ballachulish igneous intrusion.

The Ballachulish slate is also found in the continuation of the syncline to the north of Loch Leven at Callert House. Here the slate has been crumpled due to its proximity to the Ballachulish Slide (Bailey & Maufe 1960).

2.3 History

2.3.1 Opening of quarries

According to Bremmer (1869), two slate quarries were opened in the Ballachulish area at the end of the 17th century; (West Quarry in 1693 and East Quarry in 1694). Assuming that this refers to West Laroch and East Laroch respectively, it agrees with McNicol's account (1790) which states that the first quarry to be opened was West Laroch on the farm of Laroch, property of Charles Stuart of Ballachulish. This quarry was worked for several years before the vein at East Laroch was found to have *"greater natural facilities for quarrying"*.

At this time there were *"74 families containing 322 souls"* employed in the quarries producing large amounts of slate and sending them to *"Leith, Clyde, England, Ireland and even America"* (McNicol 1790.).

Transport was by sea and Ballachulish had the advantage of a safe harbour where

"Vessels of any burden can load most commodiously in fine smooth sand so near to the shore that they may be loaded by throwing planks between the vessels and the shore." (McNicol 1790).

2.3.2 Development of the Quarries

A more detailed description is given in the New Statistical Account (McGregor 1845) from which the following information has been obtained.

At this time the main quarry at East Laroch was 65m (216ft) high and 163m (536ft) long. It was worked at three different levels; the second level 20m (66ft) above the first and the third 22m (74ft) above the second. All quarried rock was carried in a train of wagons along a tram road to the shore. Rubbish comprising nearly 85% of the quarried rock was dumped into the sea. To facilitate removal of the rubbish from the upper levels, an arch (Glaic an Tobair) was built in 1822 across the high road between the quarries and the sea (Fig. 2.4). Slate from the third level was taken down the slope by means of wagons on an inclined plane, to the same bank as the second level. At this time all levels were above sea level but quarrying at lower levels was being contemplated (McGregor 1845). Blocks of workable slate were transported to sheds on the banks of the loch, where they were split and dressed into the finished product.

Production in the 19th century

At the time of the New Statistical Account, 300 were employed, mostly local people living on the Ballachulish Estate (McGregor 1845). They worked in crews of 4-6 on annual contracts, earning on average 12/- (60p) per week. Production is recorded as 8000 - 11000 tons (5-7 million slates), and the most common size was *"sizeable"*, 14"x 8" or 350mm x 200mm (Sections 2.3.5 and 3.4.1).

The next thirty years showed a considerable development in the quarries. Railroads extended to over 11 miles and 4 stationary engines and one locomotive were employed. The number of levels was increased to include two below sea level. Production figures quoted in different sources are inconsistent, but at least 15 million slates were produced per annum (Mineral Statistics for 1882-88 as compiled by Tucker in 1977).

2.3.3 The Decline of the Ballachulish slate industry

The beginning of the 20th century saw a decline in the slate industry. The number of men employed dropped from 400 at the turn of the century to 246 by 1906 and to nil at the time of World War 1 (List of Quarries, Annual Report). Transportation of slates changed from sea to rail on the opening of the Crianlarich to Fort William railway line at the turn of the century.

The Ballachulish quarries re-opened after the war, as part of a co-operative system set in place in an attempt to revive the Scottish slate industry. In 1926 drilling by compressed air was introduced, putting an end to the tedious task of drilling by hand. In spite of this mechanisation the quarries never reached the levels of production of their heyday. The last report of the working quarries was compiled for Wartime Pamphlet No 40 by Richey and Anderson in 1944. The quarries finally shut down in1955.

2.3.4 Landscaping the quarries

The extensive slate waste tips left by nearly 200 years of quarrying, which had covered the shore and loomed above the houses, can be seen in old photographs of the area. The need to reclaim the land was addressed by the Scottish Development Agency and landscaping was carried out in 1978-79 at a cost of £1.3million (Richards *et al.* 1995). Tips were stabilised and cultivated. Excess waste was used to fill the flooded pits in the quarry floors and extend the foreshore. The East Laroch Quarry is now used for leisure pursuits, the foreshore has a hotel and small marina, while the West Laroch quarries are used by local industry (Plates 5 and 6).

2.3.5 Slate Dimensions from Historical Records

Historical sources emphasise the number or tonnage of slates produced. References to the size and thickness of the slates are rare.

Year	No of slates (millions)	No of men employed	Tons (thousands)	Reference
1790		300		McNicol
1837	3	200		Carmichael J
1845	5-7	300	8-11	McGregor
1888	15	400		Tucker
<1916			6	Bailey and Maufe
1937	4	180		HMSO
1951	1	20		Carmichael I

Table 2.2 The rise and fall of the Ballachulish Slate Industry

Year	Quarry	Company	Men employed
1905	Brecklet	Ballachulish Slate Co Ltd	41
	Ballachulish		421
1934	North and South Brecklet	Scottish Slate Ltd	24
1937	Ballachulish Nos 1 & 2	Ballachulish Slate Quarry	163

Table 2.3 Extracts from HMSO List of Quarries

Year	Size	Size inches	Metric mm	Reference
1845	Sizeable	14x 8	350 x 200	McGregor
	Undersized	10 x 6	250 x 150	NSA
1916	Countess	20 x 10	500 x 250	Bailey
	Full Sizes	120 sq. in	77,420 mm^2	
	Peggies	13 x 7	330 x 180	
1937	Sizeable and undersized in the ratio of 5:3			HMSO

Table 2.4 Sizes of Ballachulish Slates

Size

Standardisation of slate sizes was introduced by Warburton, at Penrhyn, North Wales in 1738 using the so called *"Female Nobility"* sizes (Richards 1995). The system was adopted throughout the rest of North Wales and England but was never really adopted in Scotland. This was partly due to smaller slates being produced in Scotland. Slates were often referred to as *"sizeable"*, *"undersized"* and *"peggies"*, but the dimensions to which these terms referred varied from one slate area to another. The sizes of slates in Scotland continued to be random and there are only occasional references to the Warburton system, e.g. Bailey refers to *"countesses"* being produced in Ballachulish in 1916 (Table 2.5). Prejudice against Scottish slates often hinged on their random sizes.

The size of slates produced by Ballachulish quarries were predominantly *"sizeables"* 14" x 8" (350mm x 200mm) and *"undersized"* 10" x 6" (250mm x 150mm) (Table 2.4).

Thickness

The thickness of Ballachulish slates is estimated as 6-9mm from Bailey's description of the technique used to split the slate (Bailey and Maufe 1916).

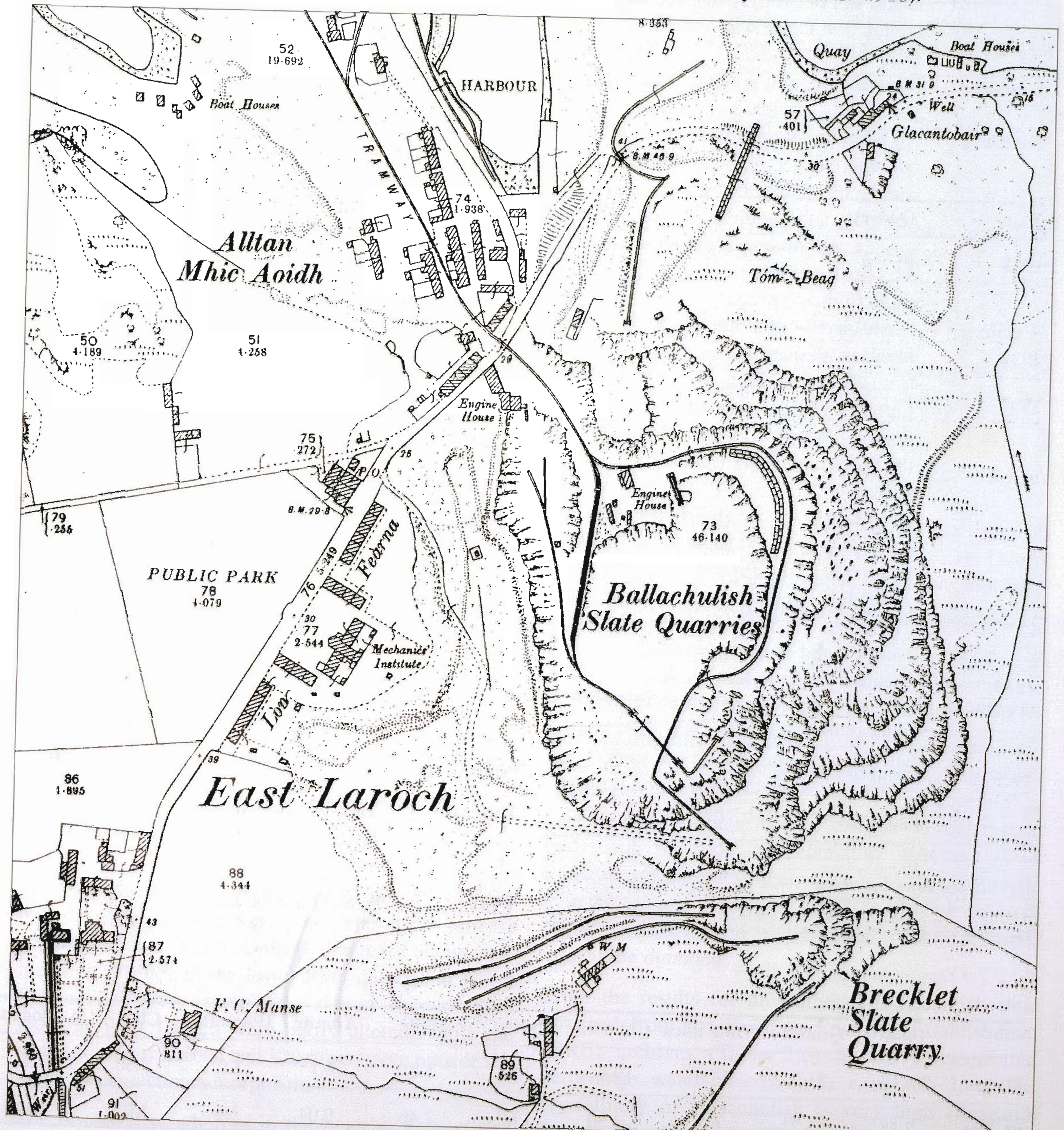


Fig. 2.4 Map of East Laroch and Brecklet Quarries in the O.S. revised edition 1898

2.4 Description of Ballachulish Slate (Plate 55)

2.4.1 Hand Specimen

Colour	Dark blue-grey to almost black where associated with graphitic layers.
Grain Size	Generally fine-grained with occasional siltier bands.
Cleavage	Fine-grained samples have a smooth cleavage surface. In coarser grained samples the surface, although rough, is still flat or even. A fine secondary crenulation fabric was noted in some samples.
Lineation	Mineral lineation is faintly visible in almost all samples.
Bedding	No bedding features in most samples but where observed it is defined by a change of colour or of grain size, generally sub-parallel to the cleavage surface. At some locations, such as the upper galleries, it is at a high angle to the cleavage.
Pyrite	Pyrites/pyrrhotite minerals were found in all quarries, varying in size from<1mm to 24mm. Those in East Laroch and Khartoum show slight rusting (oxidation) where exposed on the surface but little leaching can be seen. West Laroch pyrites/pyrrhotite were rusty in colour and some leaching had occurred. Pyrites/pyrrhotite in the lower level quarries at North Ballachulish were completely rusted through and in many case had weathered out to leave holes.
Weathering	As well as the deterioration of pyrites, yellow brown staining was seen in all quarries along cleavage and joint surfaces. Mineralisation along joints is common, e.g. by quartz and sometimes pyrites.

2.4.2 Mineralogy of Ballachulish slate

The mineralogy was determined by examination of thin sections, XRF and XRD analyses (see Research Report, Section 2).

Major minerals

The major minerals present in Ballachulish slate are quartz white mica and chlorite.

Estimates of the relative amounts of major minerals were determined (see Appendix 1). Average values are shown in Table 2.5

Formulae

Formulae of chlorite and white mica of a sample from East Laroch (EL-10) were determined by electron microprobe analysis and used as a standard for all of the Ballachulish samples.

Chlorite
EL-10 $Fe_{1.85}Mn_{0.01}Mg_{2.58}Al_{2.81}Si_{2.66}O_{10}(OH)_8$

White mica
EL-10 $Na_{0.13}K_{0.81}Fe_{0.07}Mg_{0.15}Ti_{0.02}Al_{2.67}Si_{3.14}O_{10}(OH)_2$

Minor minerals

The minor minerals present are:

Pyrite/Pyrrhotite (See Section 2.4.3)

Feldspar	Plagioclase (Albite from XRD scans).
Carbonate	Dolomite
Amphibole	Trace amounts of amphibole (probably actinolite) mineral were found in XRD scans agreeing with observations made by Hickman (1975). This mineral could well be diagnostic of Ballachulish roofing slate and used as a provenance indicator.
Apatite	
Ilmenite	Trace amounts of TiO_2 are found in all slates, which is probably present as ilmenite
Clay	Trace amounts detected

	Total	Quartz	White mica	Chlorite	Pyrite	Albite	Apatite	Dolomite	Clay	Un-allocated
Mean	96.17	31.0	33.6	19.6	3.9	5.8	0.1	1.0	4.30	0.5
St. Dev.	2.18	5.21	6.23	4.50	1.62	2.46	0.04	2.4	3.0	1.1

Table 2.5 Average mineral composition of Ballachulish Slate. *Note: Dolomite is concentrated in some samples and not dispersed throughout.*

	BRE Ref	% Water Absorption		Wet and Dry		Acid Immersion Test		Acid Vapour
Ballachulish Unknown quarry	E1694	0.23	0.17	1/3	No affect	Pass	0/3	3/3
West Laroch West Quarry	E1695	0.22	0.23	1/3	3/3	2/3	2/3	
East Laroch Main Quarry	E1696	0.27	0.30	3/3	3/3	1/3	3/3	
East Laroch Main Quarry	E1697	0.25	0.25	1/3	3/3	2/3	2/3	
East Laroch West Quarry	E1698	0.27	0.20	3/3	3/3	3/3	3/3	

Table 2.6 Ballachulish Slate tested according to BS680 in 1944 (Source: Building Research Establishment (BRE) Archives). Water absorption test was done in duplicate; other tests results show the number of passes out of three runs.

Cyrstallinity

The crystallinity of Ballachulish is classified as "very high" (Section 1.3.3).

2.4.3 Weathering

Chemical weathering is caused by the reaction of minerals such a pyrite and carbonates in the presence of water and catalysed by graphite, where present.

2.4.3.1 Pyrite/Pyrrhotite

Pyrite is present in Ballachulish slate both as amorphous material disseminated throughout the sample and as crystallised cubes called "diamonds" by the quarriers.

Neumann (1950) studied the pyrite in the Ballachulish area and found that slate in the quarries close to the Ballachulish Igneous Complex was altered. In these quarries, crystalline cubes of pyrite were changed to a mass of haphazardly orientated crystals of pyrrhotite with an irregular outline:

$$\mathbf{FeS_2 \rightarrow FeS + S}$$

These pyrrhotites were easily weathered and then fell out to leave large holes. This alteration process occurred up to 2.5km from the perimeter of the igneous intrusion. Pyrites in the lower level quarries at North Ballachulish were completely altered to pyrrhotite; those at West Laroch were partly altered, while the quarries at East Laroch and Khartoum were outside the range of contact metamorphism.

The observed weathering in the quarries agrees with the Neumann Report i.e. there was serious weathering associated with the presence of pyrrhotite and slight staining associated with the presence of pyrite (Plate 9).

Reduced Iron / Total Iron Fe^{2+}/Fe_{total}

Fe^{2+}/Fe_{total} was determined by wet chemistry analyses to be 89%; this is typical of a slate with pyrite and graphite.

2.4.3.2 Carbonates

Carbonates are found in many of the Ballachulish slates as small lens of dolomite (Hall 1982). This is confirmed by XRD scans of those samples examined in detail in this Research. Dolomite, is a carbonate that is considerable more stable than calcite.

2.4.3.3 Durability of Ballachulish Slate

The deleterious minerals, pyrite, carbonate and graphite, are all found in Ballachulish slate. This would suggest that Ballachulish slate is susceptible to weathering (Research Report, Chapter 5) which is at odds with its excellent reputation. However these minerals are present in their inert form, e.g. carbonate is in the form of dolomite which is the least reactive of the carbonates, and pyrites are found as inert crystalline *diamonds*.

From the results for unweathered Ballachulish slate obtained from the Building Research Establishment (BRE) archives (Table 2.6) it can be seen that percentage water absorption is extremely low. The crystallinity of Ballachulish is very high (Research Report Section 3.4). These two parameters are important criteria in determining the resistance of slate to chemical weathering. Added to this, the Ballachulish Slate has a high quartz content making it a very hard material which is highly durable.

2.4.4 Fabric

Samples were collected from the tips and worked faces from different areas of the quarries. Thin sections were prepared parallel and at right angles to the cleavage surface and the fabric examined. This is found to be comprised of straight and continuous cleavage domains rich in white micas separated by elongated microlithons rich in quartz. In addition the fabric of these samples, were examined using the scanning electron microscope. The fabrics were compared with those of slate from producing quarries and allocated a value according to a points scheme developed for the purpose (Research Report Section 4.3.2). The following comments on the fabric of Ballachulish slate are based on a fairly small number of samples. For a truer picture of the range of fabrics found in a quarry a much larger selection of samples should be studied.

Shape of Cleavage Domains

The cleavage domains are straight and continuous.

Spacing of Cleavage Domains

At East Laroch and West Laroch the spacing is 20µm on average. At Khartoum the spacing is 40 µm

Microlithons They have a well developed fabric due to the alignment of mineral grains.

Alignment The degree of alignment is high, averaging at approximately 50%.

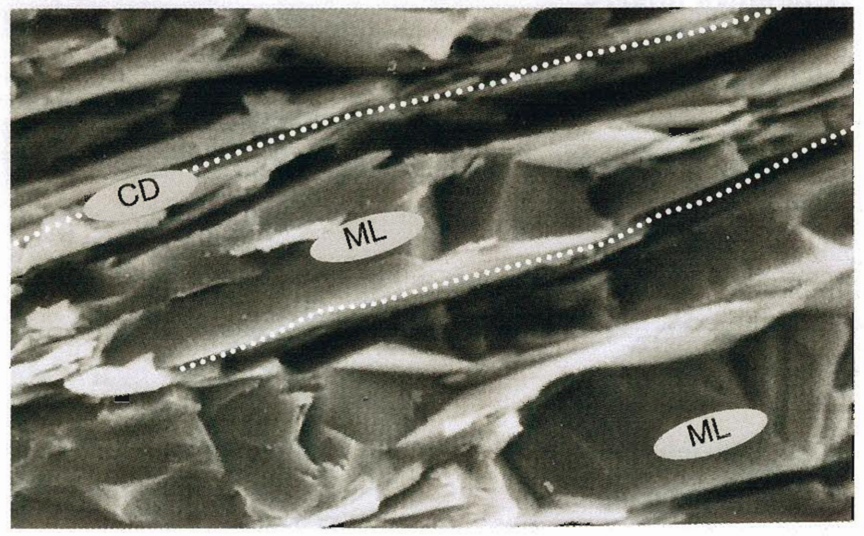
Quarry	FPS values	Commercial thickness (mm)
East Laroch	11-14	5.5
Khartoum	7-10	7.0
West Laroch	11-12	5.6

Table 2.7 Estimated thickness of slate from Ballachulish quarries.

Comment

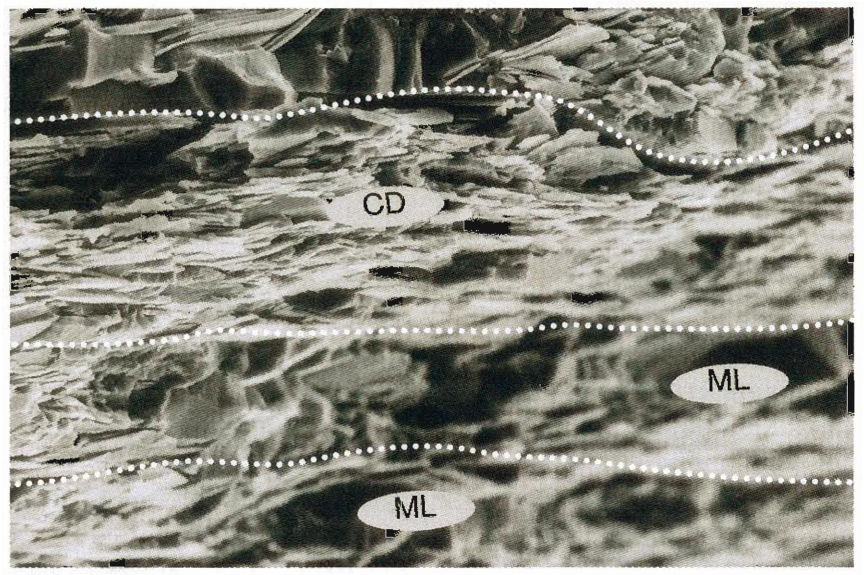
When these point scheme values are correlated to samples of Welsh and Cumbrian slate from producing quarries it is found that Ballachulish slate can be split from 4 to 8mm (Research Report, Chapter 4). The values given in Table 2.7 are averages.

According to Bailey's description (1916) of the quarriers' splitting technique a block of slate 1 – 1½ in. thick was split into four slabs. This equates to a final thickness of 6-9mm.



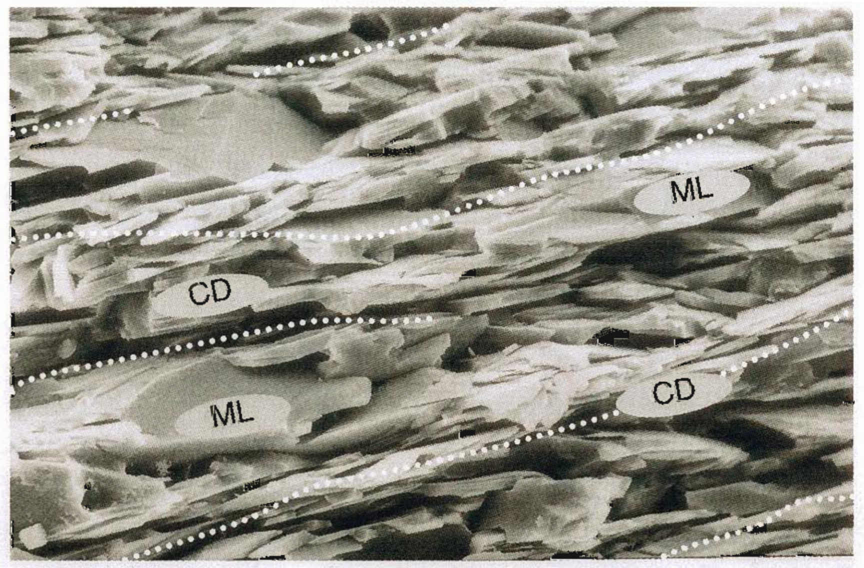
a) EAST LAROCH QUARRY EL-3 20.0µm

Finely spaced straight and continuous cleavage domains give this slate the potential to be split to 6mm



b) KHARTOUM QUARRY K-3 50.0µm

Widely spaced slightly anastomosing cleavage domains limit the potential minimum thickness from 7-8mm. Note the smaller scale



c) WEST LAROCH MIDDLE QUARRY WL-1 20.0µm

Finely spaced straight and continuous cleavage domains give this slate the potential to be split to approximately 5.5mm

Fig. 2.5 Fabric of Ballachulish slate

2.5 Quarry Appraisals

2.5.1 EAST LAROCH NN085582
(Fig. 2.2, Location 1, Fig. 2.5a, Fig. 2.4, Fig. 2.6 and Plates 1, 2 & 3)

Plate 1 East Laroch – view to the north of the quarry

Plate 2 East Laroch – view to the south of the quarry

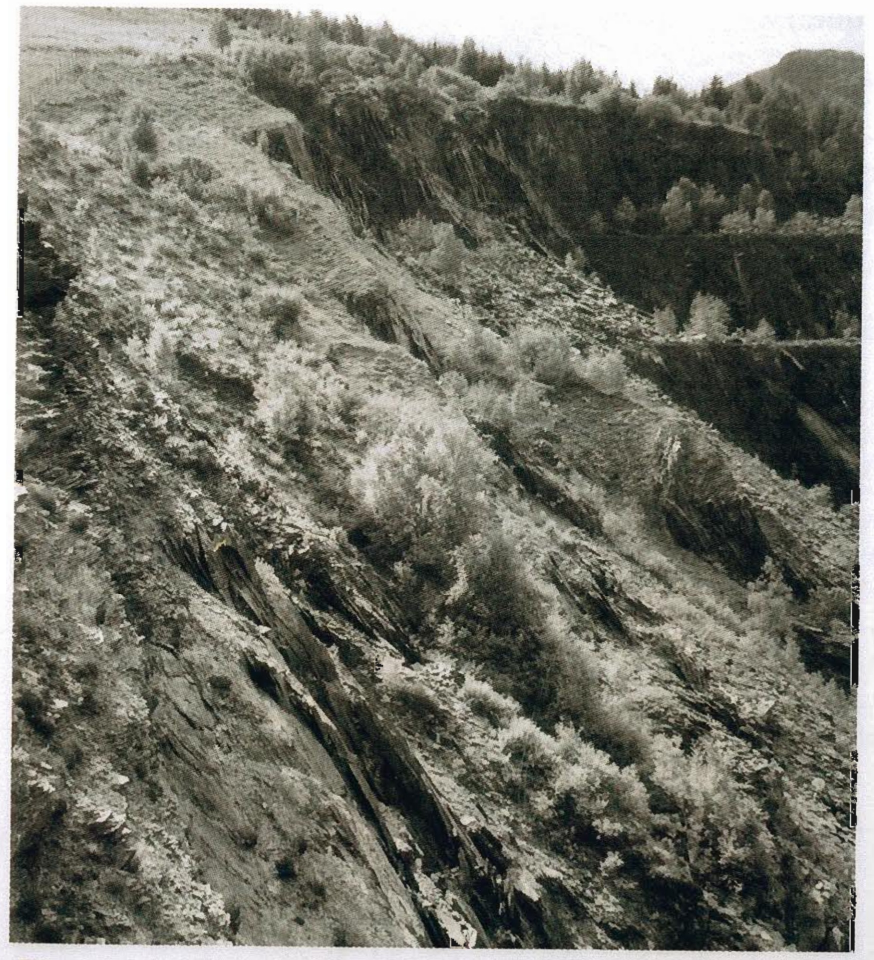


Plate 3 East Laroch – view of the landside to the SE of the quarry

2.5.1.1	**Site Details**
Location	East end of the village of East Laroch. The present workings are 400m N-S and 250m E-W from NN083580 to NN086584. The height of the quarry is 100m at the highest point. (Plates 1 & 2).
Access	Entrance from street 100m from the A82.
Ownership	Originally owned by the Ballachulish Estate now owned by Highland Council.

2.5.1.2	**Quarry Details**
Slate	Dark grey, medium grained with faint mineral lineation.
Cleavage	140°/60° in the NE of quarry to 160°/70° in the S. In general the cleavage surface is smooth but diffraction occurs locally, caused by change in the composition of the rock.
Joints	Irregular jointing was observed everywhere in the quarry but fairly widely spaced at approximately 2-3m intervals. There is a set of joints 044°/38° estimated at 2m intervals. These joints peter out at some locations and give way to kink bands.
Imperfections	Pyrites minerals are ubiquitous, varying in size; the modal size is estimated as 5-6mm. They are often rusty in colour and clustered in some locations while absent in others. Quartz veins are found in some areas of the quarry, sometimes parallel to cleavage and also cross cutting cleavage.
Weathering	As well as the pyrites rusting described above, there is some staining along the pillaring and cleavage surfaces.

2.5.1.3 Workings

The quarry was worked at seven levels or galleries, five above the present floor and two below. The lower levels or sinkings are now flooded, but the remains of the upper five galleries can be seen. On the NE side there are three levels still clearly visible, each approximately 30 m high (Plate 1). Here the slate is cut by an igneous dyke and contains numerous quartz veins (Fig. 2.6). Further south the second level has been worked back until little trace of it is left. The east of the quarry is dominated by a large rock fall. According to Richey

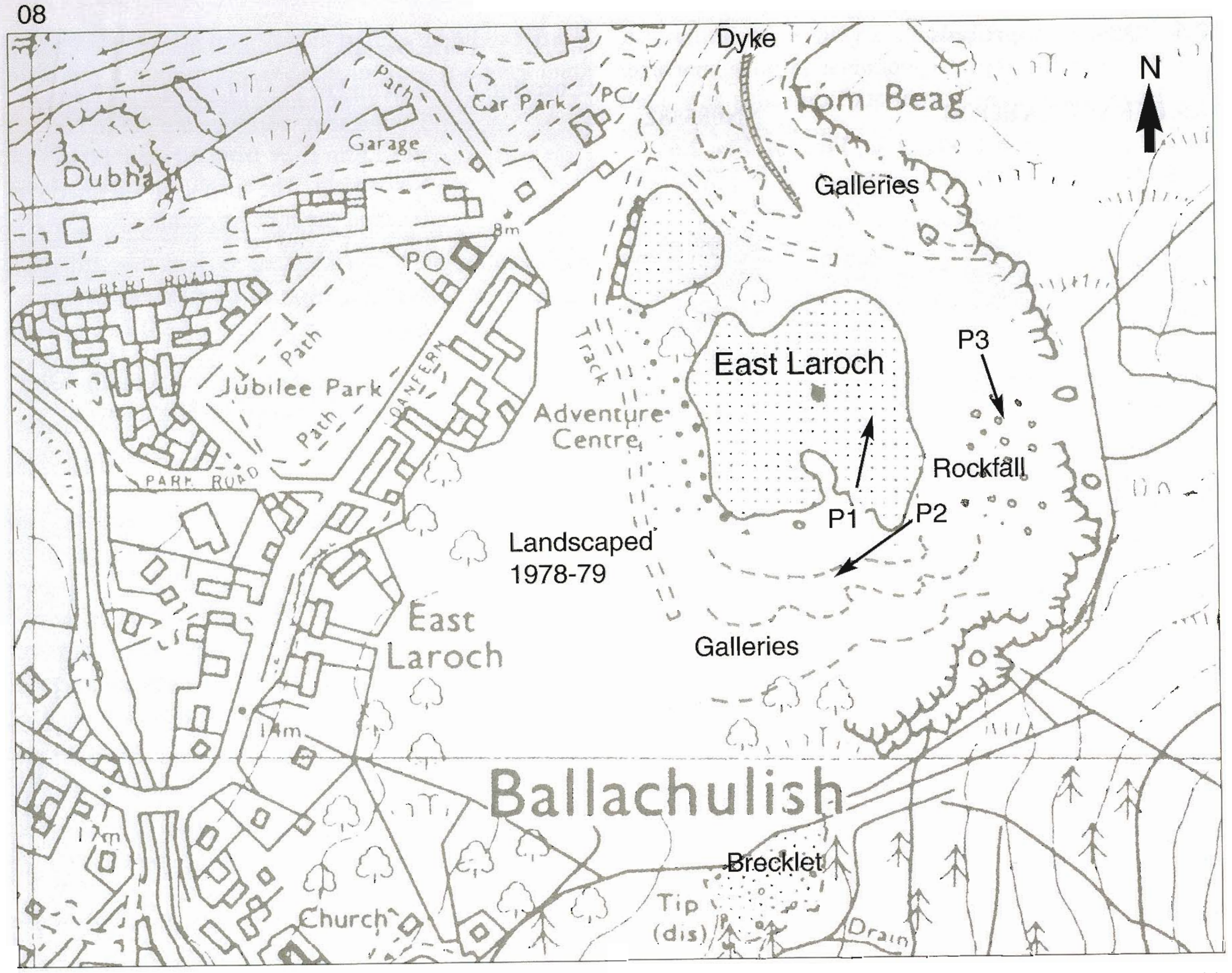


Fig. 2.6 Map of East Laroch Quarry based on OS NN05NE copyright 1990 *1:5,000*

and Anderson (1944), this slide began early in the 20th century and many subsequent slips had occurred at the time of their report. The line of weakness extends 10m outside of the rim of the quarry and is marked by a fissure running parallel to the rim of the quarry. Five galleries remain at the south end of the quarry (Plate 2).

According to Richey and Anderson (1944) there were five seams of *"especially good quality slate"*. It is no longer possible to distinguish these seams but remnants can be seen on the southern galleries, where zones of good slate are separated by zones rich in quartz veins running sub-parallel to cleavage. (These seams are highlighted by the shadows in Plate 2).

2.5.1.4 Resources

There is still a plentiful resource in the present confines of the quarry. *Limited* resources are available to the NE of the quarry (Section 1.4) and there are also *limited* resources at the south end of the quarry. More extensive development would require extending the quarry to the SE and would have to address the problem of the landslide. *Large* resources continue to the south and east of the present workings

Brecklet quarry is immediately to the south of this quarry.

2.5.2 BRECKLET QUARRY NN085579 (Fig. 2.4 and Fig. 2.6)

This quarry was located just outside of the rim of the main Ballachulish Quarry. Already defunct for nearly 40 years at the time of Richey and Anderson report in 1944, they described the quarry as follows; *"The quarry was worked in two main levels. The lower is at present largely filled with debris and water. The upper level is narrow, and the top rock is locally bent and broken to a depth of 10ft. Near the eastern end of this bench the slate rock includes some limy and sandy bands and is of poor quality"*. Today this quarry has been filled in and is completely overgrown, so that little evidence of the working remains. Most of the tips have been incorporated in the landscaping scheme of 1978/79

Resources: as for East Laroch.

2.5.3 KHARTOUM QUARRY NN084572 (Fig. 2.1, Location 2, Fig. 2.5b, Fig. 2.7 and Plate 4)

Plate 4 Khartoum Quarry – East face (NN084572)

2.5.3.1 Site Details

Location	On the east bank of Gleann an Fhiodh
Access	From the south end of East Laroch 700m from the A82 a single track road leads to the entrance to the forest and continues as a forest track to within a 100m of the entrance to the quarry. Apart from the last 100m this track is well maintained due to the presence of a reservoir near the quarry.
Ownership	Khartoum is on Brecklet Farm, part of the Glencoe Estate. The farm was sold in the 1960s to the Forestry Commission.

2.5.3.2 Quarry Details

Slate	Dark grey medium grained with mineral lineation
Cleavage	220°/68° regular cleavage with a smooth, medium grained surface.
Joints	Irregular joints and one set of joints at 045°/5-10° at 2m intervals
Imperfections	Pyrite minerals are ubiquitous.
Weathering	Slight discoloration of the pyrites and iron staining.

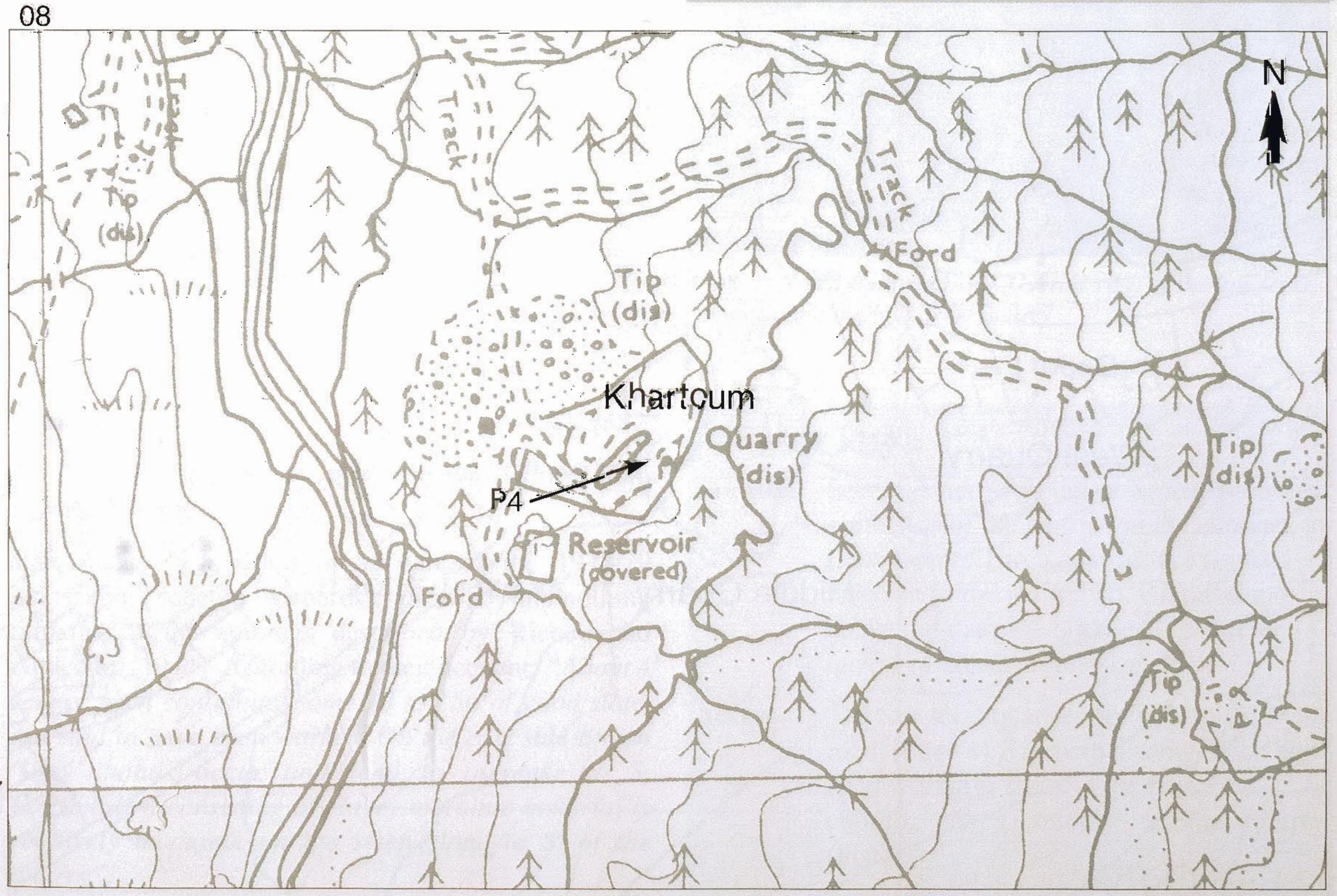


Fig. 2.7 Map of Khartoum Quarry based on OS NN05NE copyright 1990 *1:5,000*

2.5.3.3 Workings

The quarry was worked along the strike of the cleavage for a distance of approximately 50m by 5m wide except at the SE end where the workings are 10m wide (Plate 4). The entrance is at the SW end of the quarry. It was worked at two levels, the upper level is 10-15m high, the lower level is now flooded. On the eastside of the quarry there are quartz veins running sub-parallel to, and destroying the cleavage.

2.5.3.4 Resources

The present quarry could be expanded by working to a greater depth as the *"sinking"* was estimated as only 6m (20ft) deep by Richey and Anderson (1944). Expansion of the quarry along strike of cleavage in both directions should be possible in spite of heavy overburden in the NE. Only *limited* resources exist to the SW as the ground falls away towards a stream. It should also be possible to extend the quarry across strike to the east although Richey and Anderson (1944) mention limy bands 30m away.

Good quality slate, good cleavage, durable pyrites and suitable jointing all point to Khartoum as a suitable quarry for further investigation.

Large deposits of slate continue into the hillside and there are several trial holes marked on the OS map. According to the Wartime Pamphlet No 40 (Richey and Anderson 1944) the slate is similar to that in the main quarry and exploitation should be possible. Much prospecting would be needed to locate suitable seams within the slate outcrop and this is not seen as a viable option for immediate development.

2.5.4 WEST LAROCH NN073582 & NN075582

(Fig. 2.1, Location 3, Fig. 2.5c, Fig. 2.8 and Plates 5 and 6)

Plate 5 West Laroch - West Quarry now a roads depot (NN073582)

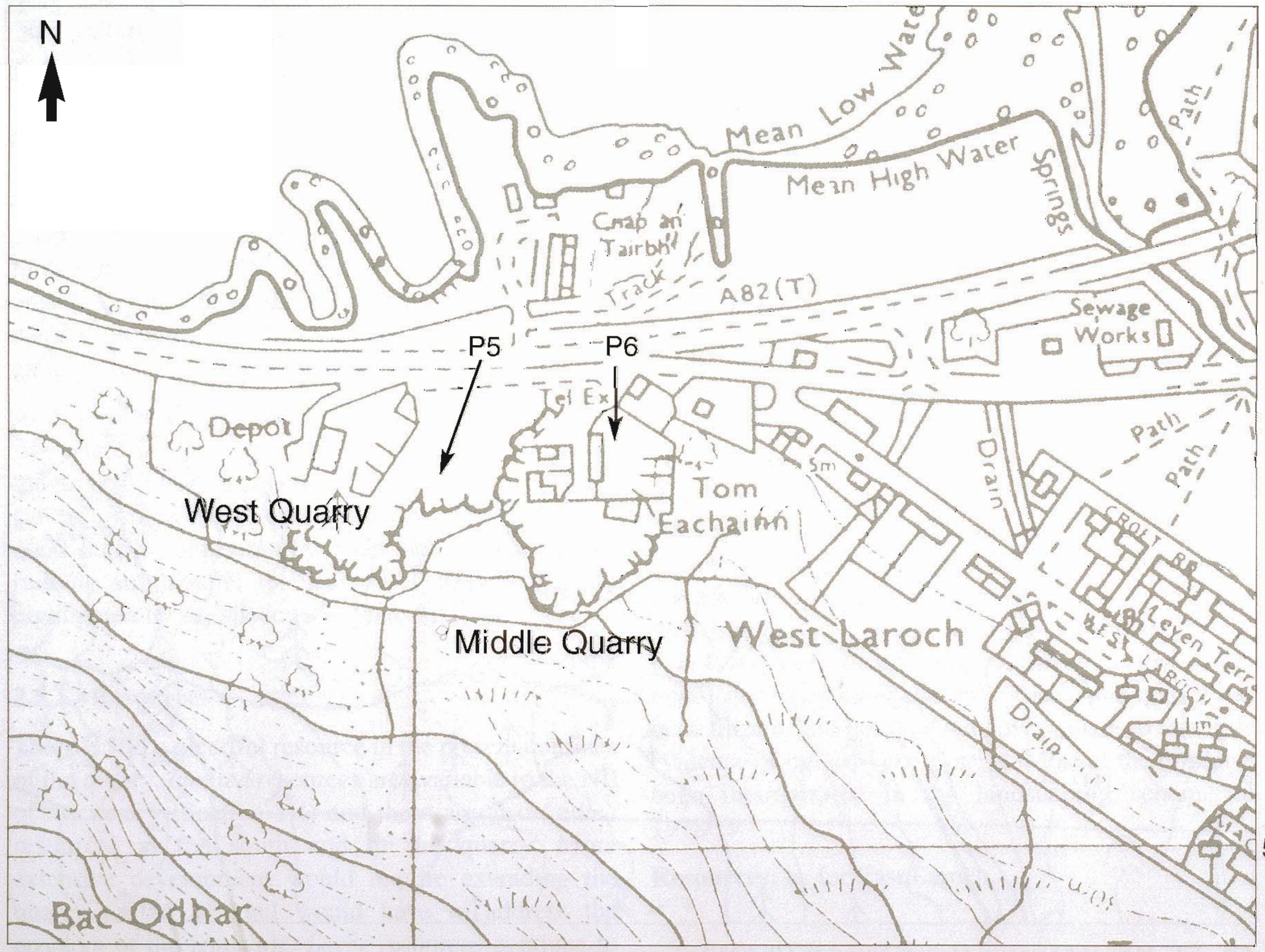


Fig. 2.8 Map of West Laroch Quarries based on OS NN05NE copyright 1990 1:5000

Plate 6 West Laroch -Middle Quarry now used by local businesses (NN075582)

2.5.4.1 Site details

Location	There are two quarries in West Laroch; West Quarry and Middle Quarry, cut into the steep slopes of Beinn Bhan.
Access	Close to the main road.
Ownership	Originally owned by the Ballachulish Estate now owned by Highland Council

2.5.4.2 Quarry Details

Slate	Dark grey colour, fine-medium grained slate
Cleavage	020°/80°. The cleavage surfaces are even.
Joints	Irregular jointing was observed but no organised set of joints.
Imperfections	Pyrites/pyrrhotite show considerable rusting.

2.5.4.3 Workings

West Quarry **NN073582**

An area of 100m EW by 100m NS was worked 40m into the hillside.

This quarry was filled in as part of the 1978/79 landscaping scheme (Richards *et al.* 1995) and nothing remains of the sinkings described by Richey and Anderson (1944). According to their account: *"About 4 seams, each containing some 10 to 15ft of good slate, are said to have been worked. On the east side brown 'limy' bands occur and tend to increase to S. Overburden, consisting of clayey morainic material is relatively moderate on the steep slope to S. of the quarry".*

Middle Quarry **NN075582**

A considerable proportion of the workings were under water at the time of the Wartime Pamphlet and have now been completely filled in. Towering above the present day floor is a face over 30m high (Plate 6).

"Two major seams totalling around 30ft (10m) are said to have been worked. Near the centre of the face there is a 3ft (1m) dyke of dark whinstone". (Richey & Anderson 1944)

2.5.4.4 Resources

Large resources exist to the south. According to Richey and Anderson (1944), there were considerable problems in working the steep slope and keeping the face free of water in the winter.

2.5.5 NORTH BALLACHULISH NN049611

(Fig. 2.1, Location 4, Fig. 2.9 and Plates 7-12)

Plate 7 North Ballachulish – Overall view of the low level quarries and the high level quarry

2.5.5.1 Site Details

Location	Several small workings are located on the north side of the narrows at the entrance to Loch Leven. Three quarries are situated adjacent to the main road. On the slope above the roadside quarries is a further quarry of considerable size (Plate 7).
Access	The low level quarries are next to the main road. (Plate 8). The path leading to the high level workings starts at the back of the church, rising steeply to the quarry (Plate 7).

2.5.5.2 Quarry Details

Low level quarries

Slate	Dark grey surface with an even texture.
Cleavage	038°/70°-80°. The cleavage surfaces are undulating in places.
Joints	Two sets of joints were observed, one pitching at 45° to the NE on the cleavage surface and the other at 10° to the SW also on the cleavage surface (125°/30°, 325°/40°).
Imperfections	Large pyrrhotites (pseudomorphs of pyrite Neumann 1950) are up to 40mm in length.
Weathering	A particularly concentration at the west end of the quarry, these pyrrhotite mineral grains have weathered out leaving large holes. Intense rusting is found in the centre of the quarry. Pyrite mineralisation occurs along the pillaring surfaces and joints (Plate 9).

High Quarry

Slate	Dark grey, fine to medium grained.
Cleavage	040°/58° Surface is smooth with smooth cleavage surfaces.
Joints	Large fallen slabs have probably broken along former joint planes.
Imperfections	Pyrite grains are 1-2mm in size and brown in colour.
Weathering	Some limonite staining along the cleavage and pillaring faces.

Plate 8 North Ballachulish – West Quarry

2.5.5.3 Workings

West Quarry NN04966110

A seam of slate about 5-10m wide was worked for 40m but narrowed to the north This seam was worked 20m high into the hillside. At the west end of the quarry the pyrites/pyrrhotites are particularly large and have fallen out leaving large holes. At the eastside of the quarry there is a concentration of quartz veins which have distorted the cleavage (Plates 8 and 9).

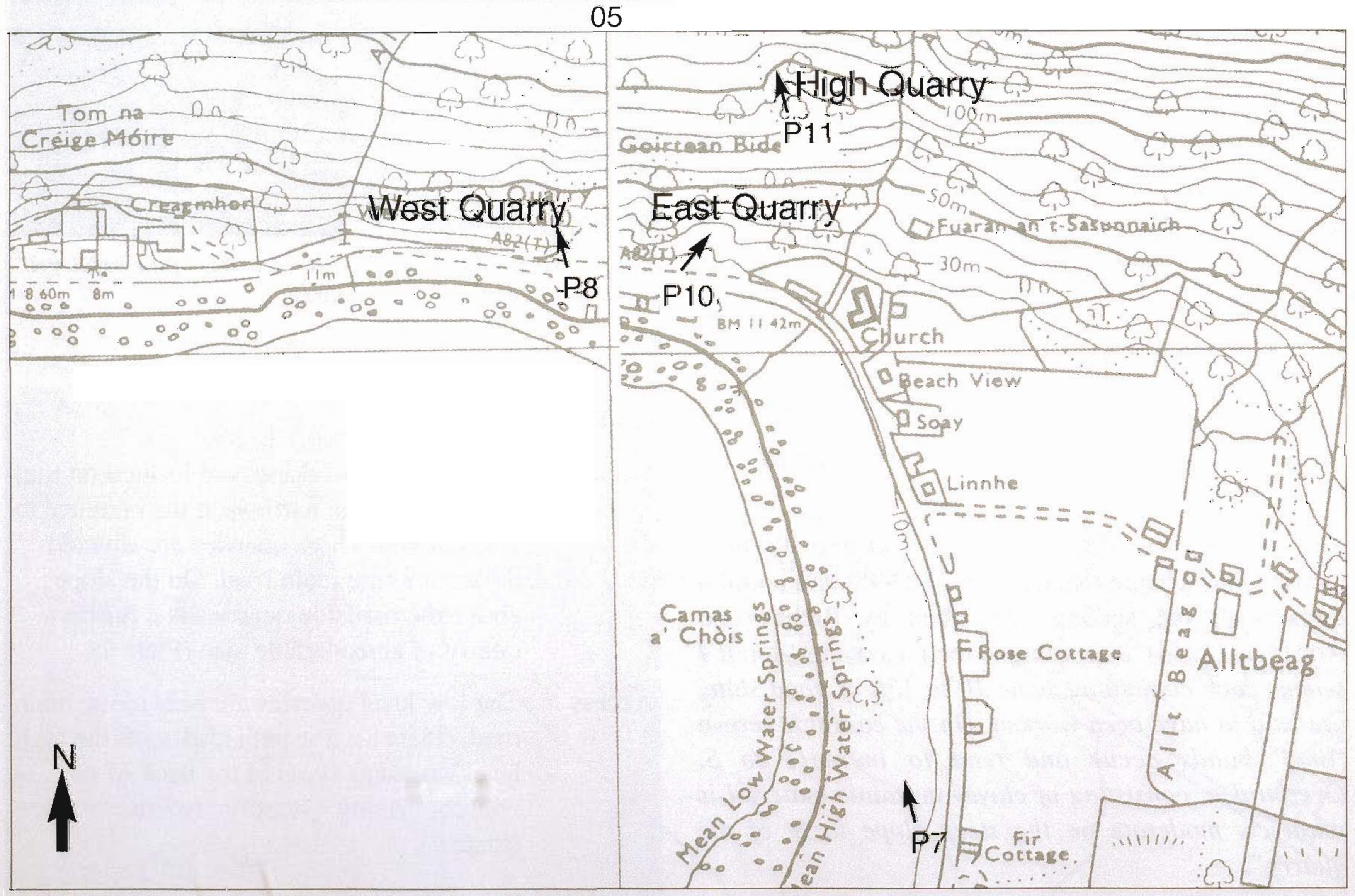


Fig. 2.9 Map of North Ballachulish Quarries based on OS NN05NE & NW copyright 1975 & 1974. *1:5000*

Plate 9 North Ballachulish – West Quarry showing the intense weathering of the pyrrhotites

Middle Quarry NN05026110

Immediately to the east of the previous quarry is an opening 5-10m wide filled with debris and densely overgrown.

East Quarry NN05076110

The next quarry to the east is estimated as 15m high and 12m wide. The remains of two galleries can be seen but the quarry is overgrown and no measurements were made (Plate10).

High Quarry NN05156125

The quarry was worked along a narrow band (approximately 5m wide) rising steeply up the hillside along the channel of a stream. Although the quarry is very overgrown, it is still possible to make out the remnants of two or more galleries (Plate 11).

2.5.5.4 Resources

These quarries are part of a large outcrop of slate folded by the Appin Syncline, with largely untouched resources stretching to the north for several kilometres (Fig. 2.2 and Plate 12). Access to the resources to the north via Alt an Amair and Alt Coire Uainean Moir was investigated (Fig 2.1). Bands of slate intercalated with limestone were found at low levels, and it was not until a height of 450m was reached in Coire Leathann at the head of Alt an Amair, that pure slate was found. A small opening to a slate mine was found in Coire Uainean Mor at NN068664 but the extent to which it was worked into the hillside was not investigated. Overburden, although absent at the top of the hills, was very thick at the lower levels. According to Richey and Anderson (1944) overburden is also "heavy" at Blairmachfoldach. The upper reaches of Abhain Righ flow through the slate belt but this area was not checked for suitable outcrop. Development of the *very large* slate resources in this area is limited by the difficult access due to the height of the outcrop and the lack of roads.

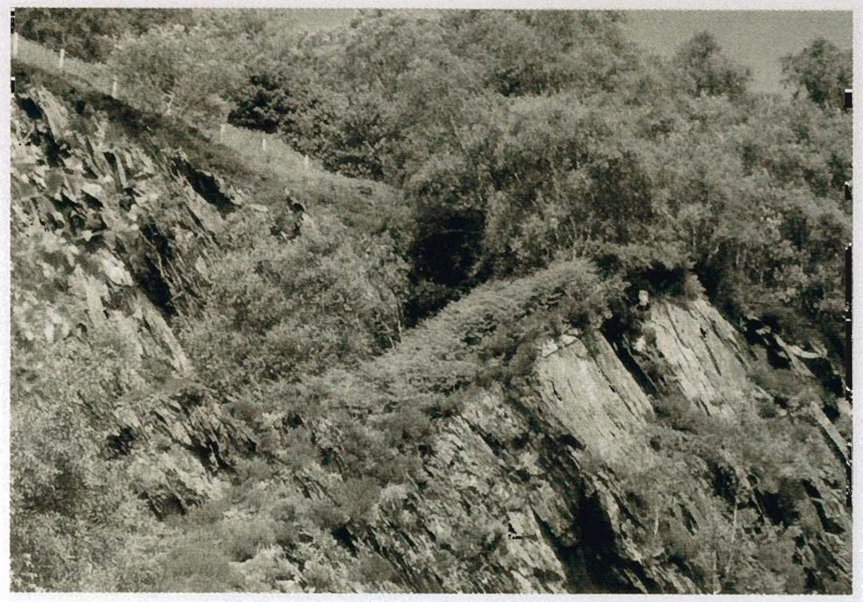


Plate 10 North Ballachulish – East Quarry showing remains of two gallaries

Plate 11 North Ballachulish – High Quarry is very overgrown

Plate 12 View of the hills to the north of Ballachulish - Beinn na Gucaig and Meall nan Cleireach

2.6 Summary

The best Scottish slate is found at Ballachulish, and there are sufficient resources for further exploitation. However there are many factors to consider when selecting a quarry for further investigation. Individual quarries have their limitations in terms of their access and proximity to centres of population.

2.6.1 EAST LAROCH

Resources *Medium.* For small-scale development, there are limited resources within the present confines of the quarry. For large- scale development the problem of the large rockfall in the SE, which has limited exploitation in the past, would have to be addressed.

Weathering Good

Access Excellent

Environmental Sensitivity

This quarry has been landscaped and is now in the centre of a tourist area used for leisure activities.

2.6.2 KHARTOUM

Resources *Medium* resources within the confines of the quarry.

Weathering Good.

Access Reasonable road and track for small scale development.

Environmental Sensitivity

The site is on Forestry Commission land and away from the main tourist attractions. However, large-scale development would be conspicuous in an area much used for hill walking. The access road is narrow and passes through the village of East Laroch.

2.6.3 WEST LAROCH QUARRIES

Resources *Large* slate deposit continues south up the steep hill behind the two quarries, but the steepness of the slope and the increasing overburden to the south make exploitation difficult.

Weathering Poor – medium.

Access Good.

Environmental Sensitivity

Close to the village and now being used as an industrial site (a roads depot, bus depot and other businesses).

2.6.4 NORTH BALLACHULISH

Resources *Very large* resources stretch many kilometres to the north of the quarries.

Weathering In the low-level quarries pyrites have been altered to pyrrhotite and have weathered badly, staining the rock in the process. Where the pyrrhotite has fallen out, large holes have been left. The high-level quarries are outside the range of this alteration (Neumann 1950) and have a less serious weathering problem.

Access Access to the low-level quarries is good; that to the high level is by a steep, poorly defined path.

Environmental sensitivity

The low-level quarries are close to hotels in an area of outstanding natural beauty. The high level quarry is less conspicuous, while the resources to the north are remote from all habitation.

2.7 Conclusion

The Ballachulish quarry proposed for further investigation is Khartoum for the following reasons:

Mineralogy: The mineralogy of the slate is good. There is a high quartz content and the ratio of white mica to chlorite is high. The iron ore mineral is pyrite but it is present as recrystallised cubes which show only superficial rusting. There is however some clay present in those samples analysed.

Crystallinity: The crystallinity of the slate is very high as measured by the intensity of XRD peaks and FWHM of between 0.12 and 0.14 2θ.

Size of slates: The cleavage is smooth and regular and would produce flat slates. However the slate is coarser grained than at other Ballachulish quarries and the potential commercial thickness, estimated at 7mm, is greater than the average for the area. Jointing is widely spaced; one set of organised joints spaced at 2m intervals, which pitch at a low angle relative to cleavage surface would place little constraint on the size on the slates.

Recovery: The proportion of the reserves that is usable slate is estimated as high. Wastage due to the presence of quartz veins would be localised while the slate in the accessible part of the quarry face is fairly homogeneous.

3 THE SLATE ISLANDS

3.1 Introduction

The Slate Islands comprise the islands of Easdale, Luing, Seil and Belnahua on the west coast of Argyll (Fig. 3.1). It was on Easdale, the smallest of these islands, that the Scottish slate industry first began. Its quarries produced more slates than other Scottish quarries until surpassed by Ballachulish in the 1860s. As the demand for slate grew in the 19th century, new quarries were opened on Seil, Luing and Belnahua, but Easdale continued to be the best known of the islands and its name is used as the general term for all the slates produced in the area. In this Report, the description 'Easdale' should be taken as referring to the whole group; the description 'Easdale Island' is used to refer to that island specifically.

Easdale Slates were transported by sea around the north coast of Scotland to all the major towns on the east coast and through the Crinan Canal to Glasgow and other centres on the west coast

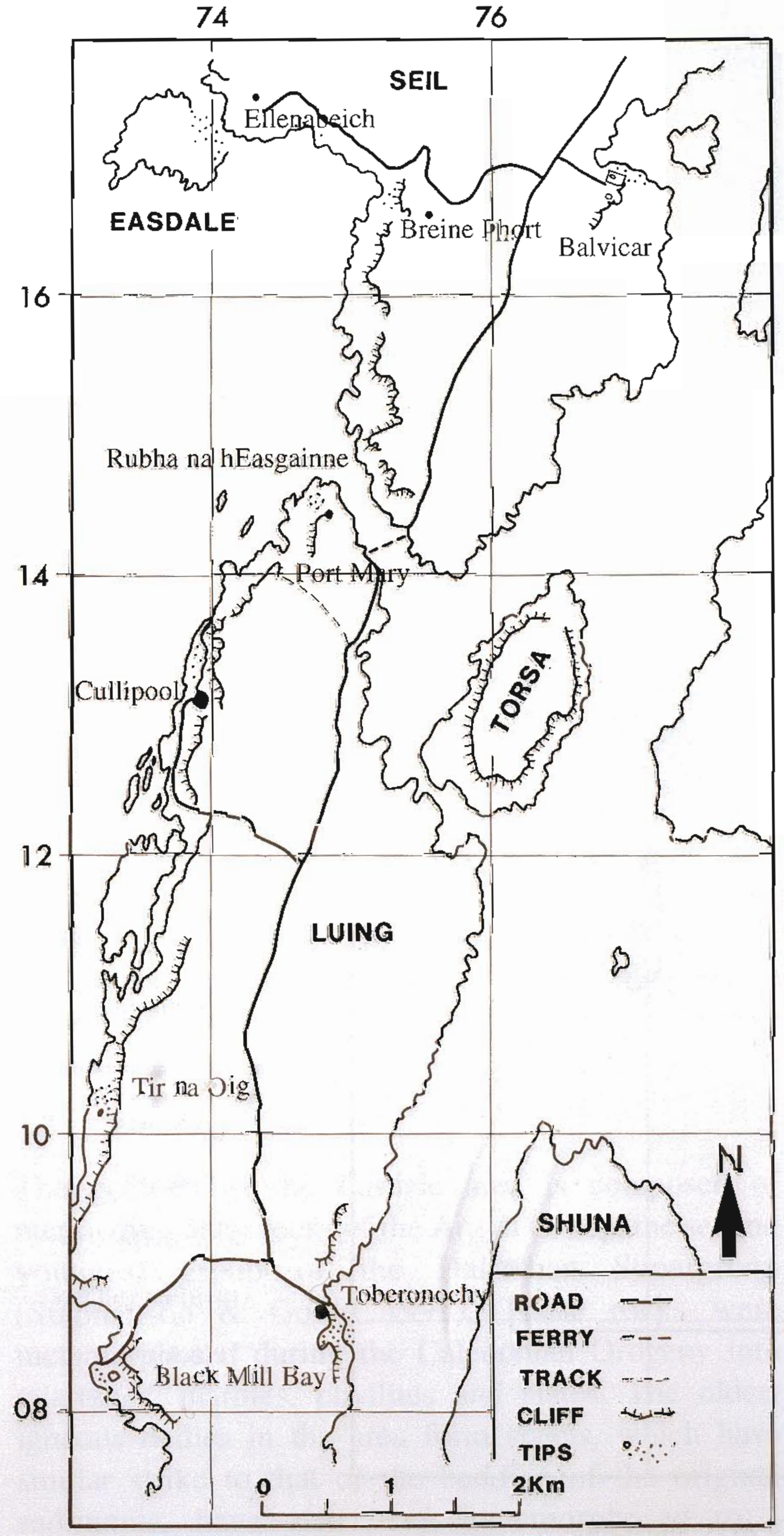


Fig 3.1 Map showing the location of the quarries of the Slate Islands.

3.1.1 Location

The slate islands are located on the east side of the Firth of Lorn, 30km SW of Oban They include the islands of Easdale, Seil, Luing and Belnahua.

Maps OS 1:50000 Landranger Series Sheet 55

1:10000 NM71 NW, NE, SW

1:10000 NM 70 NW,

BGS 1:50000 Sheet 36

The following slate quarries are described below (Fig. 3.1 and Fig. 3.2):

Location	Quarry Group	Grid Reference
Easdale Island	Easdale	NM735169 to NM740174
Seil Island	Ellenabeich	NM742172 & NM744174
	Breine Phort	NM754166
	Balvicar	NM766164 to NM769168
Luing Island	Toberonochy	NM749085
	Rubha na hEasgainne	NM748145
	Port Mary	NM745141
	Cullipool	NM739129 to NM742138
	Tir na Oig	NM733103
	Black Mill Bay	NM732082
Belnahua Island	Belnahua	NM714128 (Fig. 3.2 only)

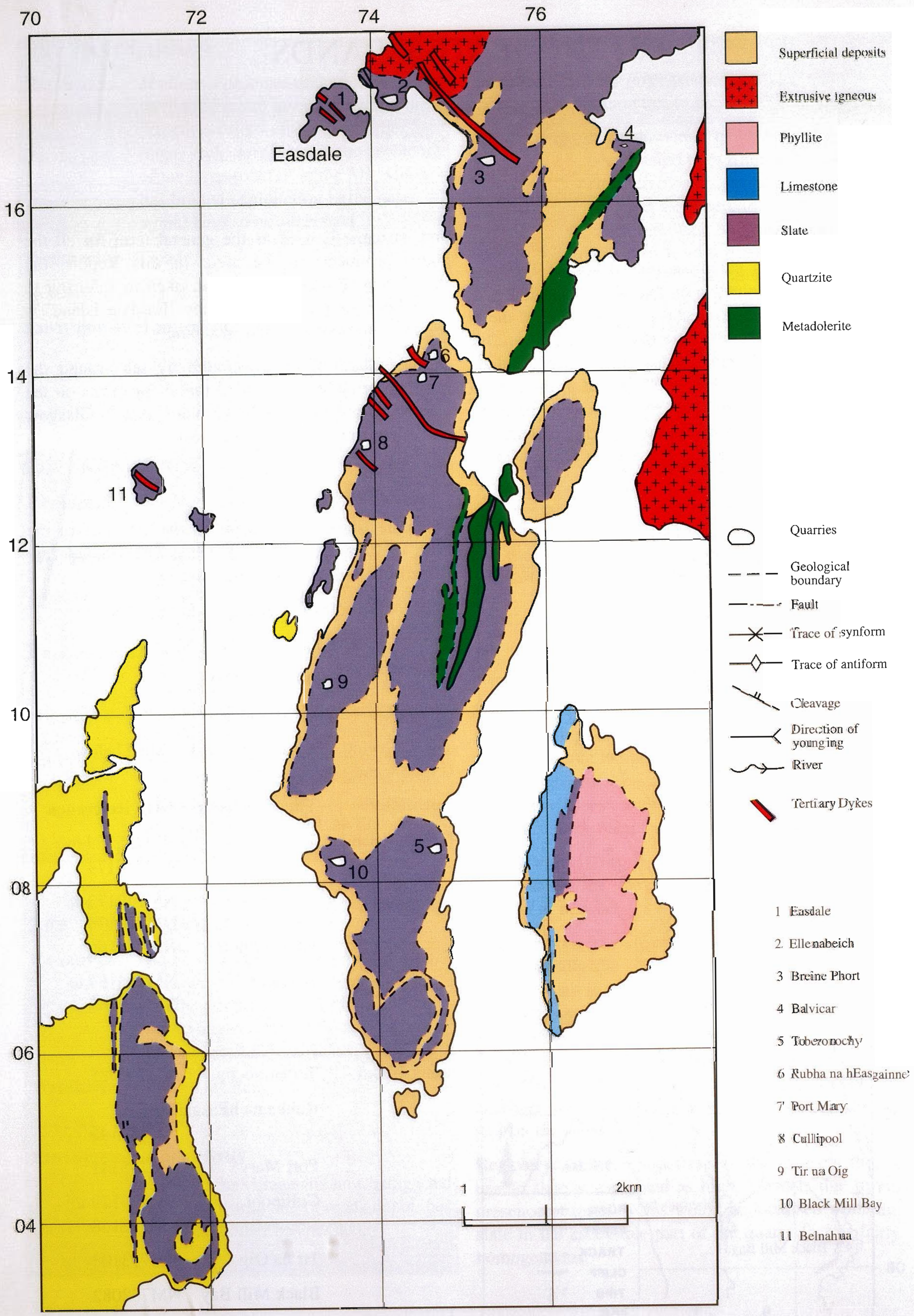


Fig. 3.2 Map showing the geology of the Slate Islands based on BGS Sheet 36

Group	Subgroup	Formation
Argyll	Tayvallich	Tayvallich Slate and Limestone
	Crinan	Crinan Grit
	Easdale	Shira Limestone and slate
		Craignish Phyllite
		Degnish Limestone
		Easdale Slate
	Islay	Quartzite

Table 3.1 Stratigraphy of the Argyll rocks of the Easdale area modified from Stephenson and Gould (1995).

3.1.2 Topography

The topography of the slate islands is low lying, with only a few hills reaching 50m or more. The level of the sea relative to the land varied at different times in their geological history, leaving behind the relics of former coastlines. The raised beaches found on most of the islands are examples of such morphology, the most continuous of which, backed by former sea cliffs, stretches along the west coast of Luing and parts of Seil. These cliffs provided a good face to start slate extraction and are the location of several slate quarries, while the raised beach was a useful platform for transporting the slates. The most striking geographical features in the area are due to igneous dykes, which cut across the slate in a NW-SE direction forming narrow ridges up to 20m high. More recent changes to the topography have been caused by slate quarrying itself; islands have been joined by waste tips, and in one case the sea has reworked the tips to form a lagoon at Ellenabeich (Fig. 3.7).

3.2 Geology

The geology of the Easdale area is composed of metasedimentary rocks of the Argyll Group, the second youngest group of the Dalradian Supergroup (Stephenson & Gould 1995). These rocks were metamorphosed during the Caledonian Orogeny into quartzites, marbles, phyllites and slates. The oldest igneous bodies in the area form sheets, which have similar strike to that of the bedding of the original sediments, have also been metamorphosed to a metadolerite or hornblende schist (BGS sheet 36). Such sills, striking NE-SW, are found at some quarries. During Old Red Sandstone (ORS) times, volcanic rock, (the Lorn Lavas), was extruded over the large areas, however most of the igneous intrusions affecting the slate area are dykes of Tertiary age and have a NW-SE trend radiating from the igneous centre on Mull. Extensive glaciation took place during the Pleistocene Epoch (Fig. 3.2).

3.2.1 Stratigraphy of the Argyll Group

The Argyll Group is subdivided into four subgroups (Table 3.1) the oldest of which is the Islay Subgroup. This comprised of thick beds of quartzite-shallow water shelf deposits. The Islay Subgroup is overlain by the Easdale Subgroup. The base of this subgroup marks an abrupt change to deeper water deposits with occasional inputs of coarser grained material.

3.2.1.1 The Easdale Subgroup

The Easdale slate is black carbonaceous pyritic slate with occasional distal turbidites of poorly graded sandstone and dolomitic beds. The slate formation is superseded by Degnish Limestone.

a) Environment of deposition

The abrupt change from coarse-grained quartzites to the fine-grained slate indicates a rapid change to deep water sedimentation probably due to subsidence of the basin floor. Sediments were probably deposited in a series of fault-controlled marginal basins with a NE-SW trend (Anderton 1985,1988). Occasional input of turbidites become more frequent up the sequence as this basin began to fill up, giving way gradually to limestone.

3.2.2 Structure of the Easdale Area

The major structure of the Western Highlands area is the Islay Anticline, one of the NW facing folds to the north of the Loch Awe Syncline, first identified by Bailey in 1916. This has been correlated with the Kinlochleven Anticline of the Ballachulish area (Section 2.2.2), recognised as a primary fold by Roberts and Treagus (1977). The Easdale slate quarries are located on the common limb of the Islay Anticline and the Loch Awe Syncline. Associated with these large scale primary folds is the dominant slaty cleavage of the area which strikes NNE and dips approximately 45° to the ESE.

Cleavage is generally striking NNE, dipping 30°-50° and the grain is generally pitching at approximately 90° on the cleavage.

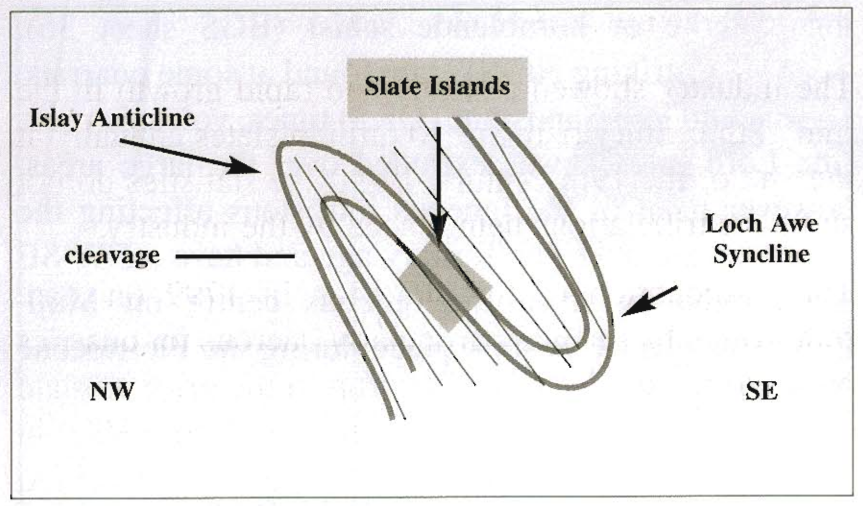


Fig. 3.3 Cartoon showing the relationship between stratigraphy of the Slate Islands and the major folds of the west of Scotland.

Minor folds of variable size are conspicuous throughout the area and have an immediate effect on the extraction of slate. These folds are open, inclined, or occasionally overturned, with axial planes dipping to the east and plunging gently to the south (Fig. 3.3 Plate 23).

Crenulation cleavage

Regionally the intensity of later deformations decreases to the NW away from the Loch Awe Syncline, however it can be seen in the Easdale area as a secondary fabric where the slaty cleavage has been crenulated into microfolds called crenulation cleavage, (formerly called strain-slip). This crenulation fabric is very common in Easdale slate giving the surface an attractive corrugated effect (Plate 15). This was called the grain of the slate but is quite different from the true grain of a slate, which is due to the alignment of minerals. This *crenulation cleavage* pitches at angle from 0° to 45° on the cleavage surface, the actual pitch being typical of a particular area. This fact was used by the splitters to ensure cleaving the slate down cleavage-dip (Peach *et al.* 1909).

Distortion of Cleavage

The cleavage is distorted by many factors:-

• Changes in lithology causing the cleavage to be refracted. (Plate 13)

• In the hinges of folds, cleavage and bedding are at a high angle and splitting occurs along both bedding and cleavage planes giving a flaky or pencil cleavage. (Plate 14)

• Undulation of cleavage observed (Plate 21)

• In proximity to Tertiary dykes the cleavage is lost.

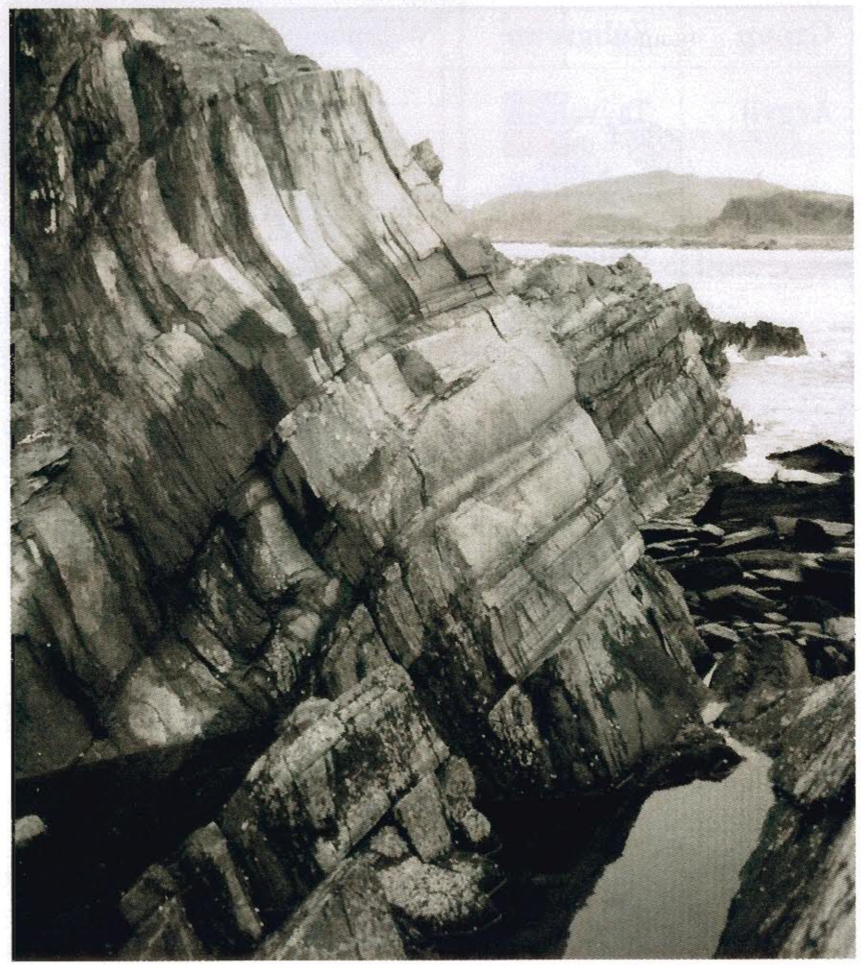


Plate 13 Refraction of cleavage due to different lithologies. The colour banding was called ribboning by the quarry men

Plate 14 Destruction of cleavage at the axis of folds

3.2.3 Effect of Geology on the Slate Quarries

The geology of the area has had a direct effect on the development of the slate quarries.

• When the sea cliffs were being carved, erosion was halted by a band of hard rock, rich in quartz veins. As a result several quarries had to break through this band of useless slate and quarrying was carried out on the landward side of the cliffs.

• While the major folding of the area produced the regular cleavage, local distortion is caused by changes in lithology and medium and minor scale folding as described above. Using the Gaelic names given by the

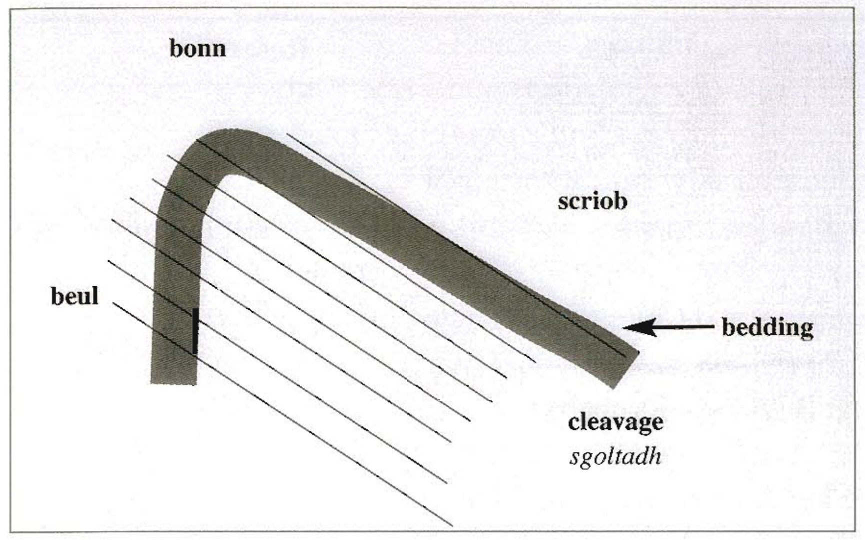


Fig. 3.4 Diagram of minor folding in the Easdale area showing the Gaelic terms used for the different parts of a fold by the quarriers i.e. where bedding and cleavage are sub parallel was called the "scriob", where the beds are horizontal was called the "bonn" and where the beds are vertical was called the "beul".

quarriers to the different parts of the fold (Fig. 3.4) larger slates were produced from the *scriob* where bedding and cleavage are sub-parallel than on the *beul* where bedding and cleavage are at a high angle.

3.3 History

It is not known when slate quarrying started at Easdale but there is an early report of a cargo of slates being sent to St Andrews in 1168 (Oban Times 1893). Glasgow Cathedral, founded in 1197, is said to be roofed with Easdale slate (Oban Times 1893). Another claimant to being the oldest slate producer is the island of Belnahua, where slate was discovered by the Norwegians in the 12th century. A few centuries later (1697) Ardmaddy Castle was also re-roofed with Easdale slate (Easdale Slate Co. 1909).

3.3.1 Opening of the quarries

Reliable records began in 1745 when the Marble and Slate Co. of Netherlorn was set up by a partnership, one of whom was the Earl of Breadalbane (Scottish Record Office 1745-70). At first 8 crews were working on Easdale Island producing a million slates a year, then in 1751 the number of crews increased when production started in Ellenabeich and Cullipool. A few years later (Black) Mill Bay gets a mention but from then on the quarries of Luing were grouped together. The earliest record of Balvicar is in 1799 when there was a problem with unsold slate due to a prejudice against them in Glasgow.

3.3.2 Development of the Quarries

The industry showed a steady and rapid growth in the mid 18th century rising to 10 million slates annually at the end of the 19th century. But these statistics do not show the tribulations being faced by the industry.

The introduction of the slate tax in 1799 on slate transported by sea was particularly onerous for quarries on these remote islands. The drop in the price of slate during the 1840s caused profits to drop from £8000 in 1841 to £25 in 1845. In 1862 when the fifth Earl died there was a long dispute over the succession and individual quarries were sold to different owners (Tucker 1976).

Natural disasters also threatened the survival of the quarries. In 1879, on the night of the Tay Bridge disaster, Belnahua was swept by exceptionally high tides, flooding the quarries and destroying houses and piers etc. Another storm a few years later on 22nd November 1881 caused severe damage on Easdale and Ellenabeich, flooding the quarries and destroying buildings. Piers were swept away and boats lost but, most damaging of all, the seawall at Ellenabeich was breached putting 240 men out of work (MacIntyre 1951).

3.3.3 The decline of the slate quarries

In the 20th century all the quarries faced the common problems of the industry, namely competition from imported slate and artificial roofing materials. From the HMS List of Quarries annual returns it is possible to trace the decline in the industry. From 1896 to 1906 the quarries of Balvicar, Belnahua, Toberonochy and Cullipool were owned by J & A McLean, who went bankrupt in 1906, although production continued on a smaller scale in the various quarries under individual proprietors.

For the same period the Easdale Slate Co. employed approximately 100 men but production ceased when the company went bankrupt in 1911, although two men continued to work Klondyke on Easdale (Table 3.5) between the wars. No production was reported for the remaining quarry at Ellenabeich, part of the Easdale group. At this time Port Mary, employing about 25 men, was owned by A MacColl, but he also went bankrupt about 1911. Production in all the quarries ceased during World War 1 and in the case of Belnahua the stoppage was permanent. In 1915, loss of manpower and shortage of shipping led to the island being evacuated.

The quarries in operation at the time of the 1937 returns were Balvicar, Toberonochy, Cullipool and Tir na Oig as well as some small scale operations. Again all production ceased at the time of World War 2 and

Year	1000s	Crews	New Quarries	Reference
1745	499	8		SRO
1750	1105	8		SRO
1751	1674	14.5	Ellenabeich and Cullipool +2 others	SRO
1766	1638	15	Luing, Belnahua, Kilchattan	SRO
1770	2708	33	More but unspecified	SRO
1792-1802	4-5 million			SRO
1838	7 million			SRO
1843	7-8 million			McPherson
1853-1859	10 million			Hunt

Table 3.2 The increase in the annual production of slates during the 18th and 19th centuries

for some this was permanent. Only Cullipool and Balvicar were re-opened in 1947 when the Scottish Slate Co. Ltd. was set up, producing 300,000 and 500,000 slates p.a. respectively (MacIntyre 1951).

Following the introduction of a ferry service from Luing to Seil, slates were transported by road.

The final demise of the industry came when the last two quarries closed in 1966 although some individual men continued on a small scale for several years after that.

Plate 15 Easdale slate showing the crenulation cleavage. Pyrites show little deterioration after more than 50 years of weathering

3.4 Description of Easdale Slate (Plates 56-59)

3.4.1 Hand Specimen

Slate	Blue-grey to black in colour depending on the amount of carbon.
Grain Size	Medium grained, finer grained at Balvicar and Toberonochy.
Cleavage	Flat but rough, crenulation fabric is common, crossing the surface at a low angle of pitch. This was called the grain of the slate which often obscures the true grain of the slate. There is a slight sheen in some samples.
Bedding	Bedding features are common in the quarries of Luing and Belnahua.
Pyrites	Pyrites are ubiquitous ranging in size from <1mm to 10mm
Weathering	The degree of weathering is variable. Most pyrites have weathered surfaces, some show leaching and in badly weathered samples the pyrite has weathered out leaving a hole. Water penetration along cleavage planes causes brown staining of the rock. This varies from quarry to quarry.
Size	The most common sizes produced were *"full sized"* and *"undersized"*.

According to Peach's account (1909) the former was on average 115 square inches (74200mm^2) and never less than 7" x 12" (180mm x 300mm). It can be inferred from this that undersized were less than 7" x 12". See 2.3.5 for a comparison with the size of slates produced in the Ballachulish quarries. Balvicar and Toberonochy had a reputation for producing larger sizes. In the late 1930s a quarry at Cuan Ferry was making extra large slates for the restoration of Iona Cathedral (Richey & Anderson 1944). (This quarry is now a caravan site).

3.4.2 Mineralogy of Easdale slate

The mineralogy was determined by examination of thin sections, XRF and XRD analyses (Research Report, Section 2).

Major minerals

The major minerals present in Easdale slate are:

Quartz	The quartz content is moderately high at 25% weight.
White Mica	Illite and occasionally paragonite. Paragonite is present in the all slates analysed from Easdale Island, one of the Belnahua samples and in addition it was present in the slate from the village hall in Toberonochy but not those from the quarry.
Chlorite	The chlorite / white mica ratio is low
Feldspar	Albite. XRD and XRF analyses indicate that the feldspar is albite.
Carbonate	Dolomite is the typical carbonate found in Easdale slate, magnesite is present in Toberonochy and Balvicar slates. Trace amounts of siderite are present in some samples.

Formulae

Two samples, one from Breine Phort (SB-6) and one from Port Mary (LP-5) were selected to determine the formulae of the white mica (illite) and chlorite by electron microprobe analysis. The formulae were then used as a basis to determine the mineralogy of slate for all the quarries in the area. (Appendix 1).

Chlorite

SB-6	$Fe_{1.97}Mn_{0.01}Mg_{2.18}Al_{2.84}Si_{2.78}O_{10}(OH)_8$
LP-5	$Fe_{1.91}Mn_{0.03}Mg_{2.66}Al_{2.76}Si_{2.63}O_{10}(OH)_8$

White Mica (Illite)

SB-6	$Na_{0.13}K_{0.63}Fe_{0.12}Mg_{0.17}Al_{2.60}Si_{3.20}O_{10}(OH)_2$
LP-5	$Na_{0.13}K_{0.68}Fe_{0.08}Mg_{0.14}Al_{2.640}Si_{3.20}O_{10}(OH)_2$

Minor minerals

The minor minerals present:

Clay	
Pyrite	Pyrite porphyroblasts are present, varying in density and size from one quarry to another and even within individual seams of a quarry. The larger pyrite porphyroblasts postdate the development of cleavage. Fine-grained pyrite minerals also occur as pockets along the cleavage domains and are often fractured and spongy. In some slates, pyrrhotite is found as inclusions within the pyrite. When present in large porphyroblasts of pyrite, pyrrhotite is protected from weathering but when present in spongy pyrite it is easily weathered to limonite (Hall 1988).
Apatite	Trace amount of apatite is present in most slates
Ilmenite	Trace amounts of TiO_2 are found in all slates which is probably present as ilmenite
Graphite	Graphite is present in varying amounts found, often concentrated in individual seams.

Crystallinity

The crystallinity of Easdale slate is classified as high (See Section 1.3.3)

Reduced Iron/Total Iron	SB-6 66%
Fe^{2+}/Fe_{total}	SB-7 52%
	LP-5 66%

The reduced iron content is lower than that expected for graphitic pyritic slates e.g. the value for a Ballachulish slate is 89% (Section 2.4.3.1).

Based on the formulae above and calculated according to the method described (Research Report Chapter 2),

Sample	Reference	% Water absorption		Wet & Dry		Acid Test	
Cullipool	E1690	0.61	0.55	Pass	Pass	Fail	Fail
Balvicar	E1691	0.94	1.34	Fail	Fail	Fail	Fail
Toberonochy	E1692	0.04		Pass		Fail	

Table 3.3 Easdale slate tested according to the BS680 (BRE Archives, unpublished)

the average composition of Easdale slate was determined and results are given in Appendix 1. There is considerable variation from one sample to the next and only the following general comments are made:

3.4.3 Weathering

Durability and Mineralogy

The moderately high quartz content of 25% weight and the high white mica/chlorite ratio are positive factors in determining the durability of a slate but the presence of pyrite, carbonates and graphite are negative factors. Yet Easdale slate is known to last for centuries. To reconcile these observations the following factors need to be taken into account:

- The most serious cause of weathering is water penetrating the cleavage domains, hence the best measure of the durability of a slate is the amount of water absorption. As can be seen (See Table 3.3.) from test results for a few fresh samples of roofing slate from the Easdale area, Toberonochy has a very low value for water absorption.

- The presence of both pyrite and carbonates is a detrimental combination reacting to form gypsum even in the absence of water. Such a combination is often found in the Balvicar slate, probably causing it to fail the Wet & Dry test.

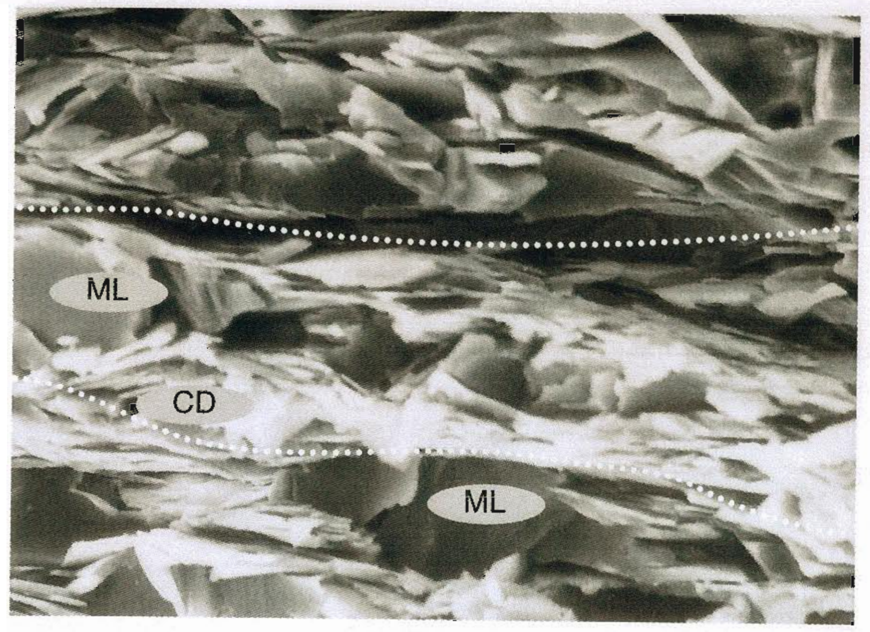
Examination of the spoil heaps in the different quarries shows a wide variation in the degree of weathering (see individual quarry reports). For example the tips at Toberonochy showed little weathering, pyrites were small and scarce, and there was only superficial staining and no leaching. The slates were fine-grained and probably impervious. In contrast the quarry faces at Balvicar were extremely badly weathered. Hence the slate for the Easdale group varies widely in terms of its durability depending on the quarry from which it is sourced.

3.4.4 Fabric

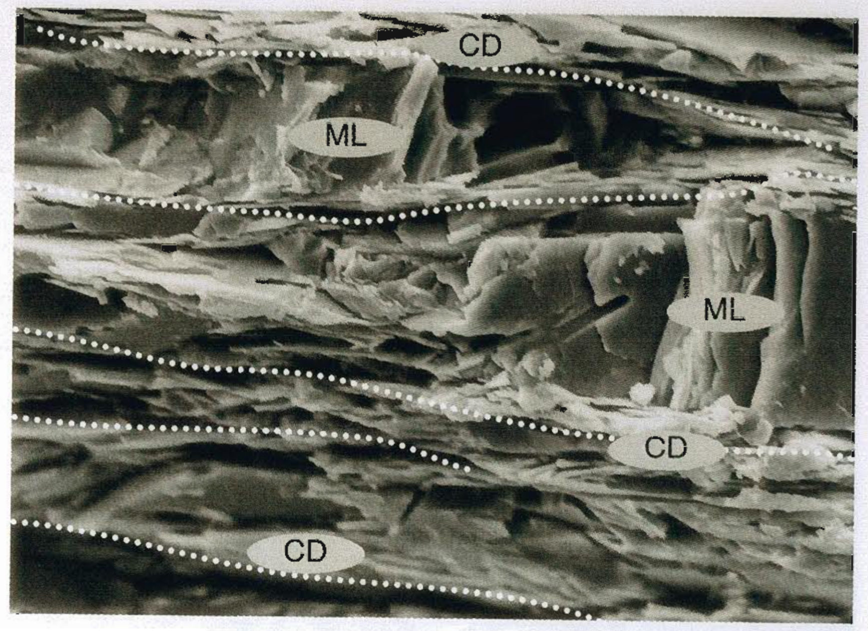
Within one quarry, slate was wrought from individual seams with variable splitting properties. Even within a seam the splitting ability improved with depth. The limited number of samples examined from such a wide range of quarries can only give a very general picture of the range of fabrics from the area. (For a full explanation of the following terms and the devised point scheme see Research Report Chapter 4).

Shape of cleavage domains	Straight and occasionally anastomosing
Spacing of cleavage domains	16µm in Toberonochy to 66µm at Belnahua. The average value is 25µm
Microlithons	The microlithons show some alignment of individual grains
Alignment	The degree of alignment ranges from 26-64% with an average value of 37%
FPS Value	5- 14 – mean 9

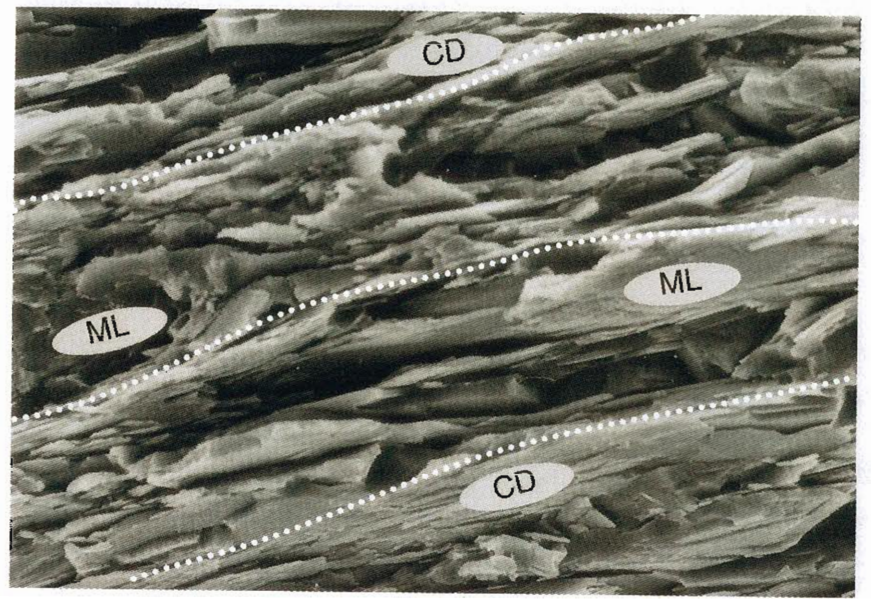
According to the relationship between FPS values and the minimum commercial thickness of the produced slate devised in the Research Report (Section 4.3.2) this equates to a potential commercial thickness of 5mm - 9mm. This agrees with the account of Peach *et al.* (1909) who state that slates were split between 3/16 inch (4.8 mm) and 3/8 inch (9.5 mm) the average being 1/4 inch (6.4mm). However slates collected in the various quarries were generally not split as thinly as possible (Table 3.4). There is considerable variation between different quarries (Research Report Appendix 4.1).



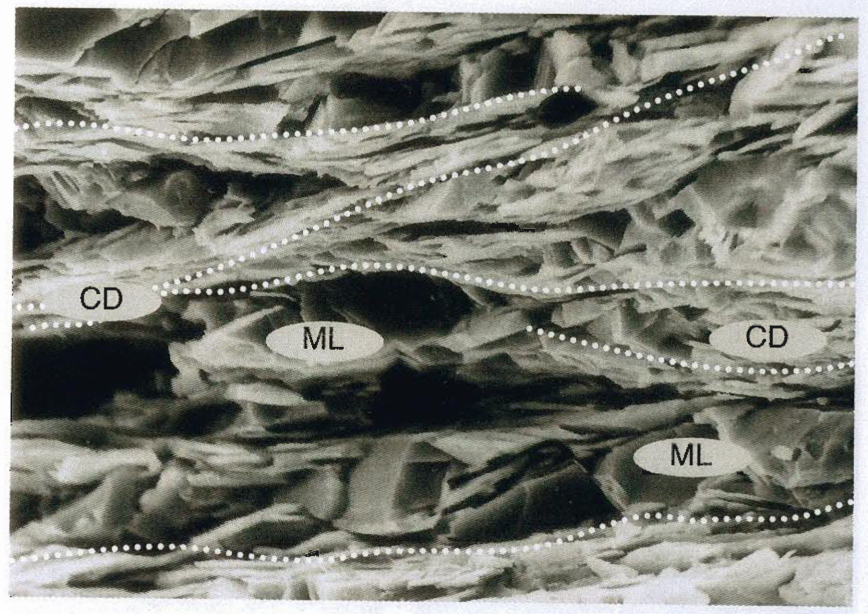
a) EASDALE ISLAND QUARRIES
EE-2 20.0µm
Finely spaced continuous and straight cleavage domains give this slate the potential to be split from 5 to 5.5mm



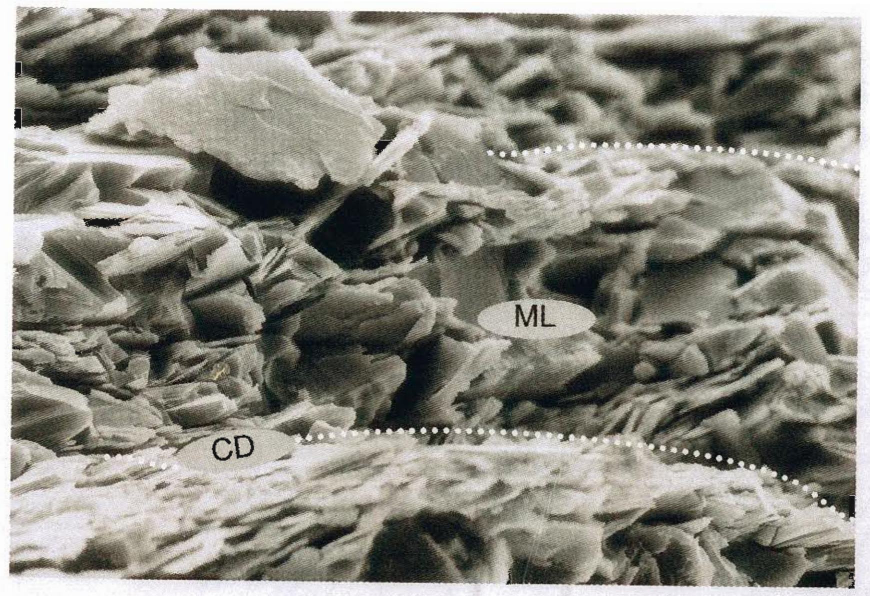
d) TOBERONOCHY QUARRY 20.0µm
LT-2
Cleavage domains are closely spaced, straight and continuous, giving this slate the potential to be split to 6mm



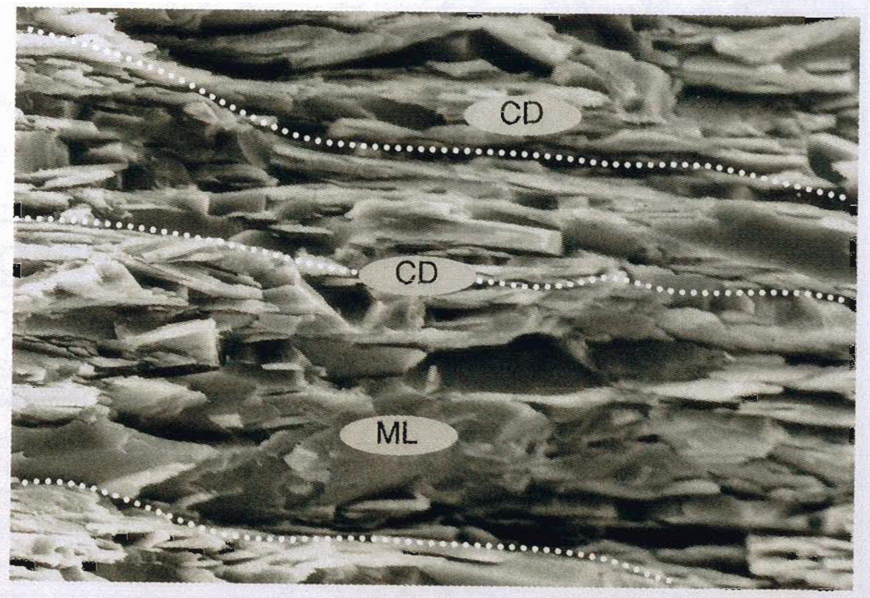
b) BREINE PHORT QUARRY 20.0µm
SB-5
Moderately closely spaced cleavage domains are straight and continuous give this slate the potential to be split to 5 – 6mm



e) PORT MARY QUARRY 20.0µm
LP-6
Cleavage domains are closely spaced, slightly anastomosing and continuous giving this slate the potential to be split to 5mm

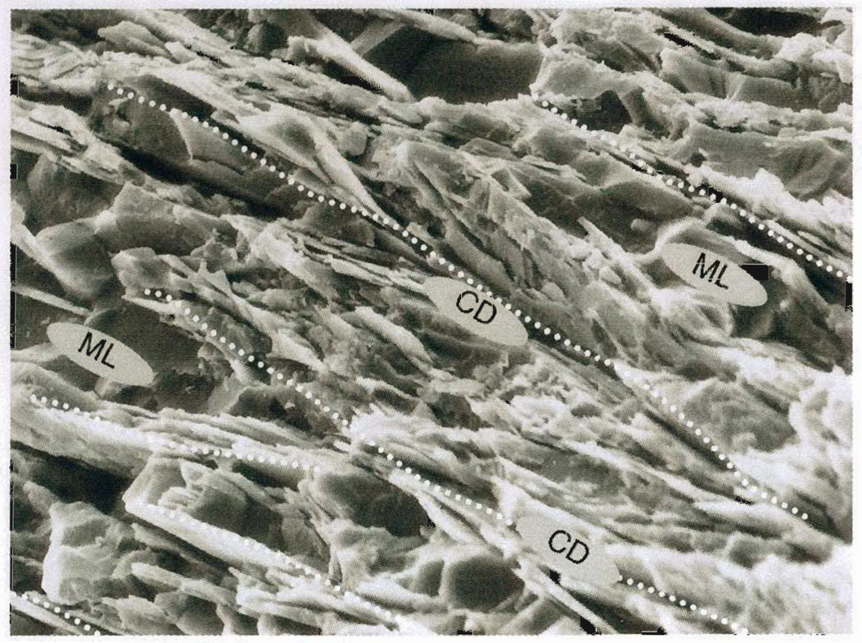


c) BALVICAR QUARRY 20.0µm
SB-2
Cleavage domains are widely spaced, irregular and discontinuous, limiting the ability to split the slate to approximately 8mm

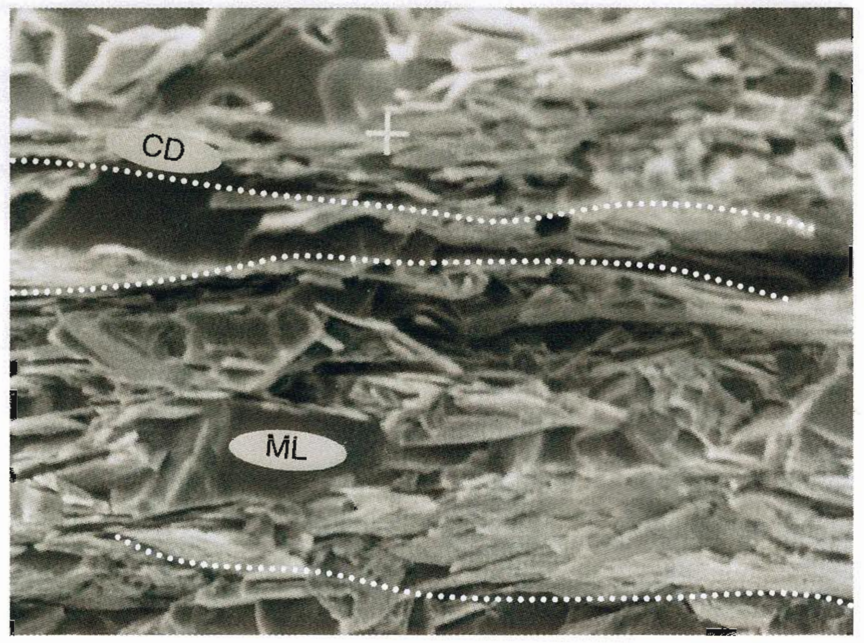


f) CULLIPOOL QUARRY 20.0µm
LC-2
Straight continuous and fairly closely spaced cleavage domains make up to 40% of the area - capable of being split to 6.5mm

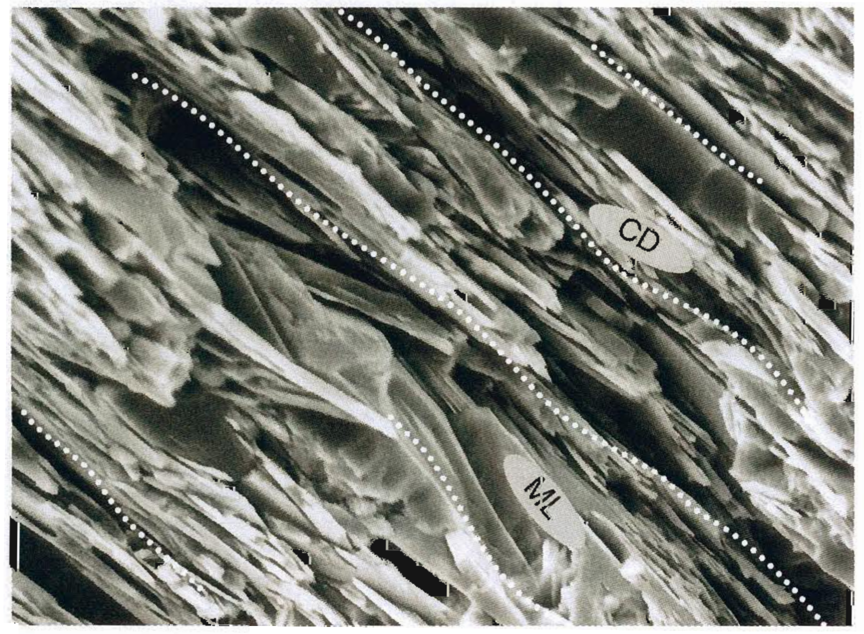
Figure 3.5 Fabric of Easdale Slate



g) TIR NA OIG QUARRY ⊢20.0µm⊣
LT-5
Cleavage domains although fairly closely spaced are discontinuous and irregular. Capable of being split to about 9mm



i) BELNAHUA QUARRY ⊢100.0µm⊣
BB-1
Cleavage domains are fairly straight and continuous but very widely spaced limiting the potential minimum thickness to >7mm. Note the smaller scale



h) BLACKMILL BAY QUARRY ⊢20.0µm⊣
LB-1
Finely spaced, continuous and generally straight cleavage domains make up to 60% of the area. This slate has a potential thickness of 5mm

Figure 3.5 (continued) Fabric of Easdale Slate

Sample	Quarry	Actual Thickness (mm)	FPS Values	Commercial Thickness (mm)
EE-3	Easdale Island	9	11	6
EX-1	Unknown	10	6	9
LC-3	Cullipool	9	7	8
LT-2	Toberonochy	8	10	6
BB-1	Belnahua	15	10	7

Table 3.4 Thickness of finished slate and minimum commercial thickness as predicted by the FPS (Research Report Section 4).

3.5. Quarry Appraisals

3.5.1 EASDALE ISLAND QUARRIES NM735169 to NM740174

(Fig. 3.1, Fig. 3.5a, Fig. 3.6 and Plates 16-17)

Plate 16 Creag an Dun on north west of Easdale Island, now flooded

Plate 17 Overall view of Ellenabeich and Easdale Island (NM742172 to NM744174)

3.5.1. Site Details

Location	Small island of the SW coast of Seil, covering an area of approximately 15 hectares.
Access	Access is by passenger-only ferry from Ellenabeich.
Ownership	Mr Clive Feigenbaum of Ruislip.

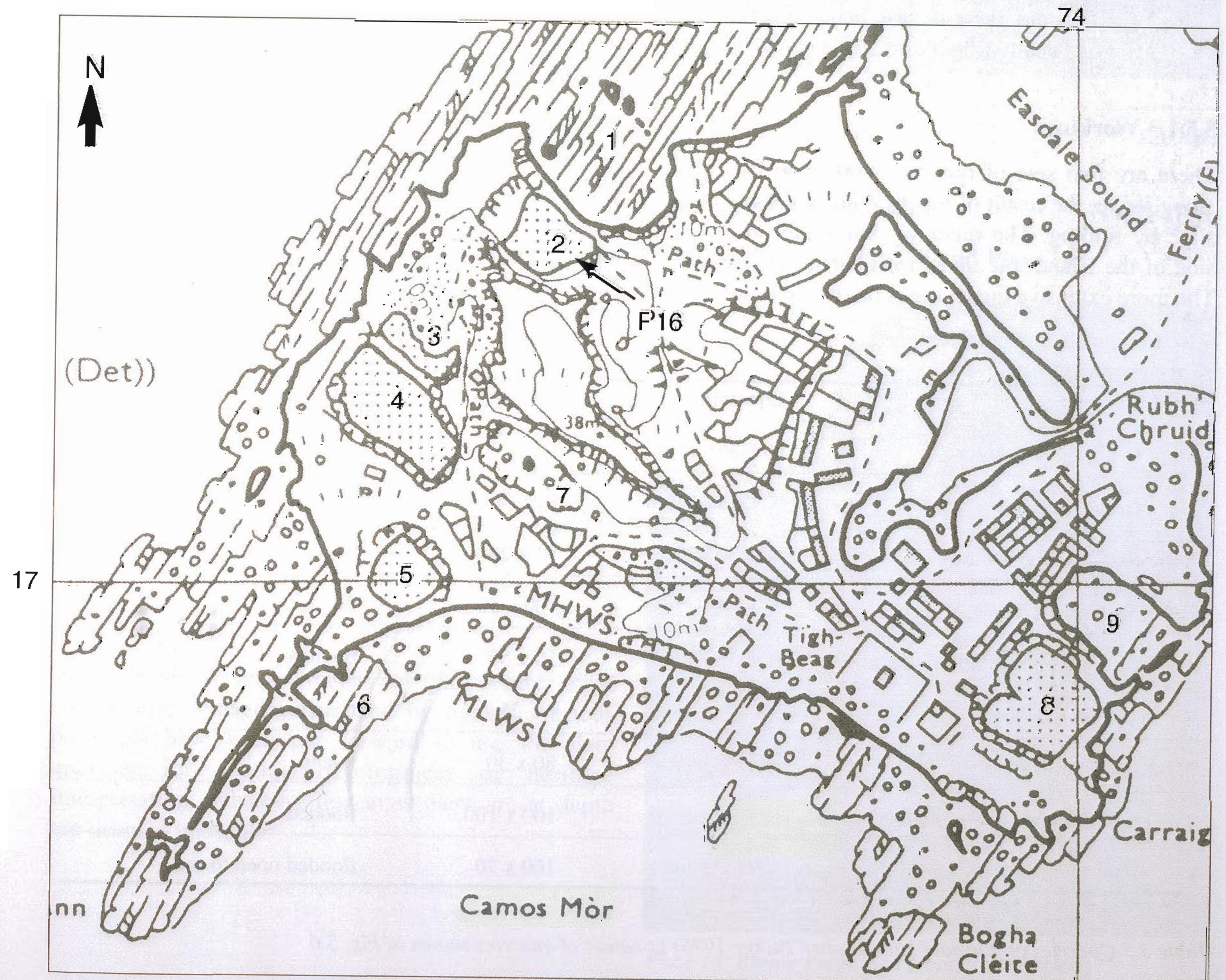


Fig. 3.6 Map of Easdale Island Quarries based on OS NM71NW copyright 1975. *1:5,000*
Numbers refer to quarries listed in Table 3.5.

3.5.1.2 Quarry Details

Slate	Blue grey medium to coarse grained.
Cleavage	030°/55°. The crenulation cleavage lineation pitches at 10-20°S on the cleavage surface.
Bedding	030°/90° but undulating in the west quarries.
Joints	J_2 280°/70° @ 50cm intervals.
Imperfections	Pyrites are ubiquitous up to 4mm in size. Quartz veins are localised in vicinity of the numerous dykes.
Weathering	Most of the pyrites are rusty on the surface, occasionally there is an aureole of staining around the pyrites and in some cases these have weathered out leaving a small hole. There is very little weathering on the cleavage faces, but the other faces do show rusty staining. On splitting the slate, there is little penetration of weathering along cleavage.

3.5.1.3 Workings

There are two sets of quarries worked in two bands along strike, the result of repetition of the same bed of slate by folding. The older workings are on the east side of the island; the unnamed quarries in Table 3.5. The more extensive quarrying is on the west side of the island where seven quarries have been identified. Several small scale workings were also observed.

Most of the quarries have been excavated to over 60m in depth. Numerous dykes and sills cut across the island separating the quarries. Indeed, most of the walls of individual quarries are made of igneous intrusions and associated quartz veins. This harder rock also makes up the sea walls. Table 3.5 shows a list of the larger quarries on the island named according to a map compiled by Mr. T R Jones, resident of Easdale Island, in 1976 (Tucker 1976).

3.5.1.4 Resources

The resources of the island are *exhausted* (Section 1.4). Several of the quarries are already open to the sea and all, apart from Klondyke (Fig. 3.6), have only a narrow wall left to protect the island from the onslaught of the sea. At the time of writing planning permission is being sought to use the western quarries for cod farming.

3.5.2 ELLENABEICH QUARRIES NM742172 & NM744174

(Fig. 3.1, Fig 3.7 and Plate 17)

3.5.2.1 Site Details

Location	Ellenabeich is on the SW tip of the island of Seil facing Easdale Island. There are two quarries within the confines of the village.
Access	Through the narrow streets of Ellenabeich (sometimes called Easdale).

	Quarry	Location	Size (m)	Comment
1	**Craig na h-Uamha**	NN7365 1732	100 x 80	flooded open to sea
2	**Creag an Duin**	NN7364 1725	80 x 50	flooded
3	**An Toll mar Thuath**	NN7353 1717	50 x 20	flooded
4	**An Lub Chlear**	NN7353 1715	100 x 50	flooded
5	**Creag Rubha nam Faoileann**	NN7353 1700	50 x 50	flooded
6	**An Staca Dhubh**	NN7350 1690	? x 25	open to the sea
7	**Klondyke**	NN7363 1708	80 x 30	inland
8	**East Quarry 1 unnamed**	NN7398 1670	100 x 100	flooded
9	**East Quarry 2 unnamed**	NN7402 1698	100 x 70	flooded open to sea

Table 3.5 Quarries on Easdale Island (after Tucker 1976) Location of quarries shown in Fig. 3.6

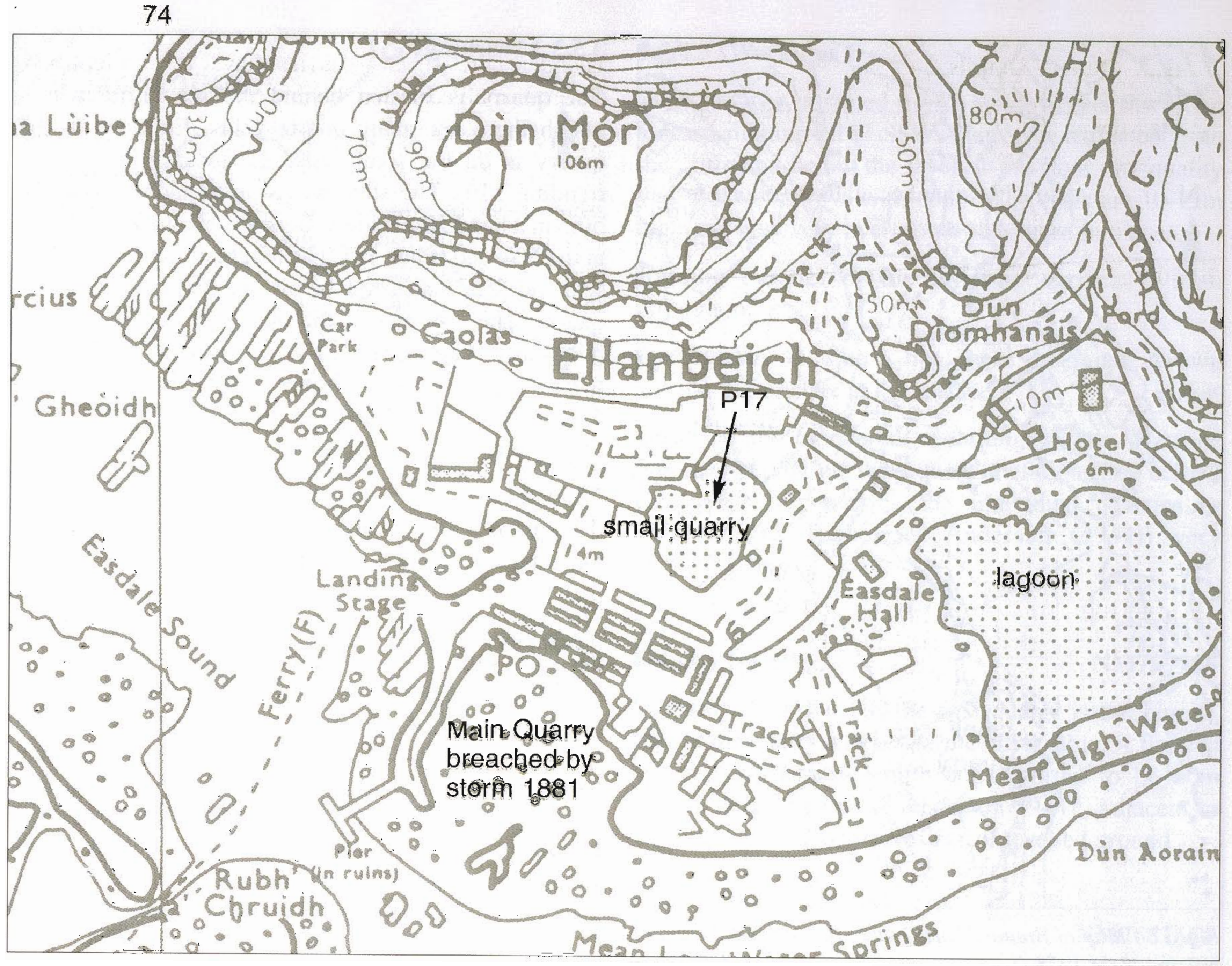


Figure 3.7 Map of Ellenabeich Quarries based on OS 71NW copyright 1974 *1:5,000*

3.5.2.2 Quarry Details

These quarries occur along strike from the quarries on the east of Easdale Island, and the slate shares the same properties as noted in Section 3.5.1.2.

3.5.2.3 Workings

The larger of the quarries is 120m in diameter and was 90m (260ft) deep when the sea wall was breached during an exceptionally high tide in 1881 (Peach *et al.* 1909.). The second quarry is inland and about 100m in diameter (Plate 17).

3.5.2.4 Resources

These quarries are situated in the centre of a conservation village surrounded by houses. Various proposals have been put forward to use the slate quarries for marina development or heritage interpretation. Whatever resources there are at depth are deemed unusable.

3.5.3 BREINE PHORT NM754166

(Fig. 3.1, Fig 3.5b, Fig 3.8 and Plate 18)

Plate 18 Breine Phort, Seil Island (NM754166)

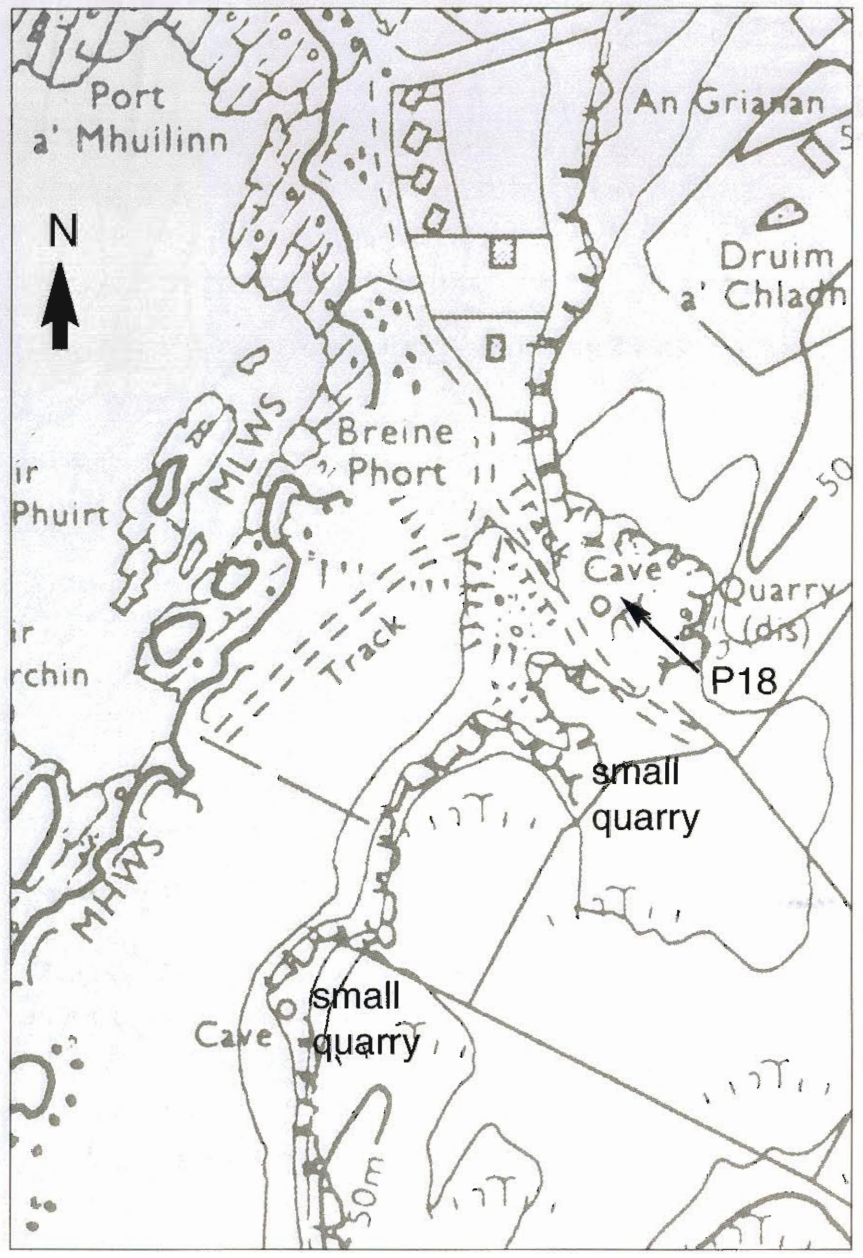


Fig. 3.8 Map of Breine Phort Quarry based on OS NM71 NE copyright 1978 *1:5,000*

3.5.3.1	Site Details
Location	1km to the east of Ellenabeich at Phort a'Mhuilinn.
Access	500m road to manse and then farm track for 100m.
Ownership	Mr. Anderson, Kilbride Farm, Seil

3.5.3.2	Quarry Details
Slate	Blue grey medium grained.
Cleavage	020°/52°. The crenulation lineation pitches at10° S on the cleavage surface.
Bedding	Variable, vertical and overturned at the west end.
Joints	J_1 290°/80° @ 0.5m.
Imperfections	Pyrite form specks to 2-3mm but are not very abundant.
Weathering	Some leaching of the pyrites; weathering has penetrated the cleavage planes. Weathering on all surfaces is common.

3.5.3.3 Workings

The quarry is located behind the sea cliffs, within which there are many quartz veins. Entrance to the quarry is on the south side, the location of a dyke trending 310°. The slate was worked along strike for 50m in a band 20m wide with an extension into the cliff at the NW end (Plate 18). The height of the face is 20m, with no slate extracted below the floor level of the quarry. The SW end of the quarry is cut by igneous dykes distorting the strata. As well as irregular jointing there is a set of joints parallel to the pillaring surface. There is also minor folding on the NW with amplitudes of 1.5-2m.

The land rises steeply to 50m on the NE and E side of the quarry. The exposed slate appears weathered almost down to the top of the quarry.

3.5.3.4 Resources

Medium resources are available within the confines of the quarry. Richey & Anderson (1944) recommend further development to the east of the present workings. After a short break to the south, the sea cliffs continue for a further 1km along strike, reaching heights of 40m in places. The remains of two small workings along this cliff face were noted. Very large slate deposits are available along this part of the coast.

3.5.4 BALVICAR NM766164 to NM769168

(Fig. 3.1, Fig 3.5c, Fig 3.9 and Plate 19)

Plate 19 Quarry No 1 Balvicar on Seil Island (NM769168)

3.5.4.1	Site Details
Location	South east of Seil in the clachan of Balvicar
Access	From main road at Balvicar.
Ownership	Ms Isabel Smith, Seil.

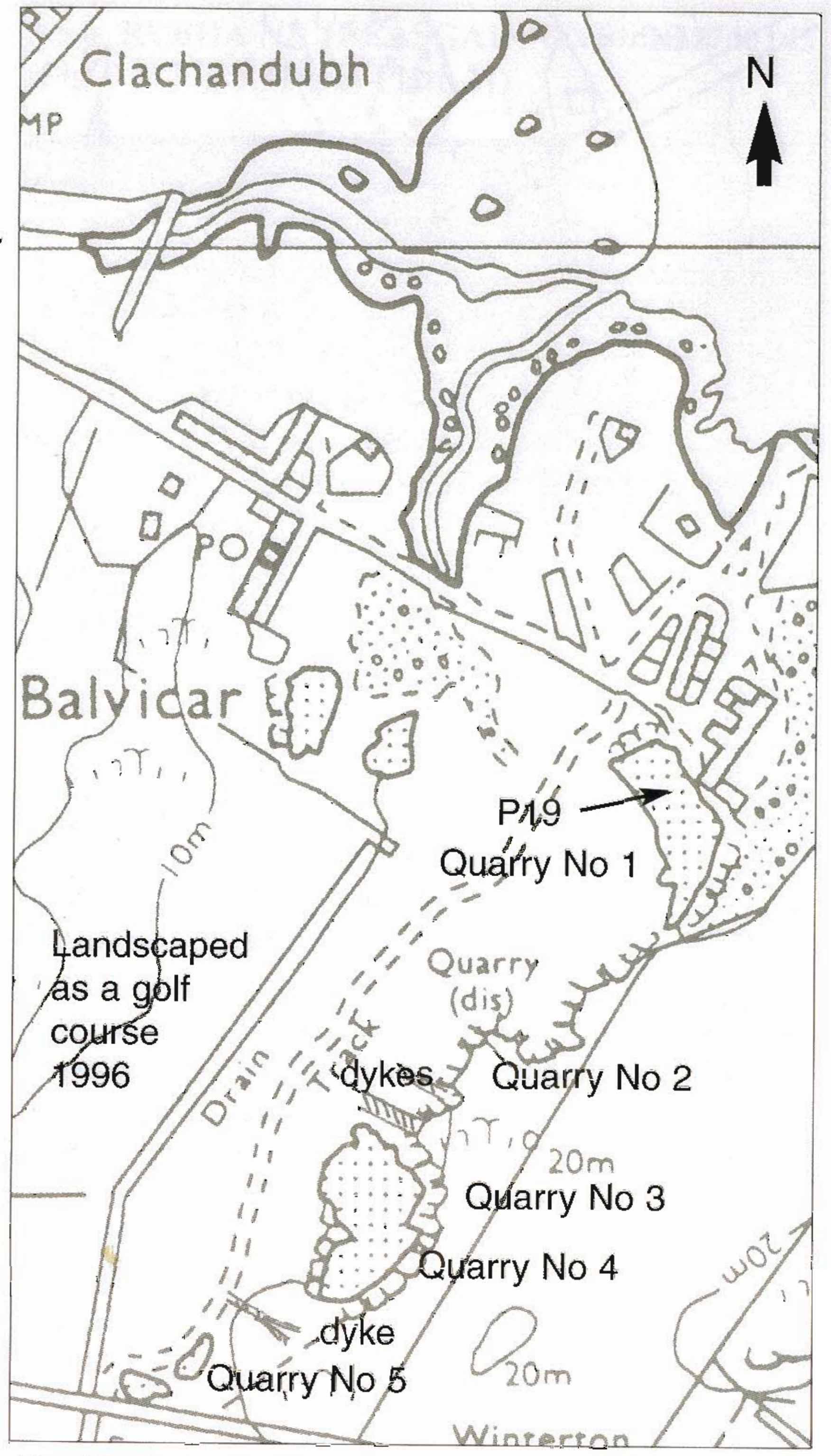


Fig. 3.9 Map of Balvicar Quarries based on OS NM71NE copyright 1978 *1:5,000*

3.5.4.2	Quarry Details
Slate	Blue-black fine grained.
Cleavage	040°/30° The crenulation cleavage lineation pitches at 10°S to almost horizontal on the cleavage surface.
Bedding	Bedding is subparallel to cleavage 038°/50°.
Joints	There is a set of joints parallel to the pillaring surface @ 30cm intervals J_1. Two other sets of joints were observed namely. 295°/80° at 10cm intervals and 080°/80° at 30-50cm intervals.
Imperfections	Pyrite and graphitic films are common.
Weathering	Bands of crumbling rock rich in graphite with deep rusting along pillaring line were observed. White staining due to weathering noted in places.

3.5.4.3 Workings

The slate was extracted from a series of quarries along a scarp running NNE-SSW. Slate was extracted from the cliffs and below the level of the floor, the quality was said to improve with depth. The cliffs are 10-15m high and now very overgrown and rotten in places.

Jointing parallel to the pillaring surface is seen throughout.

Overburden is small but there is much brown weathering of slate at the surface.

Quarries are numbered according to the Wartime Pamphlet report, but subsequent alterations (see below) have made recognising the individual quarries as described by Richey & Anderson (1944)) very difficult.

Quarry No 1 **NM769168**

Counting from the NE the first quarry is the largest. Part of the quarry was below the water table. A flooded sinking is 100m in length and reported to be 60m (200ft) deep (Richey & Anderson 1944). Adjacent to the sinking is an extensive area of levelled ground.

Quarry No 2 **NM7681664**

Slate was extracted for 100m along the cliff face at this location. The slate is very black and graphitic in this quarry.

Between Quarries No 2 and 3 there is the remains of a narrow passage cutting through the minor igneous intrusion which was the site of a tramway.

Quarry No 3 &4 **NM767165**

These quarries were worked after Richey and Anderson's report (1944) and have now merged into one large quarry. It is an irregular shaped quarry 30m by 50m and surrounded by cliffs that are approximately 20m high. The quarry is now flooded.

Quarries No 5 **NM766164**

These are two small workings about 10m in diameter, now flooded holes. The unworked ground between these two quarries is cut by two or maybe more dykes

3.5.4.4 Resources

There are *medium* resources in the Balvicar quarries. These quarries have been worked in a narrow wedge-shaped outcrop between a metadolerite sill on the east and alluvium deposits on the west. Apart from localised extension of the present workings there is little room for further exploitation. Quarry No 1 (Plate 19) is now the site of a fish processing plant and its owner's private residence. Quarries Nos 3 & 4 were being worked up to 1966.

Since the writing of the above description the flat, peaty ground to the west of the workings has been landscaped and is now a golf course. Little evidence of the tramway, which serviced the quarries, now remains.

3.5.5 TOBERONOCHY NM749085

(Fig. 3.1, Fig 3.5d, Fig 3.10 and Plate 20, 56)

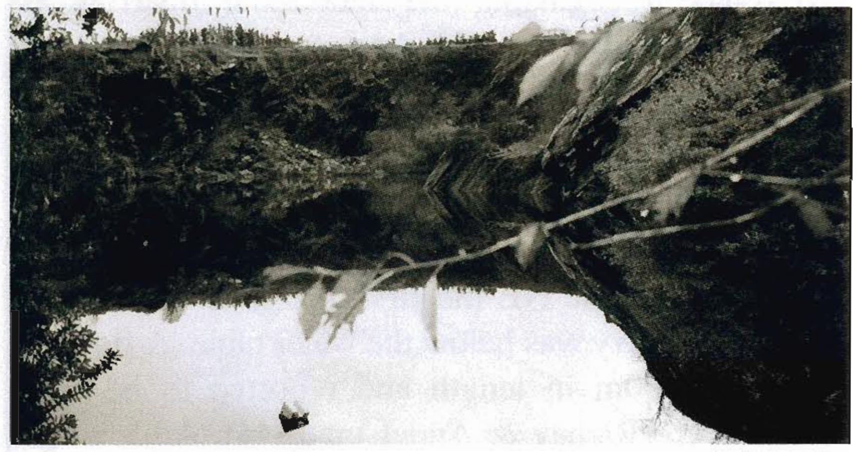


Plate 20 Toberonochy on west coast of Luing (NM749085)

3.5.5.1 Site Details

Location	South end of the village of Toberonochy on the east coast of Luing 100m from the sea.
Access	There are two entrances to the rim of the quarry, one at the north end between houses in the village and the second an overgrown path 100m from the sea on the east side of the quarry. The tips have been landscaped into two piers with a small anchorage in between.
Ownership	Mr. J Galbraith, Toberonochy, Luing.

3.5.5.2 Quarry Details

Slate	Fine-grained, bluish-grey in colour.
Cleavage	020°/40-57°. The cleavage surface is less affected by crenulation than that seen at the west of Luing.
Bedding	003°/45°
Joints	J_1 270°/85°
Imperfections	Pyrites are not abundant, but are present as 1mm specks dispersed and in occasional clusters.
Weathering	Pyrites are slightly rusty, but there is no leaching.

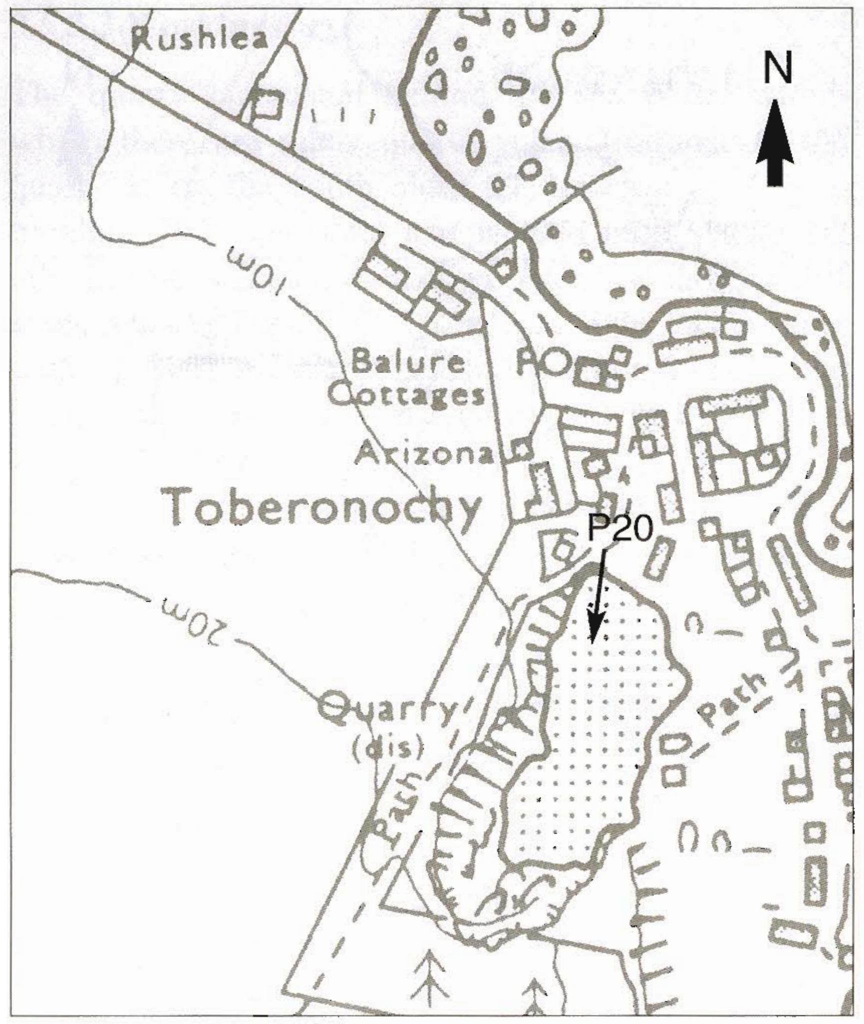


Fig. 3.10 Map of Toberonochy Quarry based on OS NM70NE copyright 1974 1:5,000

3.5.5.3 Workings

Toberonochy quarry is 130m long by 50m wide. As this quarry is flooded, with vertical walls, no measurements were possible in the actual quarry (Plate 20).

According to Mr. Galbraith (per. com.) the quarry was 25m (75ft) deep in 1933 when it was pumped out. Three bands of slate were worked, the thickest being 20m (70ft) wide, but most were only 600mm-1.5m (2-5ft) (Peach *et al.* 1909). The depth of the quarry had increased considerably by 1937 when, according to Richey & Anderson (1944), it had reached a depth of 50m (175ft). Mechanisation was used to lift the slate (a steam crane was introduced before World War I and a Crossley engine was in use before World War II).

Slates were carried by tramway to the shore to be dressed, the most common size produced was 12"x 6" (300mm x 150mm), (Mr. Galbraith per. com.). Slates were then transferred onto ships at the pier.

3.5.5.4 Resources

The surrounds of the present quarry are very overgrown, making it difficult to gain access to the area, however the resources are probably *limited.* The present workings are at the north end of raised sea cliffs and the north face of the quarry is bounded by a dyke, so that any extension of the quarry would have to be to the south along strike of cleavage. Overburden is estimated as 2m on the south side of the quarry.

3.5.6 RUBHA NA H-EASGAINNE NM748145

(Fig. 3.1, Fig 3.11 and Plate 21)

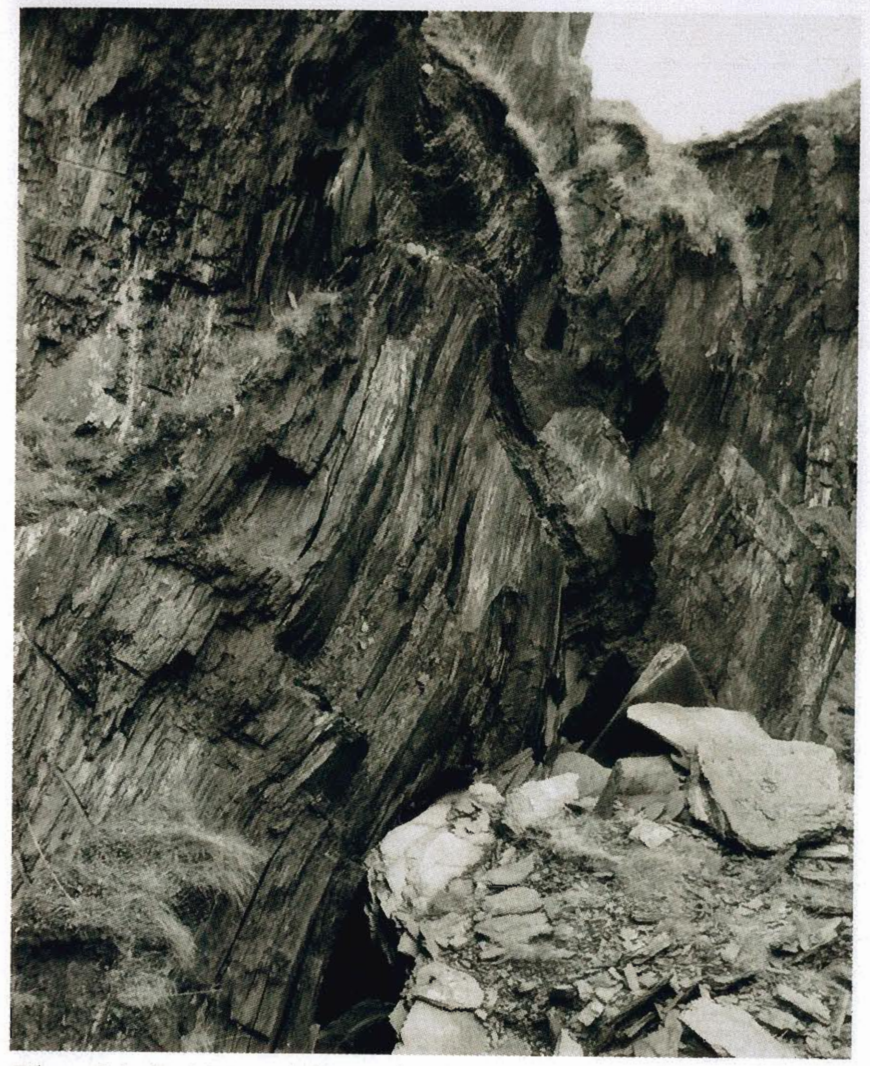


Plate 21 Rubha na hEasgainne or Cuan Point north of Luing. The cleavage is undulating due to folding (NM748145)

3.5.6.1 Site Details

Location	North of Luing also called Cuan Point.
Access	Access is along a boggy path 250m NW from Cuan Ferry.
Ownership	Mr S Cadzow, Ardlaroch Farm, Luing.

3.5.6.2 Quarry Details

Slate	Blue grey with slight sheen, medium grained.
Cleavage	022°/80°. The crenulation cleavage lineation pitches horizontally on the cleavage surface. This surface is undulating at this locality.
Joints	Irregular, but no systematic set of joints were noted.
Imperfections	Large pyrites up to 10mm in length are abundant, graphite bands are also present.
Weathering	Pyrites are rusty on the surface and surface staining is common. Graphitic beds are associated with crumbling slate. White colour weathering was also noted.

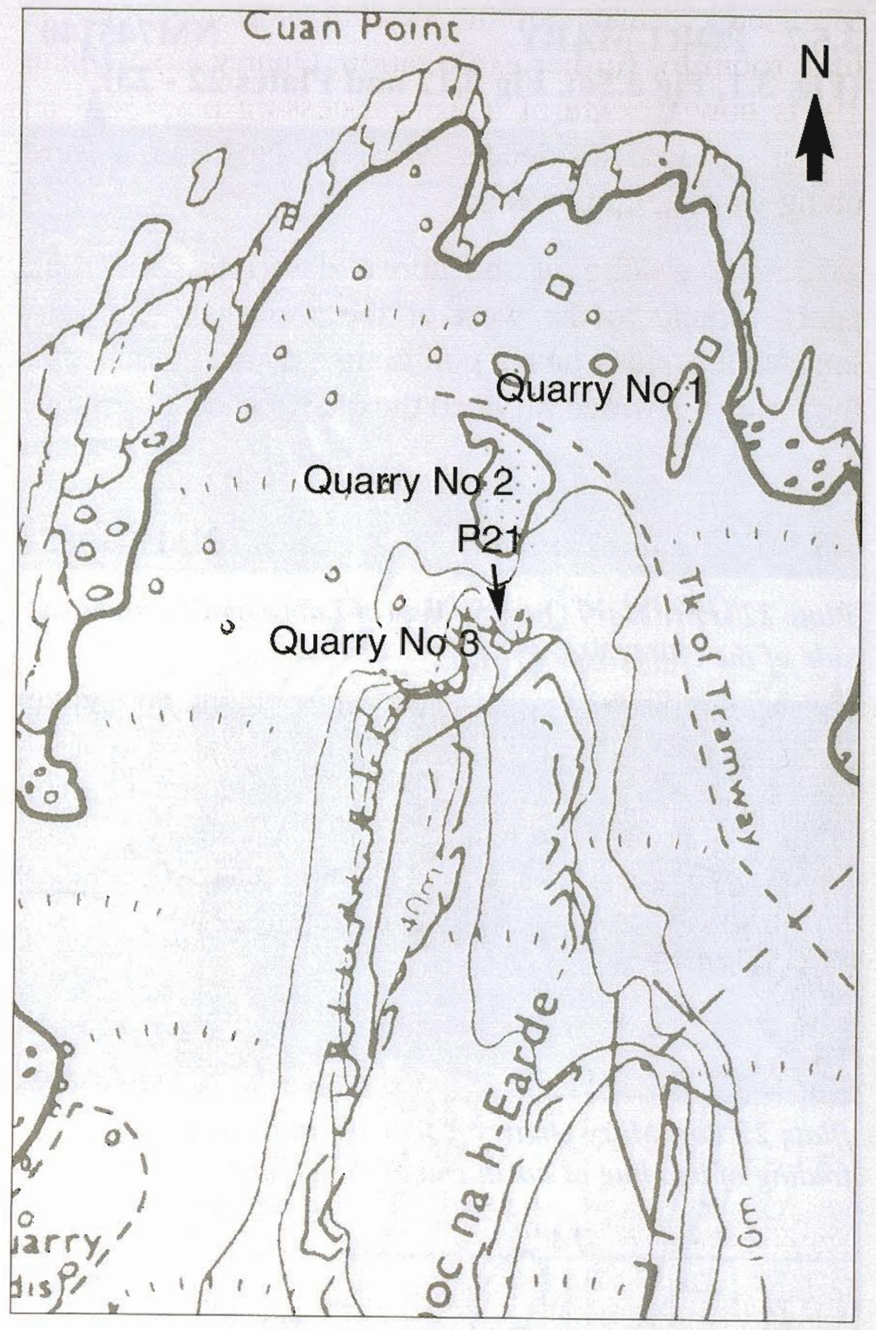


Fig. 3.11 Map of Rubha na hEasgainne Quarries based on OS NM71SW & SE copyright 1975 1:5,000

3.5.6.3 Workings

Slate has been extracted from two large sinkings and several small ones. Slate has also been quarried from the cliff face to the east and to west of the point.

Quarry No 1 **NM74871452**
50m x 10m depth unknown flooded.

Quarry No 2 **NM74791448**
50m x 30m depth unknown flooded.

Quarry No 3 **NM74751440**
50m x 25m into the cliff face.

The largest working is at Quarry No 2. Minor folding can be seen in this area causing the cleavage to undulate (Plate 21). In Quarry No 3, jointing is along bedding planes in the hinges of minor folding. Thick beds of graphite were also found at this locality.

These quarries were serviced by a tramway along the raised-beach platform to Cuan Ferry.

3.5.6.4 Resources *See Section 3.5.8.4*

3.5.7 PORT MARY NM745140
(Fig. 3.1, Fig 3.5e), Fig 3.12 and Plates 22 - 23)

Plate 22 Port Mary Quarry, west of Luing on the landward side of the cliffs (NM745140)

Plate 23 Port Mary Quarry. Cleavage destroyed due to folding of bedding at north end of the quarry

3.5.7.1 Site Details	
Location	West coast of Luing 1km north of Cullipool. Port Mary 200m from end of the ghost village. A further unnamed quarry is 400m to the SSW along the raised beach platform.
Access	Access is along a fairly well maintained farm track to the deserted clachan of Port Mary. Access to the unnamed quarry is along the raised beach platform.
Ownership	Mr S Cadzow, Ardlaroch Farm, Luing.

3.5.7.2 Quarry Details	
Slate	Dark grey slate.
Cleavage	Port Mary Quarry: 036°/40°-50°. The crenulation cleavage lineation pitches at 10-15°S on the cleavage surface. Unnamed Quarry: 020°-030°/30° The crenulation cleavage lineation pitches at 10-15° S on the cleavage surface.
Joints	Port Mary Quarry: J_1 290°/70°-90° at irregular intervals. J_2 200°/70° @ 0.5m. Unnamed Quarry: joints are irregular and one set of, subvertical joints striking 090°-136°.
Imperfections	Pyrites are large (4 x 8mm) and there are occasional graphitic bands.
Weathering	Pyrites are rusty but exhibit little leaching. Locally intense rusty weathering was noted.

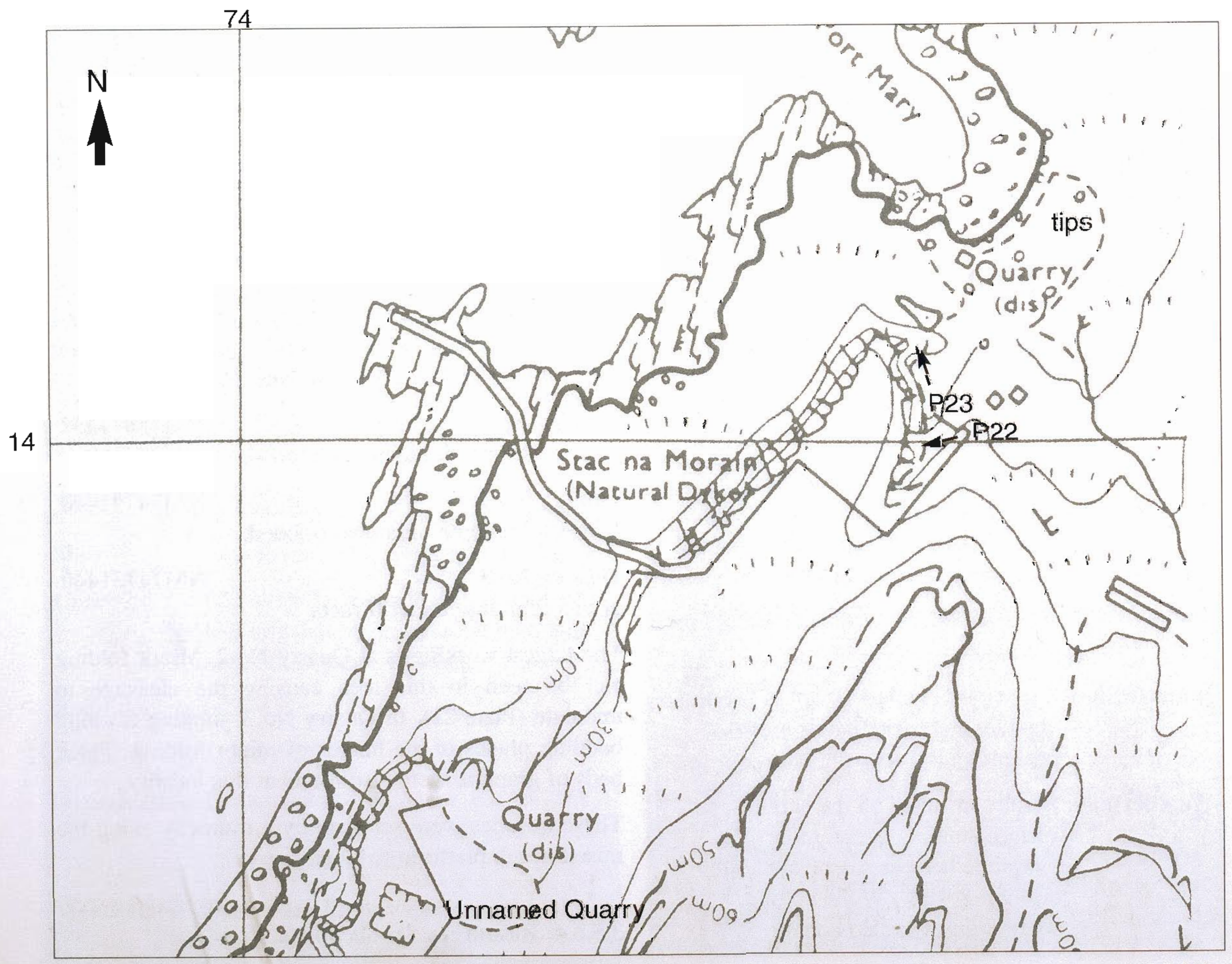


Fig. 3.12 Map of Port Mary Quarries based on OS NM71 SW copyright 1975 *1:5,000*

3.5.7.3 Workings

Port Mary NM74481400

The workings are located on the inland side of the sea cliffs which are approximately 15-20m high. The quarry is 100m long. The axes of two anticlines can be traced from N -S of this quarry; the joining syncline is less obvious. In the hinge zone of the more westerly anticline at the north end of the quarry jointing is parallel to bedding or orthogonal to the fold axis (Plate 23). Ribboning due to bedding is prominent. The south end of the face is cut by two dykes.

The Unnamed Quarry NM74111366

The area between the two quarries is densely cut by dykes, Stac na Morain being the largest. Similar to Port Mary, this quarry is tucked behind the cliffs. The quarry is 50m along strike and 30m deep. The SW face of the quarry is there is a cluster of quartz veins and dykes and the cleavage of the surrounding slate is flaky i.e. "pencil cleavage".

The jointing is irregular, with some orientated sub parallel to the pillaring surface and some parallel to the cleavage planes. The dip of the cleavage is only 20°, considerably less than that usually found in the area.

3.5.7.4 Resources *See Section 3.5.8.4*

3.5.8 CULLIPOOL NM739129 to NM742138
(Fig. 3.1, Fig 3.5f, Fig 3.13 and Plates 24-25)

Plate 24 Cullipool Quarries Nos 1 & 2 west of Luing. These quarries open onto the raised beach platform seen in the foreground (NM741137)

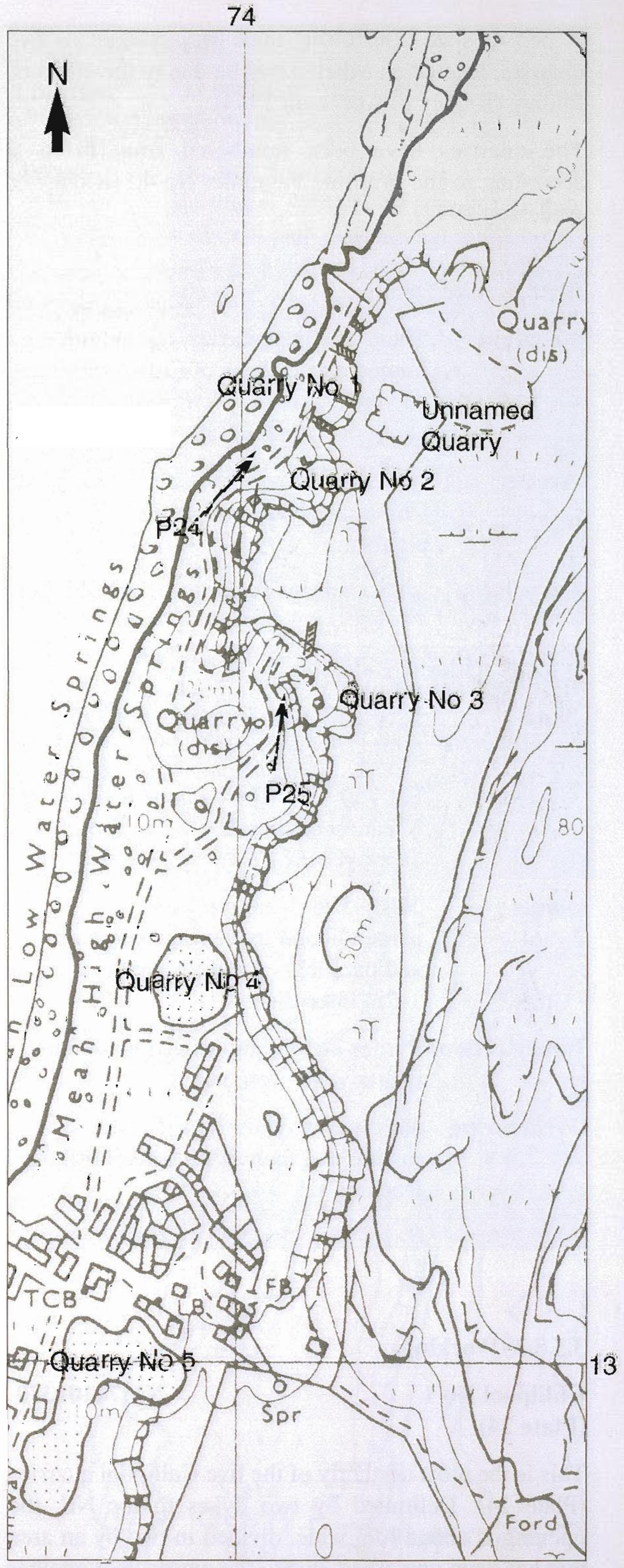


Fig. 3.13 Map of Cullipool Quarries based on OS NM71SW copyright 1975 *1:5,000*

A bed of slate 20m (70ft) thick was worked in five quarries, located en echelon maybe due to the effect of folding (Richey & Anderson 1944).

The quarries have been numbered from N to S according to the Wartime Pamphlet No 40 (Richey & Anderson 1944).

3.5.8.1 Site Details	
Location	There are five quarries, two within the immediate confines of Cullipool village and the remaining workings to the north along the raised beach.
Access	Access is through the narrow streets of Cullipool village and along the platform.
Ownership	Mr S Cadzow, Ardlaroch Farm, Luing.

3.5.8.2 Quarry Details	
Slate	Blue grey, with a strong crenulation fabric (Plate 15).
Cleavage	020°/50°-55°. The crenulation cleavage lineation pitches @ 10°S on the cleavage surface.
Joints	300°/85°@ 1-2m intervals perpendicular to cleavage surface J_1 and parallel to the cleavage planes J_0 at 1-2m intervals.
Imperfections	Pyrites are ubiquitous and numerous quartz veins were noted.
Weathering	Most pyrites show superficial rusting, but there is in general little leaching.

3.5.8.3 Workings

Cullipool No 1 (Plate 24) **NM74101370**

This is the most northerly of the five Cullipool quarries (Plate 24). Delimited by two dykes to the NE, the opening is about 40m wide, divided in two by an area that has been unworked, due to the presence of another dyke. This quarry was worked 20m into the cliff face down dip of the cleavage, leaving an overhanging face almost 40m in height. The slate at the north end of the quarry is impregnated with quartz running along cleavage. A dyke meanders through the slate near the top of the face.

Cullipool No 2 **NM74051362**

Similar to No 1, this quarry is delimited by dykes. The quarry is 20m wide and worked down dip 50m into the cliff face. Part of the seaward side of the quarry has been left unworked due to a graphitic layer and also quartz veins. Pronounced folding can be see on the seaward side of the south wall, which continues into the next quarry.

Cullipool No 3 (Plate 25) **NM74051345**

This is the largest working of all the quarries on the west of Luing being nearly 200m along strike and worked into the cliff a distance of 100m. The northern end of the quarry was worked at three different levels. A dyke separates the lower two levels (Plate 25). The immediate vicinity of the dyke was not worked presumably due to the destruction of the cleavage. Two Tertiary dykes cut across the quarry from WNW to ESE dividing the quarry into 3 sections. Two thirds of the quarry at the southern end was worked to a precipitous height of 40m. The seaward side of the quarry was left intact for part of the length of the quarry, due to the continuation of the folding seen in the previous quarry.

Plate 25 Cullipool No 3. The slate is cut by an igneous intrusion, which runs parallel to cleavage (NM741135)

Cullipool No 4 **NM73951325**

Slate was extracted from the platform over an area of 50 x 50m to unknown depth. These working are now flooded.

Cullipool No 5 **NM73901300**

The workings are 150m long by 30m wide with an extension into the cliff face at the NE end. Depth of quarry was reported as 30m (100ft) below sea level (Richey & Anderson 1944.). This quarry is now flooded.

3.5.8.4 Resources

The slate deposit covers an area of $2km^2$ stretching from the north of the island at Rubha na hEasgainne through Port Mary to Cullipool indicating *very large* resources, but to what extent these resources are exploitable is unknown (Fig. 3.2). The slate at Rubha na hEasgainne and at Port Mary shows considerable distortion of cleavage suggesting that there are only limited to medium resources available. The best seam of slate is at the southern end at Cullipool and has been quarried to great depth. This seam was reported to be 20m wide but is staggered westwards to the north and probably continues in the Sound of Luing. To the south the ground is low lying and overlain with alluvium. Further exploitation of this seam is possible within the confines of the Cullipool quarries, but the quarries have been left in an unstable state with a high cliff overhanging in places. Medium resources are available in the Cullipool quarries. The continuation of the slate belt to the north would be less productive due to more intense folding of the strata as reported in the various quarry reports.

3.5.9 TIR NA OIG (Fig. 3.1, Fig 3.5g, Fig 3.14 and Plate 26) NM733103

Plate 26 Tir na Oig - Two quarries on the west of Luing (NM733103)

3.5.9.1 Site Details	
Location	On the coast, 1km north of Black Mill Bay on the west side of Luing.
Access	The best approach is along a farm track starting at Ardlarach Farm from which a narrow path drops down to the coast through a natural break in the cliffs
Ownership	Mr. S Cadzow, Ardlaroch Farm, Luing

3.5.9.2 Quarry Details	
Slate	Dark grey-black, fine-medium grained.
Cleavage	360°/62°. The crenulation cleavage lineation pitches 10°S on the cleavage surface.
Joints	Jointing is irregular. Joints parallel to the cleavage surface J_0 are at 0.5m intervals; subvertical joints strike from 060° to 125° at 0.5-1.5m intervals.
Imperfections	Pyrites, graphitic layers and quartz veins are all present.
Weathering	Brown staining due to weathering is common.

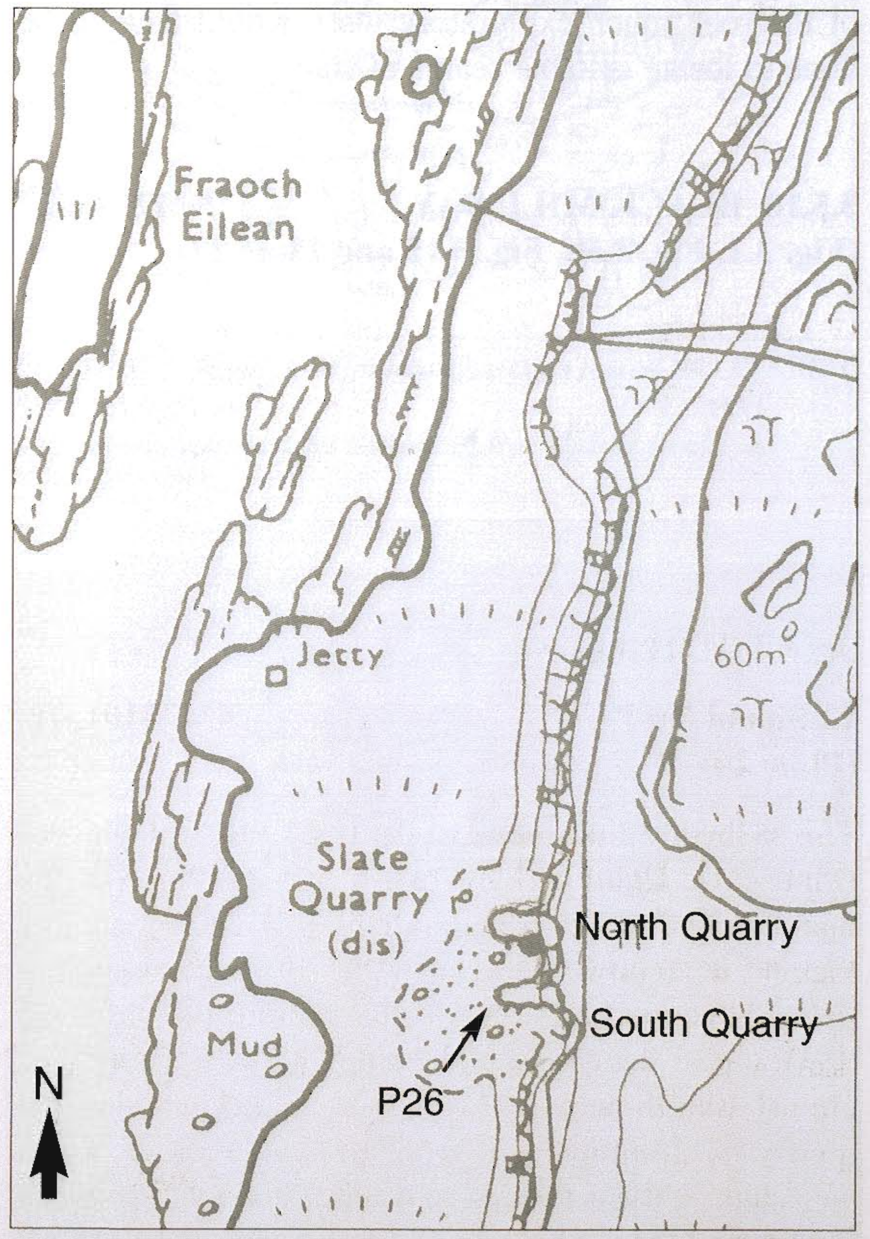


Fig. 3.14 Map of Tir na Oig Quarries based on OS NM70NW copyright 1974 1:5,000

3.5.9.3 Workings

Two quarries were worked 20m into the cliff face over a 50m face in each case. The exposed face in the north quarry is cut by a dyke (340°/60°). Folding is extensive with associated veins of quartz. Also present are several graphitic layers. Similar folding is found in both quarries. These observations do not agree with the report of quarry owner Mr. J S McCowan in the late 1930s. *"Slabs of good size separated by clean joints are obtained measuring up to 10ft in length."* were reported (Richey & Anderson 1944). This may be due to the good rock having been worked leaving the less productive material. Overburden is estimated at 1-2m.

Slate was transported along a tramway to a jetty built especially for the purpose. The remains of the transport system can still be seen, including a steam engine (intact but rusty), bogies and remains of the tram lines, although no sign of the jetty can be seen.

3.5.9.4 Resources

Resources of slate are *very large* covering several square kilometres along the cliff to the north and south of the quarries and also into the hillside to the east. No material has been extracted below the level of the platform. Slate outside the vicinity of the quarry is also affected by folding etc. and before further exploitation of the rock much exploratory work would have to be done to locate suitable seams of slate.

3.5.10 BLACK MILL BAY NM732082
(Fig. 3.1, Fig. 3.5h, Fig. 3.15 and Plate 27)

Plate 27 Blackmill Bay Quarry on the west of Luing (NM732082)

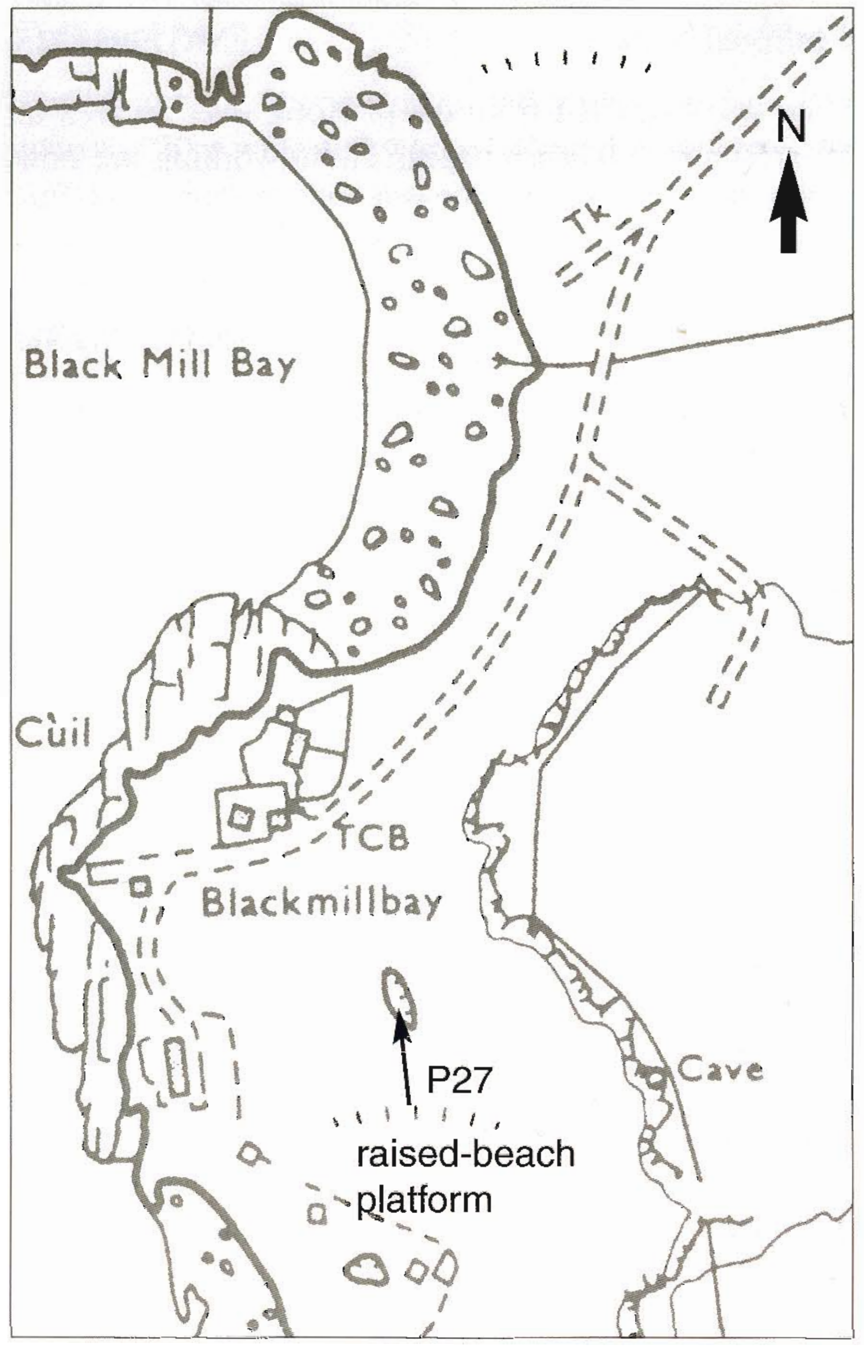


Fig. 3.15 Map of Black Mill Bay Quarry based on OS NM70NW copyright 1974 1:5,000

3.5.10.1 Site Details	
Location	Raised beach platform at Black Mill Bay on the west side of Luing.
Access	The remains of the quarries are within 100m of the pier.
Ownership	Mr. S Cadzow, Ardlaroch Farm, Luing.

3.5.10.2 Quarry Details	
Slate	Dark grey – black, fine-medium grained.
Cleavage	010°/40°-60° and undulating.
Imperfections	Slate is very graphitic, pyrites approximately 5mm square.
Weathering	Pyrites are rusted through, with much brown staining. Garsten Cottage was built about 1910 and probably roofed with local slate. The slate is now in poor condition and only 50% could be re-used (per. com. owner).

3.5.10.3 Workings

Several small workings 1 – 2m deep were located on the raised beach platform. These have now been filled in and in some places used as a local dump.

3.5.10.4 Resources

The former sea cliffs follow the coast about 200m inland for nearly 1km. No evidence of quarrying was seen. Only the northern part of the cliffs were looked at closely, where cleavage is distorted by quartz veins. Slate was very graphitic.

Although the deposits of slate are *very large*, resources of usable slate are probably *limited* to *medium*.

3.5.11 BELNAHUA NM714128
(Fig. 3.1, Fig. 3.5i, Fig. 3.16 and Plate 28, Plate 57)

Plate 28 The island of Belnahua off the west coast of Luing (NM714128)

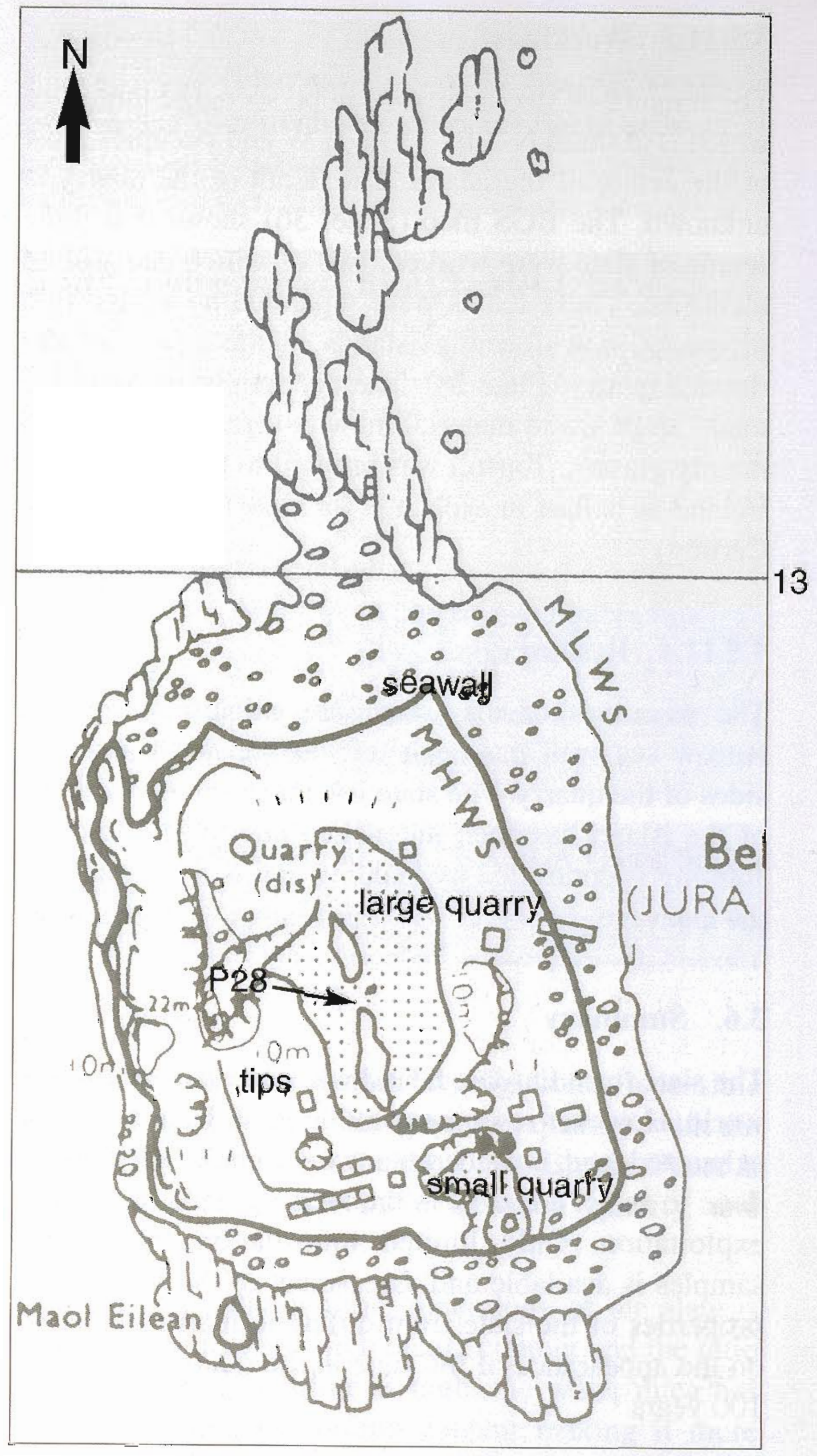


Fig. 3.16 Map of Belnahua Quarries based on OS NM71 SW copyright 1975 1:5,000

3.5.11.1 Site Details	
Location	The island of Belnahua is situated 2 km west of Cullipool in the Sound of Luing.
Access	By boat from Cullipool on the island of Luing. The pier on the east side of the island collapsed about 10 years ago (per. com. boatman). At present it is only possible to land in reasonably calm sea conditions.
Ownership	Mr. Paul Carling

3.5.11.2 Quarry Details	
Cleavage	324°/42°. The crenulation cleavage lineation pitches at 40°S on the cleavage surface. The cleavage is distorted in the vicinity of quartz veins, wrapping around nodules of quartz with pressure shadows. Pyrite occurs in these shadows.
Joints	Jointing is irregular, apart from one set of joints striking E-W and dipping 80°S.
Imperfections	Pyrite is ubiquitous from < 1mm specks to 5mm. Occasional graphitic layers were found. A band of limestone is located to the west of the island.
Weathering	Pyrites are rusty in colour but exhibit little leaching. Some brown staining was noted on cleavage surfaces.

3.5.11.3 Workings

The remains of two quarries can be seen, the largest of which is 200mm N-S by 150m E-W and occupies most of the centre of the island. The depth of the quarry is unknown. The BGS map (Sheet 36) shows that three seams of slate were worked, two of which can still be identified. These seams were separated by a band rich in quartz, now forming islands in the centre of the flooded quarry (Plate 28). The flat area of the island is made up of waste material, now covered in vegetation mainly grasses. Topsoil was brought to the island from Ireland as ballast in exchange for slate (per. com. Mrs. Carling)

3.5.11.4 Resources

The resources of the island are exhausted. Only a narrow sea wall has been left on the north and east sides of the quarry. The slate left intact on the westside of the island has been untouched due to late folding. Jointing is controlled by bedding and is not parallel to the cleavage.

3.6. Summary

The slate from Easdale Island was once said to roof the world. However resources on this small island are now exhausted and considerable work would need to be done to select a quarry in the area, suitable for further exploitation. Only limited information from fresh samples is available and assessment of the weathering properties of the slate from different quarries is based on the appearance of the slate in the quarries after 50-100 years.

3.6.1 Easdale Island	**EASDALE ISLAND QUARRIES**
Resources	*Exhausted*

3.6.2. Seil Island	**ELLENABEICH QUARRIES**
Resources	*Limited*
Weathering	Good
Access	Poor
Environmental Sensitivity	Ellenabeich is a conservation village with narrow streets.
Comment	No action due to its location.

3.6.3 Seil Island	**BREINE PHORT**
Resources	*Medium* resources are available along the cliff face and below the level of the present workings, with possible extension to the east
Weathering	Slate in the tips and quarry faces show extensive rusty weathering.
Access	Reasonably good.
Environmental Sensitivity	Low, apart from a few houses near the entrance this slate quarry is remote from the villages in the area and hidden from view behind the cliffs.
Comment	Re-opening this quarry is a possibility due to its location however further work would need to be done to determine the quality of the slate.

3.6.4 Seil Island	**BALVICAR**
Resources	*Medium* resources present due to a metadolerite sill to the east and alluvium to the west.
Weathering	Poor to bad
Access	Good
Environmental Sensitivity	High, this area has been landscaped as a golf course.
Comment	Re-opening not recommended in view of the poor quality slate and high environmental sensitivity.

3.6.5 Luing Island	**TOBERONOCHY**
Resources	Resources are *limited* in the immediate vicinity of the quarry as this quarry has been worked to >60m and is now flooded.
Weathering	Excellent.
Access	Good. Close to the road and the sea.
Environmental Sensitivity	The quarry is located in a village with narrow roads and surrounded by attractive former quarriers' cottages.
Comment	There is good quality slate in this area and it is worth exploiting if sufficient resources can be found and the environmental problems overcome.

3.6.6 Luing Island	**RUBHA NA H-EASGAINNE**
Resources	*Medium* resources but recovery is expected to be low due to geological factors such as folding.
Weathering	Poor to medium.
Access	There is no road leading to these quarries.
Environmental Sensitivity	Low; this quarry is remote from all habitation.
Comment	Not recommended due to the inaccessibility of the quarries and complexity of the geology

3.6.7 Luing Island	**PORT MARY**
Resources	*Medium* resources but recovery would be poor, due to folding.
Weathering	Poor to medium.
Access	Good farm track to the north quarry.
Environmental Sensitivity	Low; this quarry is hidden quarry in a remote area.
Comment	This quarry is in a good location but the probable usable slate is likely to be extremely low

3.6.8 Luing Island	**CULLIPOOL**
Resources	*Medium* resources within the confines of Quarry No 3
Weathering	Medium-good
Access	Poor, through the narrow street of the village.
Environmental Sensitivity	High, this quarry is close to the village.
Comment	Possibility for small scale development within the confines of the Quarry No 3.

3.6.9 Luing Island	**TIR NA OIG**
Resources	Although the slate resources are *large* in this area, good slate is *limited* and recovery poor due to geological factors such as folding.
Weathering	Medium.
Access	Very inaccessible.
Environmental Sensitivity	Low, these quarries are in a very remote area.
Comment	Not recommended due to the inaccessibility of the quarries and probable reserves are likely to be extremely low.

3.6.10 Luing Island	**BLACK MILL BAY**
Resources	*Large* resources of slate but potential usable slate is probably *limited*.
Weathering	Poor.
Access	Good.
Environmental Sensitivity	Apart from one or two houses this quarry is in a remote area.
Comment	Not recommended due to the poor quality of the slate

3.6.11 Belnahua Island	**BELNAHUA QUARRIES**
Resources	*Exhausted.*

3.7 Conclusion

No quarry is ideal for further investigation as a possible source of Easdale slate. Resources in quarries with the best quality slate are exhausted and Breine Phort is proposed as a compromise between quality and resource.

Mineralogy: Although the mineralogy of the slate is good in that there is a high quartz content and the ratio of white mica to chlorite is high, the white mica has low potassium plus sodium content making it more prone to weathering. The iron ore mineral is pyrite/pyrrhotite which is present as small crystals or is disseminated throughout the rock and is extensively weathered.

Crystallinity: The crystallinity of the slate is very high as measured by the intensity of XRD peaks and FWHM of 0.11 to 0.12 2θ.

Size of slates: Where the cleavage is smooth and regular it would be possible to produce thin flat slates. The fabric of the few samples analysed suggests potential commercial thickness at 5-6mm. However minor folding of the cleavage would increase the thickness and reduce the size of the slates. Jointing is closely spaced which would also limit the size on the slates produced. However the joints are generally orientated parallel to the cleavage and pillaring surfaces which would minimise this constraint.

Recovery: The proportion of the reserves in the present quarry that is usable slate is estimated as low due to the presence of igneous intrusions and quartz veins. However the large resources in the area outside the confines of the quarry may be worth investigating.

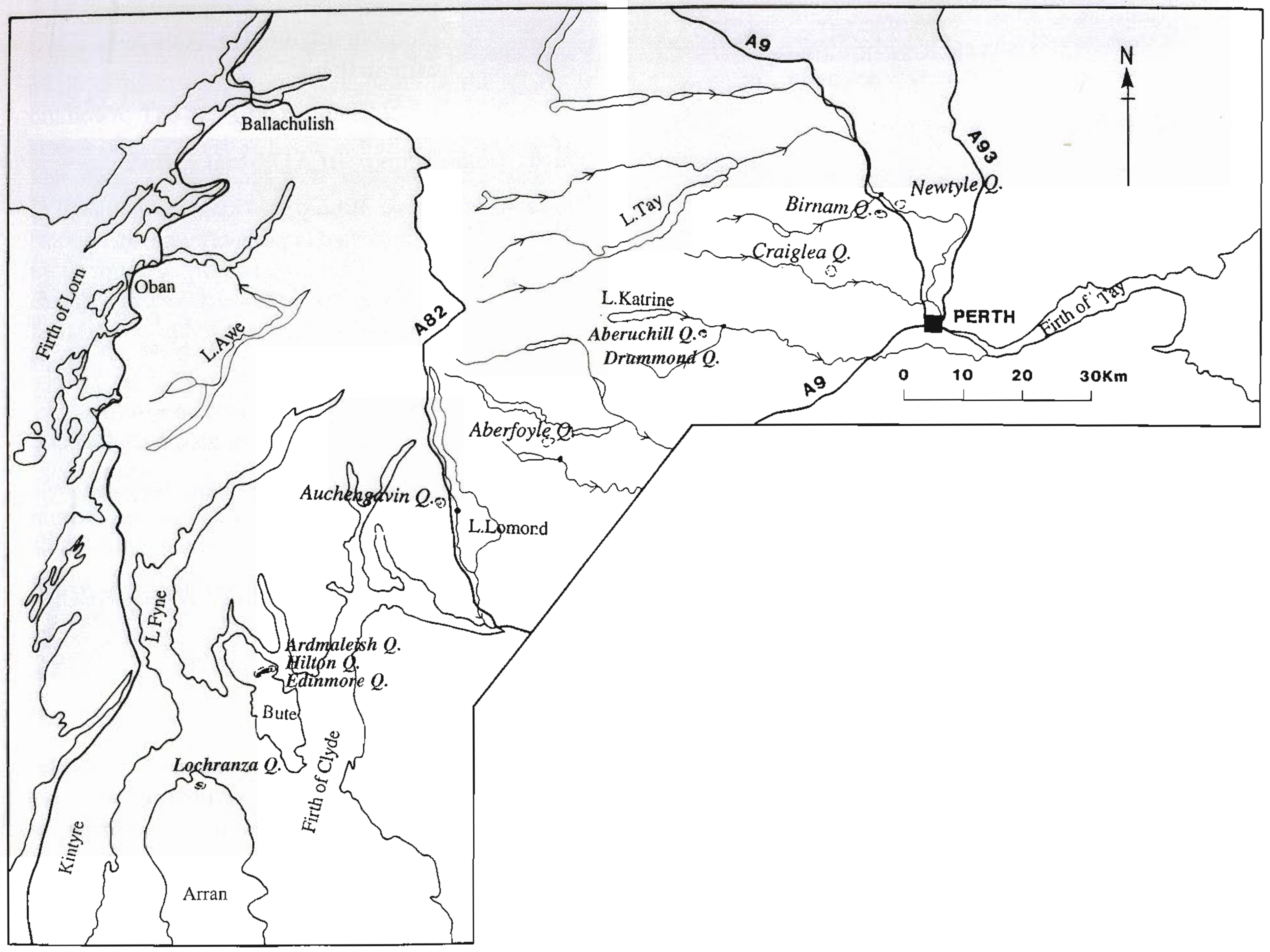


Fig. 4.1 Location of the Highland Border Slate Quarries

4 THE HIGHLAND BORDER SLATE QUARRIES

4.1 Introduction

4.1.1 Location

A slate belt stretching from Arran in the west to Dunkeld in the east has been quarried at several places to provide slate both locally and nationally (Fig. 4.1). Locations are given for individual quarries in Section 4.5 *Quarry Appraisals.*

The following quarries are described:-

Location	Quarry Group	Grid Ref
Arran	Lochranza Quarry	NR963504
Bute	Ardmaleish, Hilton and Edinmore Quarries	NS052680-NS075696
Luss	Auchengavin Quarry	NS347928
Aberfoyle	Aberfoyle Quarries	NN502029-NN508033
Comrie	Aberuchill and Drummond Quarries	NN716197& NN709188
Logiealmond	Craiglea Quarry	NN950322
Dunkeld	Birnam and Newtyle Quarries	NO039404-NO047411

4.1.2 Topography

The Highland Boundary Fault, a complex fracture zone, extends across Scotland from the Mull of Kintyre to Stonehaven. Associated with this fault zone is a rampart of hills which makes a striking topographical feature, marking the boundary between the low rolling countryside of the Midland Valley and the rugged Highlands. The slate belt lies to the north of this line from Arran to Dunkeld, where it is finally cut out by the Fault. Within the Highlands a distinction can be made between the slate outcrops and the more predominant grits e.g. the slate area is characterised by smooth rounded hills in sharp contrast to the more rugged mountains to the north. *"Slate under the influence of the weather crumbles into small debris, over which a mantle of vegetation spreads, that gives the hills a smooth green aspect"* (Geike 1901).

4.2 Geology

The youngest group of the Dalradian Supergroup, the Southern Highland Group, lies immediately to the north of the Highland Boundary Fault. This Group includes the slate which is the subject of this chapter.

4.2.1 Stratigraphy of the Southern Highland Group

This Group crops out from the west coast of Ireland to the SE in Scotland. It consists of coarse-grained metagreywackes with subordinate fine-grained slates and phyllites. Sedimentary structures are indicative of a wide range of environments, making it difficult to correlate across the Group. It is generally assumed that the slate bed facies are highly diachronous (Harris & Fettes 1972). However there is a general trend in that the older parts of local successions are composed of the finer grained slate and phyllite units and the younger parts are the coarser grained grits. Correlation is also complicated by across strike changes in metamorphic grade, which has led in the past to equivalent stratigraphical units being given different names (Stephenson & Gould 1995) (Table 4.1).

Locality				
Arran	**Bute**	**Luss**	**Aberfoyle & Comrie**	**Logiealmond & Dunkeld**
North Sannox Grits	Rothesay Grits	Beinn Bheula Schist	Ben Ledi Grit	Dunkeld Grit
		Bullrock Greywacke	Leny Grit	Birnam Grit
Lochranza Slates	Dunoon Phyllites		Aberfoyle Slates	Birnam Slates

Table 4.1 Local names given to Highland Border slate and adjacent metagreywackes

Environment of deposition

The predominantly psammitic rocks of the Southern Highland Group were deposited by turbidity currents on a subsiding continental shelf, forming major submarine fans. The slate units represent the more distal parts of these fans. Relative to the older Dalradian rocks the psammites of the Southern Highland Group have a higher proportion of feldspar, high-grade metamorphic and granitic grains. This led to the idea that a new source area existed to the southeast. However palaeocurrent indicators show a north-west dispersal similar to the rest of the Dalradian Supergroup, and the change in mineralogy is now considered to be due to exposure of higher grade metamorphic rock and granites at the source area as it was eroded (Anderson 1985).

4.2.2 Structure of the Southwest Highlands

The principal structure in the Southwest Highlands is the recumbent Tay Nappe (Fig. 4.2). This primary fold has been tightened and extended producing a parallel-sided flat lying nappe of large amplitude. A later episode of deformation, probably related to uplift, folded the Tay Nappe into large open folds with a NE-SW trend such as the Cowal Antiform. This structure, which is a downbend or monoform, trends a few km north of the Highland Boundary Fault from Arran to Dunkeld, dividing the Southern Highlands into a flat belt and a steep belt.

Slate quarries are generally located in the hinge zone of the Tay Nappe (also called the Aberfoyle Anticline), to the south of the Highland Border Monoform. This is within the steep belt where the cleavage is strikes ENE-WSW and dips 50-80° either to the SE or NW. The erosional level is such that the lower limb of the Tay Nappe is exposed and sedimentary structures are overturned (Fig. 4.2).

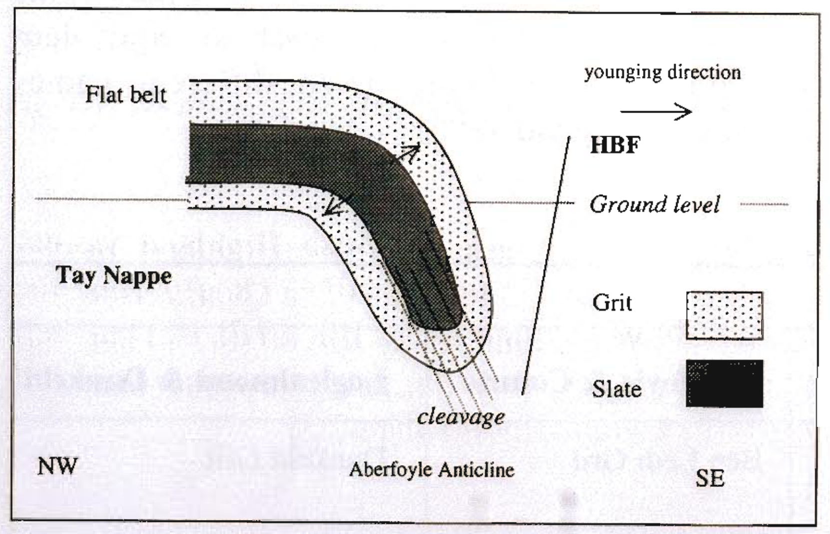


Fig. 4.2 Cartoon of the geological structure of the area to the north of the Highland Boundary Fault (HBF)

4.3 History

It is difficult to give a generalised history of the Highland Border quarries, distributed as they are across a large area of Scotland. Instead a brief historical paragraph is included for each individual quarry in Section 4.5 *Quarry Appraisals* below.

4.4 Description of Highland Border Slate (Plates 60 to 65)

4.4.1 Hand Specimen

Highland Border Slate is coarse to medium grained with frequent silt bands. Colour is variable with blue-grey, green and purple often found in the same quarry. Different bands are indicative of primary bedding features, and changes can be seen at a scale ranging from centimetres within one sample (Plate 29) to tens of metres in a whole quarry (Plate 44).

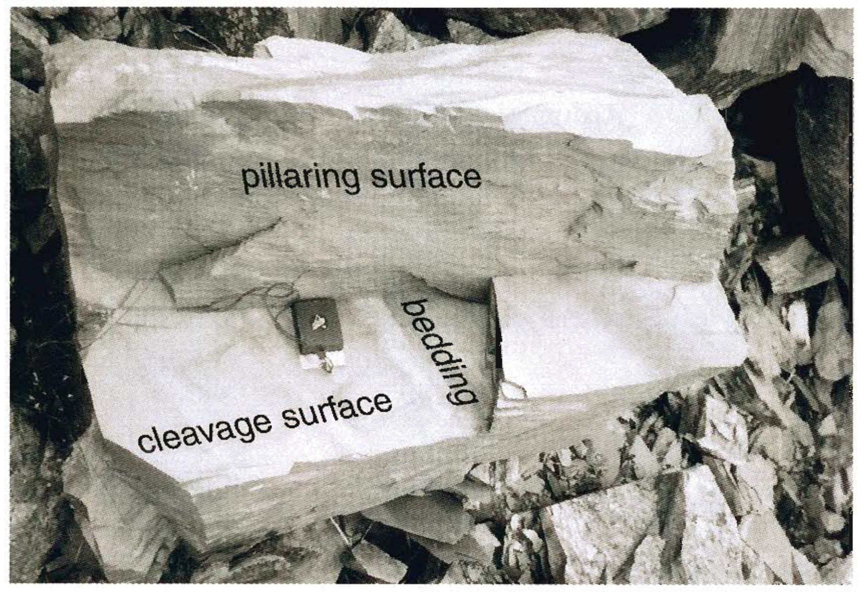


Plate 29 Highland Border Slate from Drummond Quarry near Comrie

4.4.2 Mineralogy of Highland Border Slate

The mineralogy of a number of samples is shown in Appendix 1.

Major Minerals

The minerals present are quartz, white mica and chlorite.

Minor Minerals

Carbonate is present as calcite, often concentrated in individual bands of slate.

Iron is present as haematite, pyrite is uncommon.

No graphite.

White mica	Si	Ti	Al	Mg	Ca	Mn	Fe	Na	K	Anions
B2	3.16	0.01	2.45	0.27	0.00	0.01	0.26	0.21	0.74	$O_{10}(OH)_2$
AB-5	3.12	0.01	2.63	0.12	0.00	0.00	0.22	0.23	0.68	
DN-4	3.15	0.00	2.61	0.12	0.00	0.00	0.19	0.20	0.73	
Chlorite										
B2	2.68	0.01	2.67	3.00	0.01	0.06	1.56	0.00	0.00	$O_{10}(OH)_8$
AB-5	2.66	0.00	2.77	2.21	0.00	0.08	2.23	0.00	0.00	
DN-4	2.68	0.00	2.85	2.19	0.00	0.04	2.10	0.00	0.00	

Table 4.2 Formulae of chlorite and white mica for a few Highland Border slate samples

Formulae

The formulae of samples from Bute (B2), Aberfoyle (AB-5) and Dunkeld (DN-2), determined by electron microprobe analyses, are shown above (Table 4.2).

Crystallinity

The crystallinity values were determined for a range of samples collected from all the quarries as well as for some used slates. In every case the samples have been subjected to varying degrees of weathering and values are therefore lower than would be obtained if fresh samples were available.

Locality	Crystallinity
Arran	Medium
Bute	High
Luss	Very high
Aberfoyle	Low-medium
Comrie	Medium
Logiealmond	High
Dunkeld	Medium

Table 4.3 Crystallinity of Highland Border slate as determined by the relative intensity of XRD peaks

4.4.3 Weathering

Chemical weathering is affected by the amount of reduced iron available for oxidation in the presence of water. The amount of reduced iron determined by wet chemistry analyses was found to be very variable.

Reduced iron/Total iron

Iron in chlorite is usually present as Fe^{2+} (reduced iron), while that in haematite is Fe^{3+} (oxidised iron), therefore the ratio of reduced iron to total iron is dependent on the amount of haematite present. This ratio affects the colour of the slate, for example in DN-1, a green slate, haematite is below the XRD detection limit and most of the iron is present as Fe^{2+} in the chlorite. In contrast in DN-4, a purple slate from a nearby quarry, there is substantial haematite present and the percentage of Fe^{2+}/Fe_{total} is low (Table 4.4).

Sample	Quarry	% Fe^{2+}/Fe_{total}	Colour
B2	Bute	42	grey
Ab-5	Aberfoyle	32	grey
DN-1	Newtyle North	78	green
DN-4	Newtyle South	39	purple

Table 4.4 Reduced iron: total iron ratio affects the colour of the slate

Water absorption

Water absorption values for fresh Highland Border slate are only available for Aberfoyle Quarry. Here the levels are above the limit set by BS680 (0.3%) but well within that proposed by the new European Standard (0.6%). (Research Report Chapter 5)

Durability of Highland Border Slate

Slates with pyrite and calcite weather rapidly (Research Report Ch. 5) but in the absence of pyrite those with calcite, even at high concentrations, can be

a) The barn at Frances Field (Kipney) is now suffering from nail sickness

b) Bonellas Cottage has recently been re-roofed using the original slate with less than 10% wastage

Plate 30 Two buildings roofed with slate from Craiglea Quarry

very durable e.g. Cumbrian slates. In general, Highland Border slates have no pyrite, and calcite if present is at low concentrations. This is supported by the fact that the few Aberfoyle slates tested passed the Wet and Dry test and the Acid Immersion test of BS680 (BRE archives).

The vulnerable mineral in these slates is chlorite, where the reduced iron can be oxidised to produce the limonite staining observed in most quarries.

The percentage weight of quartz varies from one area to another, the highest being Arran at 30% and the lowest Aberfoyle at 15%. This latter figure is one reason that Aberfoyle Slate has a reputation for softening after 20 to 30 years. An example of a durable slate from Craiglea Quarry was found at Logiealmond.

4.4.4 Fabric

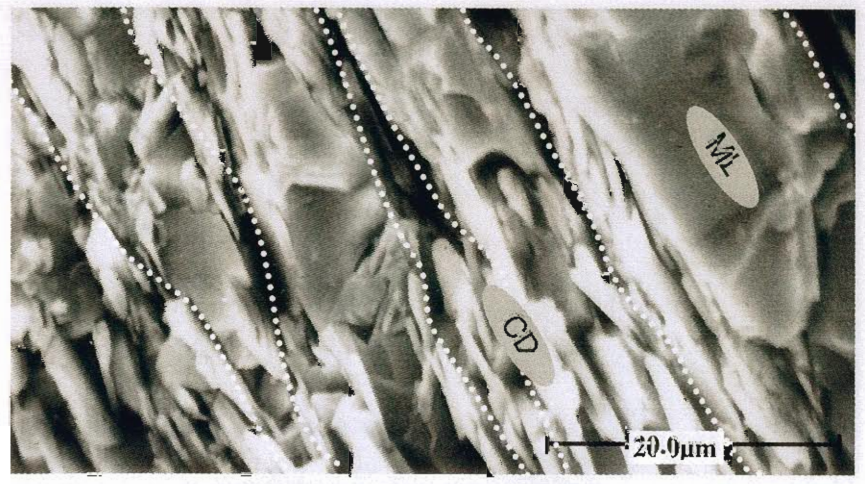
The fabric in Highland Border slate shows considerable variation within one quarry, let alone from one area to another (Table 4.5).

Comments

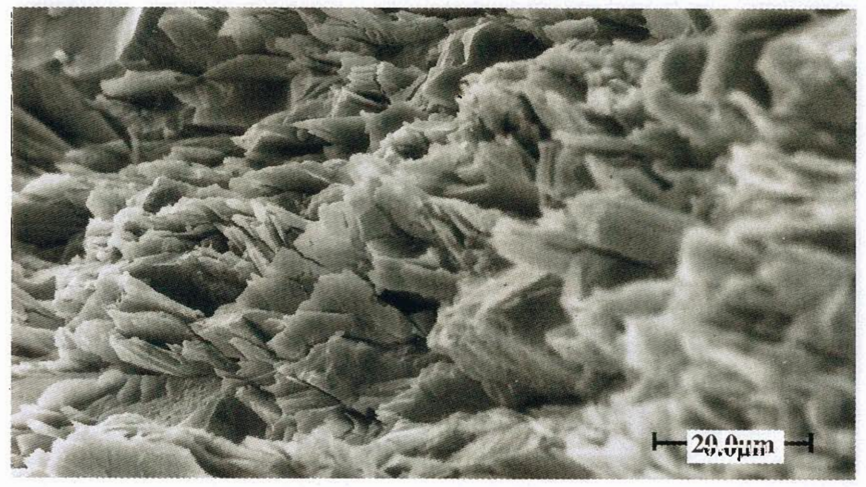
- The overall mineralogy of Highland Border slate makes it suitable as a roofing material although the low quartz present in some slates accounts for some samples softening within 50 years on a roof. Limey bands (containing calcite) should be avoided.
- The crystallinity, although low compared with the Ballachulish and Easdale slates, is similar to *unweathered samples* from North Wales and Cumbria.
- Fabric is less well developed than in Ballachulish, Easdale and North Wales slate but better than in Cumbrian.

Locality	Grain size	Shape of Cleavage Domains	Degree of Alignment	Potential commercial thickness (mm)
Arran	Fine grained	Straight and continuous	Medium	5
Bute	No results			
Luss	Fine grained	Undulating and continuous	High	6
Aberfoyle	Medium-coarse	Anastomosing and continuous	Medium-good	7
Comrie	Medium-coarse	Anastomosing and discontinuous	Low	10
Logiealmond	Fine grained	Straight and continuous	Low	7
Dunkeld	Fine grained	Straight and continuous	Good	7

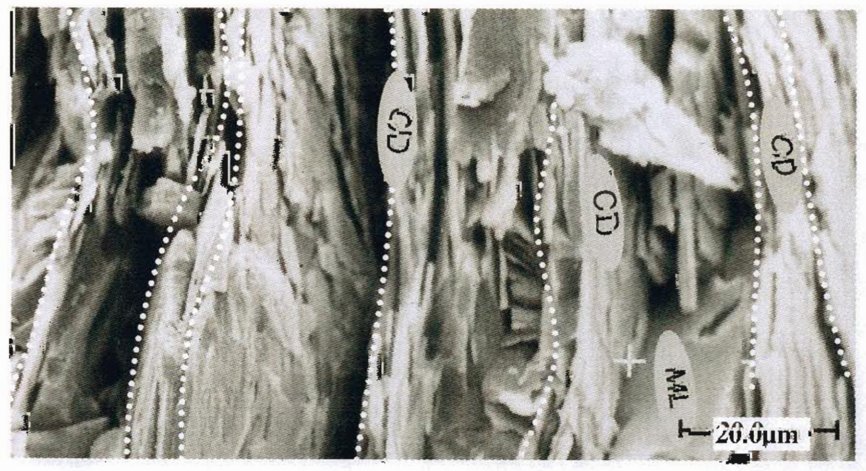
Table 4.5 Variation of cleavage for different Highland Border slate quarries



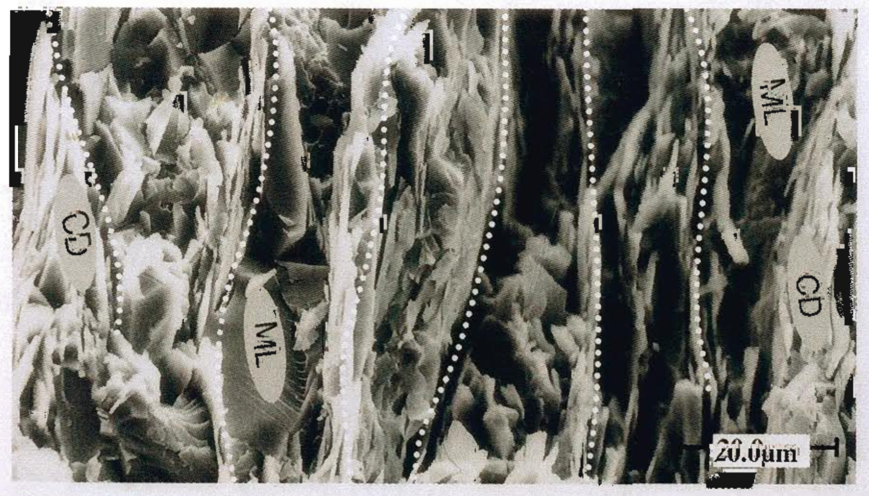
a) Arran LOCHRANZA QUARRY A-1
Cleavage domains are straight, continuous and very closely spaced making it possible to split the slate to approximately 5mm



b) Bute HILTON QUARRY B-3
Poorly developed cleavage fabric. It was not possible to estimate the ability to split this slate.

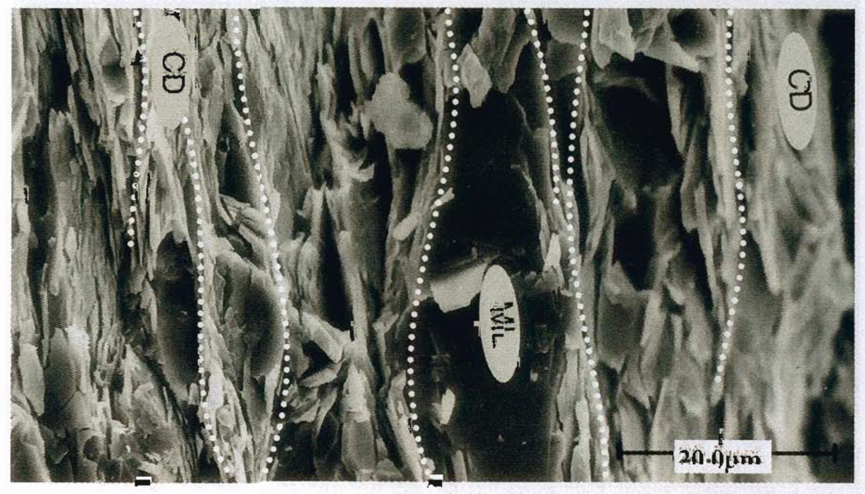


c) Luss AUCHENGAVIN QUARRY LS-1
Finely spaced continuous cleavage domains but curvilinear which will affect its ability to be split along a plane. Estimated thickness 6mm.

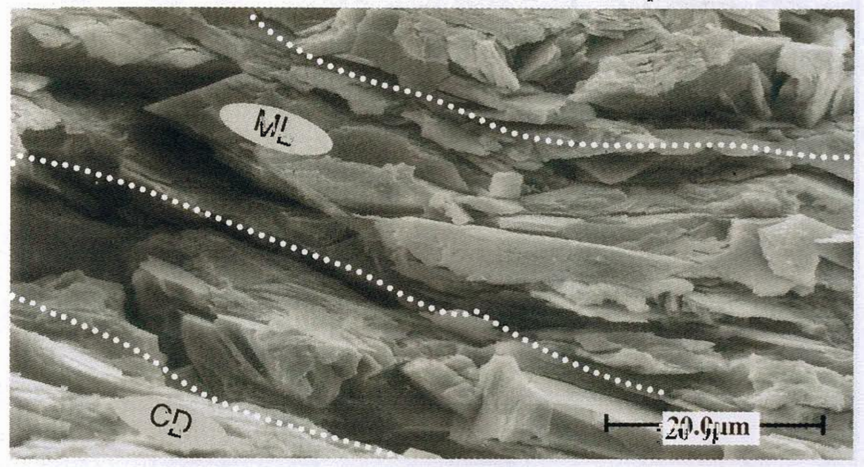


d) ABERFOYLE QUARRIES AB-5
Cleavage domains are continuous, widely spaced and anastomosing around microlithons with little fabric. Estimated thickness 6.5 - 7mm.

e) Comrie ABERUCHILL QUARRY AU-1
Widely spaced, discontinuous cleavage domains, microlithons with little fabric makes this potentially a very thick slate ~10mm



f) Logiealmond CRAIGLEA QUARRY CR-3
Cleavage domains are fairly closely spaced and slightly anastomosing. However, they are also discontinuous and irregular giving this slate the potential to be split to 6mm.



g) Dunkeld Middle Level BIRNAM QUARRY DB-1
Cleavage domains are unevenly spaced and discontinuous giving this slate the ability to be split > 6mm.

h) Dunkeld NEWTYLE NORTH QUARRY DN-3
Finely spaced straight and continuous cleavage domains separated by elongated microlithons give this slate the potential to be split to 5mm.

Fig. 4.3 Fabric of Highland Border slate

4.5 Quarry Appraisals

4.5.1 ARRAN QUARRIES NR963504 (Fig. 4.1, Fig. 4.3a), Fig. 4.4, Fig. 4.5 and Plate 31)

The slate quarries lie within the Dalradian outcrop, north of the Highland Border Fault at the Cock of Arran. The fault itself is obscured by the large granitic intrusions which make up the mountains of Arran.

Plate 31 Slate quarry on the north of Arran

4.5.1.1 Site Details	
Location	The Lochranza Quarries are located in the north of Arran about 3 km from the ferry pier at Lochranza, at a height of 300m. The main quarry is at NR963504 with two smaller workings at NR961503.
Maps	OS 1:50000 Landranger Series Sheet 69 1:10000 NR 95 SW BGS 1:50000 Arran Special Sheet & Sheet 21
Access	To the west of the village of Lochranza there is a minor road leading north to the Cock of Arran. This unpaved road becomes a mere grassy track as it rises to 240m. The track passes within 500m of the quarries, which lie to the SE. The trace of an old road leading to the main quarry can be seen in the evening light.
Ownership	Mr. C. Fforde, Arran Estate Office, Brodick, Isle of Arran

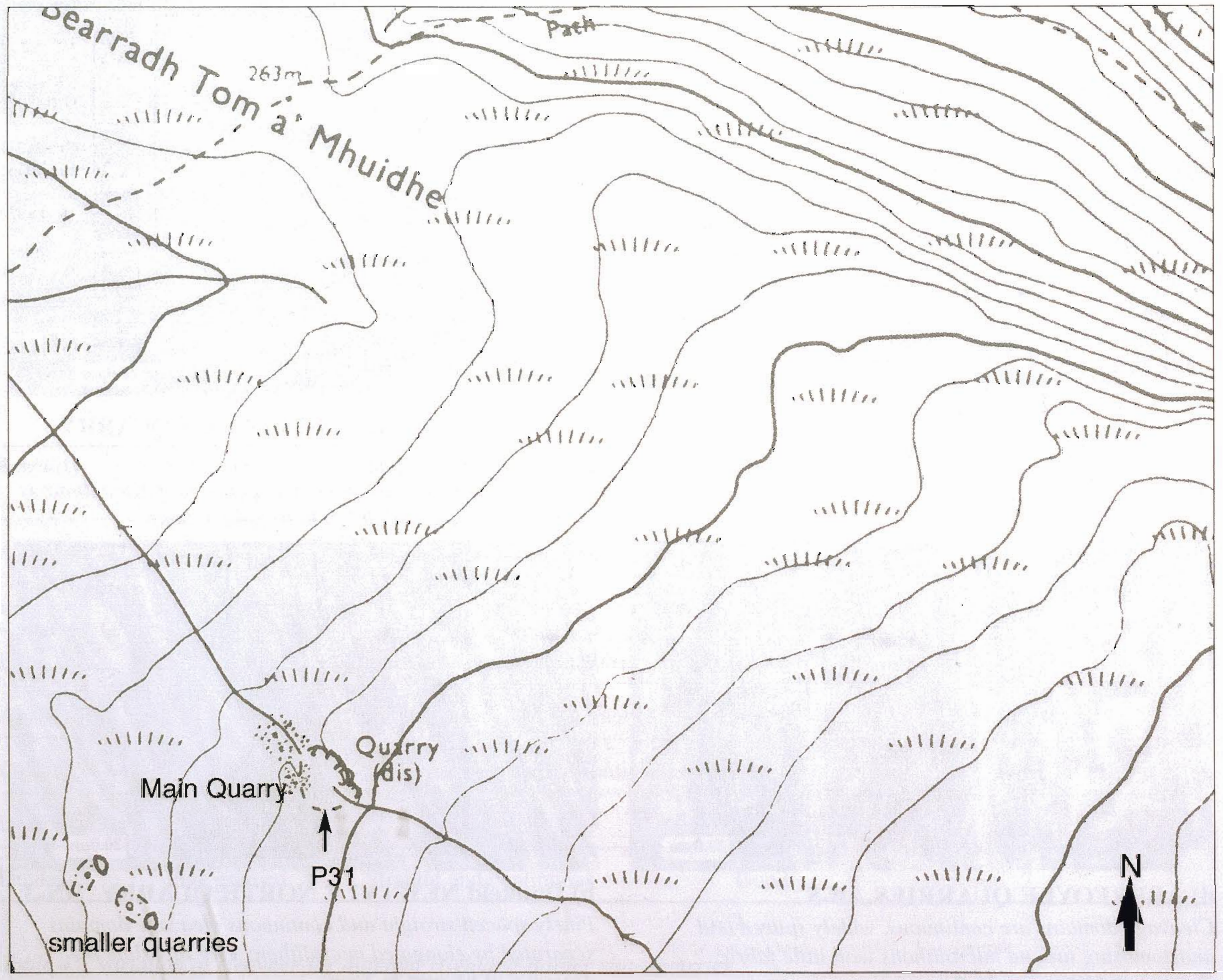


Fig. 4.4 Map of the Arran Quarries based on OS NR95SE copyright 1979 1:5,000

4.5.1.2 History

The Dukes of Hamilton owned all of Arran for over four centuries (McNaughton 1840), although early in the 20th century the estate was divided between different branches of the family. The quarries have not been worked for over 150 years. The only known records are kept in the Arran Estate Office at Brodick. Here production figures are given for the 18th century which reveal that the quarries were in production between 1773 and 1781. 200 to 300 thousand slates were sold annually at £1 per thousand (Gunn 1903). In the 1840s slate production had already ceased which, according to the Rev. Allan McNaughton (1840), was due to the distance from the harbour at Lochranza and *"the direction of the strata which is contrary to the declivity of the mountain"*. Some of the slate was exported and some sold locally.

4.5.1.3 Geology

Stratigraphy

The outcrop pattern in the area consists of alternating bands of slate and schistose grit. The slate was quarried in the oldest local formation, the Lochranza Slate, bounded on both sides by the younger Glen Sannox Grits (BGS Sheet 21) (Fig. 4.4).

Structure

The geology of North of Arran is dominated by the presence of the Tertiary Granite, which intruded the Dalradian rocks and modified their structure. In common with the other slate formations along the Highland Boundary Fault, the Lochranza Slate occupies the core of the overturned Tay Nappe (Aberfoyle Anticline) bounded to north and south by younger grits. In Tertiary times the rising magma pushed the country rock upwards forming the semi-circular Catacol Synform, which lies concentric with the granite (Anderson 1946, Shackleton 1958). The axial trace of this synform runs through the Lochranza Slate formation, accounting for the arcuate outcrop pattern of the slate (BGS Sheet 21). Instead of the more normal cleavage dipping steeply south-east, the cleavage is variable; dipping southwards at the north of the outcrop near Craith Glas Cruithe, while in Glen Chalmadale near the southern boundary of the outcrop the dip is eastwards. In the slate quarries the cleavage is dipping at a low angle to the north-east.

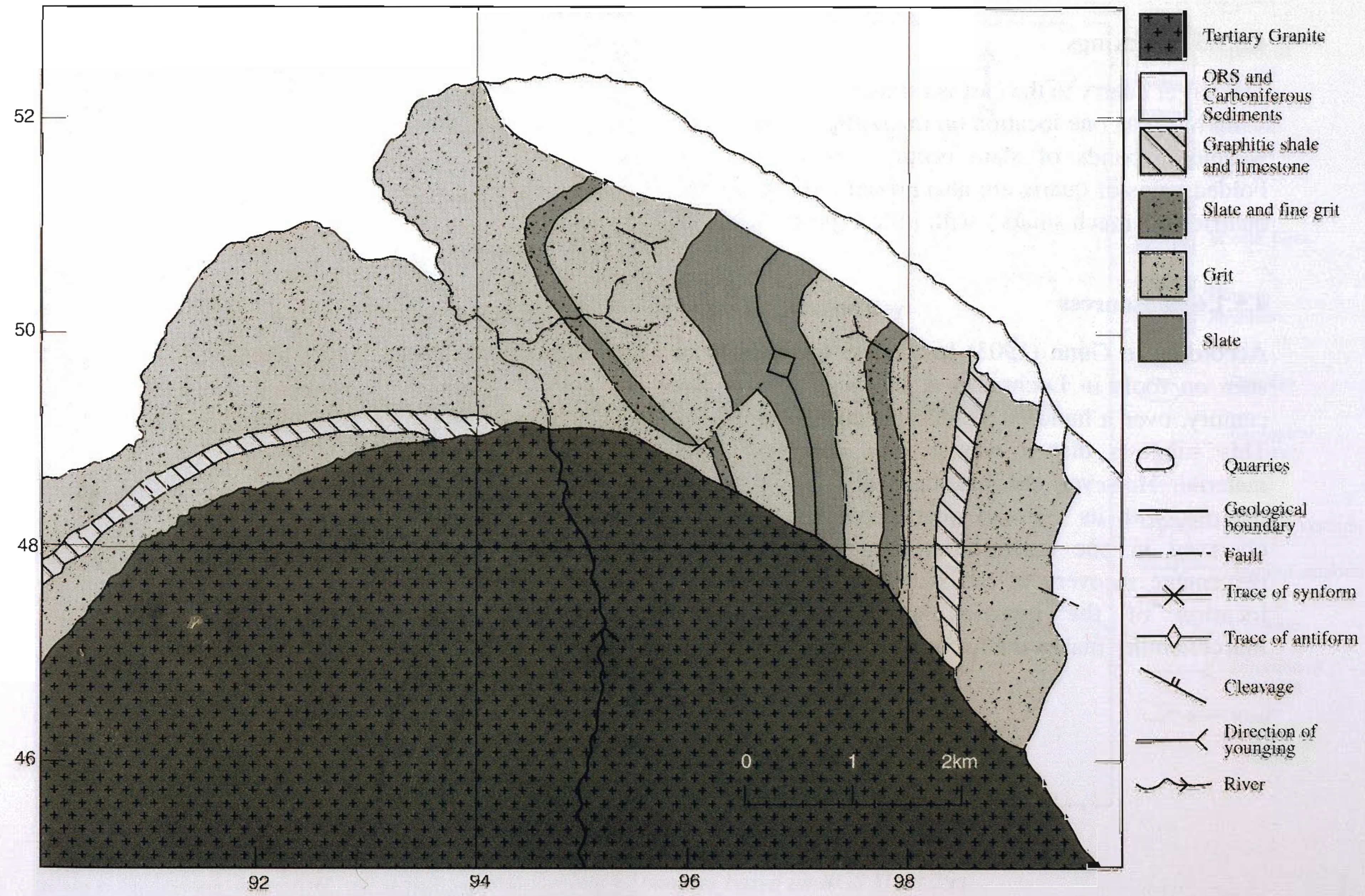


Fig. 4.5 Sketch of the geology in the area of the Arran Slate Quarries based on BGS Sheet 21

4.5.1.4 Quarry Details

Slate	The slate is dark grey with a relatively smooth texture. Lenses of lighter green slate are estimated at 10% of the formation.
Cleavage	The strike varies from 270° to 310° and dips 20° to 25°. The cleavage appears regular and the variation in strike is a result of the low angle of dip.
Bedding	Bedding is at a low angle to cleavage estimated as 15°.
Joints	As well as irregular fractures, one set of joints is observed pitching on the cleavage surface at a low angle to the west at 0.5m intervals.
Imperfections	There are numerous silty bands and occasional quartz veins.
Weathering	One band of crumbly slate (1-3cm thick) was observed and another band of pebbly quartz with minor recumbent folds.
Overburden	Less than 1m.

4.5.1.5 Workings

The larger quarry to the east is estimated at 30m x 10m x 3m high. At one location on the north face the badly weathered bands of slate occur at 0.5m intervals. Folded veins of quartz are also present. The two other quarries are much smaller with little exposed slate.

4.5.1.6 Resources

According to Gunn (1903) local slate was still to be seen on roofs in Lochranza at the beginning of this century, over a hundred years after quarrying ceased. This suggests that it was a very durable roofing material. However, the heterogeneous nature of the outcrop, with its veins of quartz and silty bands all observed in one small outcrop, suggests that the percentage recovery of the slate was very low. The location of the quarries at 300m and their inaccessibility makes their reopening unviable.

4.5.2 BUTE QUARRIES NS052680-NS075696 (Fig. 4.1, Fig. 4.3b, Figs 4.6 – 4.9 and Plates 32-34)

The Bute slate quarries are located north of Kames Bay at the point of Ardmaleish and on the southern slopes of the hills to the north (Fig. 4.6).

Plate 32 Slate quarry at Ardmaleish Point on the west of the island of Bute (NS075696)

Plate 33 Slate quarry on Hilton Farm on the island of Bute (NS059684)

Plate 34 Slate tips at the quarry near Edinmore Farm on the island of Bute (NS052680)

4.5.2.1 Site Details

Location	Ardmaleish Point	NS075696
	Hilton Farm	NS059684
	Edinmore Quarry	NS052680
Maps	OS 1:50000 Landranger Series Sheet 63	
	1:10000 NS 06NE	
	BGS 1:63360 Sheet 29	
Ownership	The Marquis of Bute	

4.5.2.2 History

Slate production made little impact in the industrial heritage of Bute with its prosperous cotton, agricultural and fishing industries. An early mention of Bute slate was in 1445 when 11s 10d was paid by the Royal Chamberlain for 130,000 slates from the quarries of Bute sent to Dumbarton to repair the King's Castle (Hewison 1845). The Provan Lordship's House, the oldest in Glasgow, is reputed to be roofed with Bute

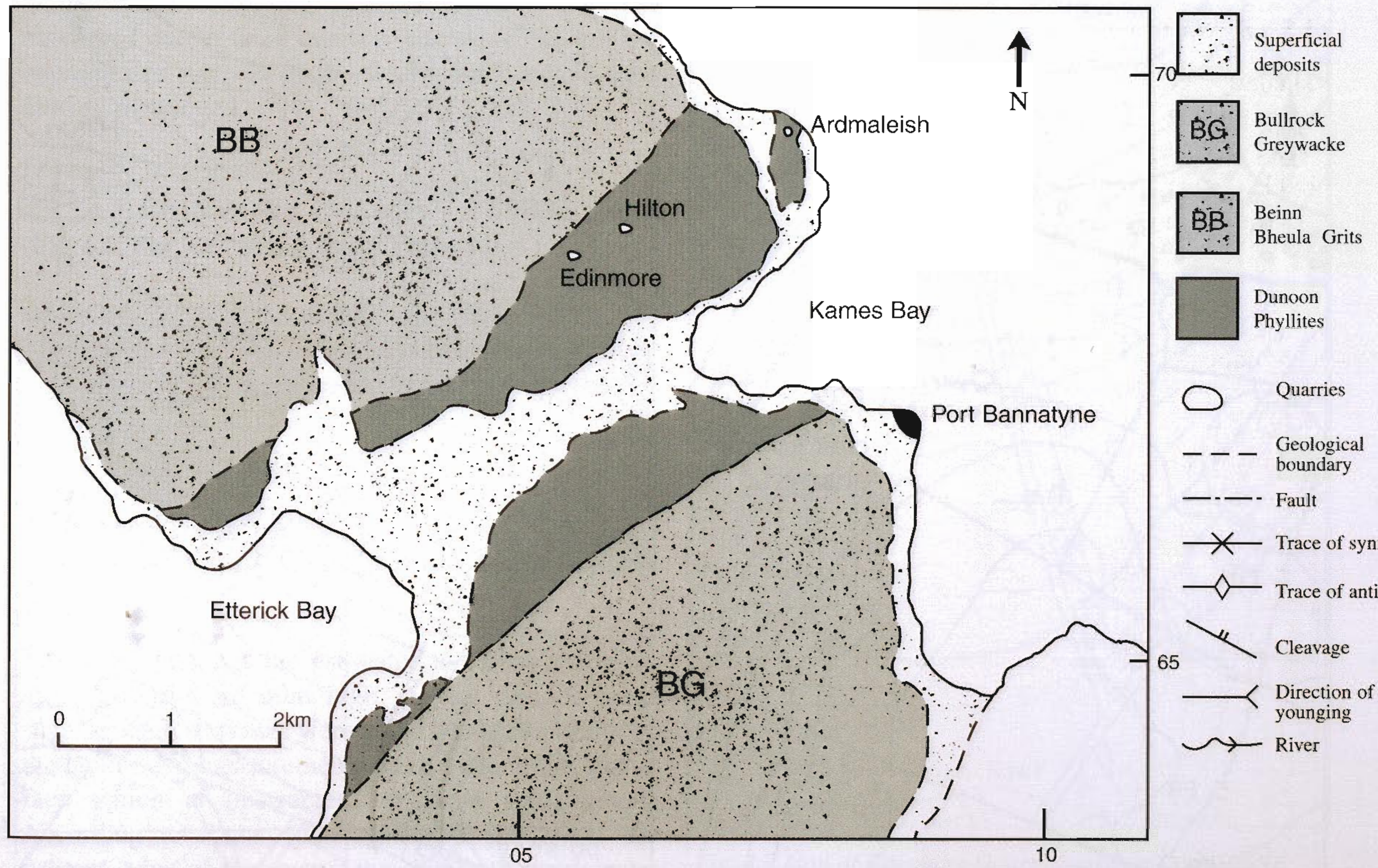


Fig. 4.6 Sketch of the geology in the area of the Bute Slate Quarries based on BGS Sheet 29

slates (Marshall 1955). Slate production had almost ceased in the 1880s although Hilton Quarry was re-opened for a time just prior to 1920 to rebuild Wester Kames Castle .

4.5.2.3 Geology

The rocks of the north of Bute are made up of psammitic grits divided by a thin band of slate. This band, called the Dunoon Phyllite, crosses the island from Etterick Bay in the west to Kames Bay in the east (Fig.4.6). Most of the low ground in this area is covered with alluvium and the slate is only exposed on an escarpment to the north and on the gentle hills to the south. The boundary between alluvium and slate is highlighted by a change from the lush farmland vegetation of the former to the sparse growth of the latter. One outcrop is found at sea level i.e. the very old working at Ardmaleish. The other Bute quarries are located at intervals along the southern slopes of the northern escarpment at a height of approximately 120m.

4.5.2.4 Quarry Details

4.5.2.4.1 ARDMALEISH QUARRY NS075696
(Fig. 4.1, Fig. 4.6, Fig. 4.7 and Plate 32)

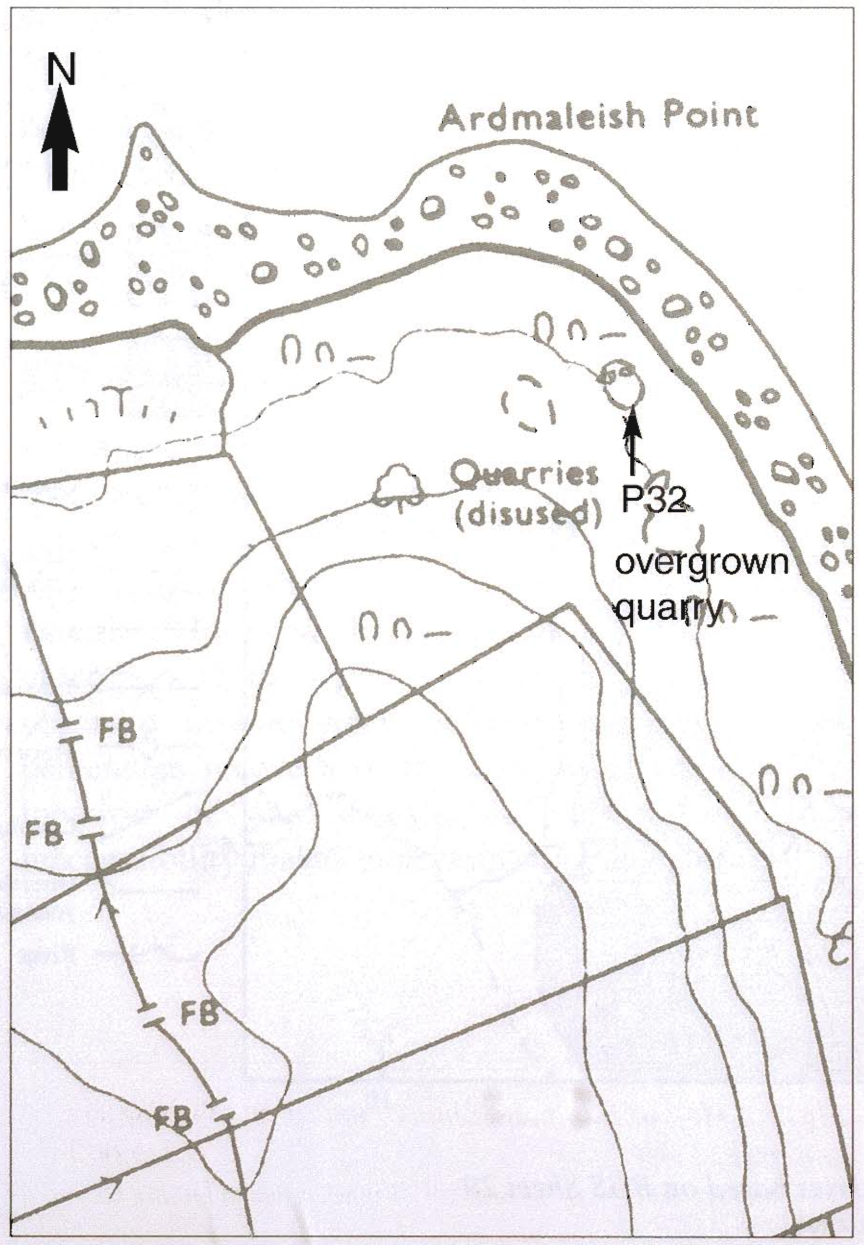


Fig. 4.7 Map of Ardmaleish Quarries based on OS NS06NE copyright 1980 1:5,000

Access	500m along the shore.
Colour	Light grey, occasionally green.
Cleavage	060°/60° average.
Joints	Irregular.
Bedding	Bedding/cleavage intersection at 15°.
Imperfections	Thick veins of quartz and grit bands.
Weathering	There is considerable rusty weathering in this quarry.

Workings

There are two small workings approximately 20m x 10m in size now completely overgrown with gorse. Thick veins of quartz are exposed on the shore next to the quarry, which extend into the north part of the quarry. This was the source of slate for the King's Castle (Section 4.5.2.2).

4.5.2.4.2 HILTON QUARRY NS059684
(Fig. 4.1, Fig. 4.6, Fig. 4.8 and Plate 33)

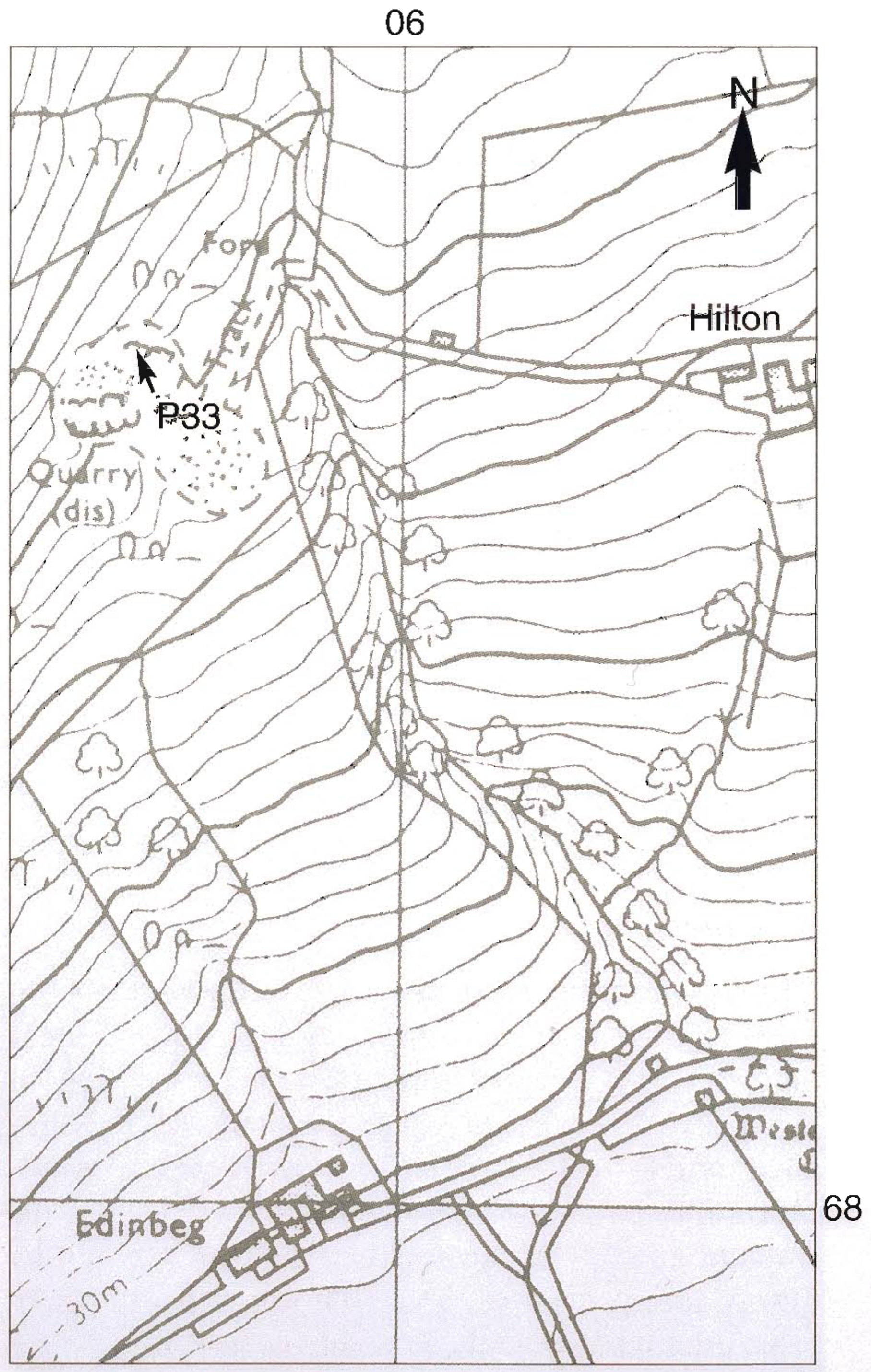


Fig. 4.8 Map of the Hilton Farm Quarries based on OS NS06NE copyright 1980 1:5,000

Access	A well maintained path rises steeply up to Hilton Farm, from which a poorer path fords a stream and contours around the hill at the height of the quarries 120m.
Colour	Blue grey
Cleavage	070°/30°
Joints	Irregular
Imperfections	Silty bands are common, quartz veins also present.
Weathering	A band of slate ½m thick has weathered to a yellow powder.

Workings

There are two workings at this location. The easterly one was worked diagonally across strike. The size is estimated at 30m x 5m, height 20m. This quarry is very overgrown.

The second quarry to the west has been worked more recently and is probably the one opened at the beginning of this century especially to re-roof Wester Kames Castle (NS062681 & Section 4.5.2.2). This quarry was worked along strike for 30m and is 10m wide. The overhanging face to the SW was left unworked due to thick quartz veins, which distort the cleavage, as well as to the weathered band of slate already mentioned.

4.5.2.4.3 EDINMORE QUARRY NS052680
(Fig 4.1, Fig. 4.6, Fig. 4.9 and Plate 34)

Access	A well maintained road leads directly from Edinmore Farm to the quarries ½km further on.
Colour	Grey-blue/grey.
Cleavage	030°/30-35°

Workings

The large workings are estimated as 200m x 50m in area. The tips are 30m high. A few flooded areas suggest some workings were below the present floor of the quarry. No measurements were made at the quarry face which is obstructed by large spoil heaps. According to Richey and Anderson (1944), at the western edge of the quarry the slates are overlain by flaggy green gritstone. The slate tips appear to have been used fairly recently, probably as road fill.

4.5.2.5 Resources

The slate outcrop is a little over 1km wide and 4km long tapering to the west, while the inlier at Ardmaleish is significantly smaller. The slate seam in Hilton Quarry is approximately 5m thick probably extending to the west along strike. It is not known whether the same seam was worked at Edinmore Quarry. A more detailed survey is needed to determine the extent of the usable slate in this area.

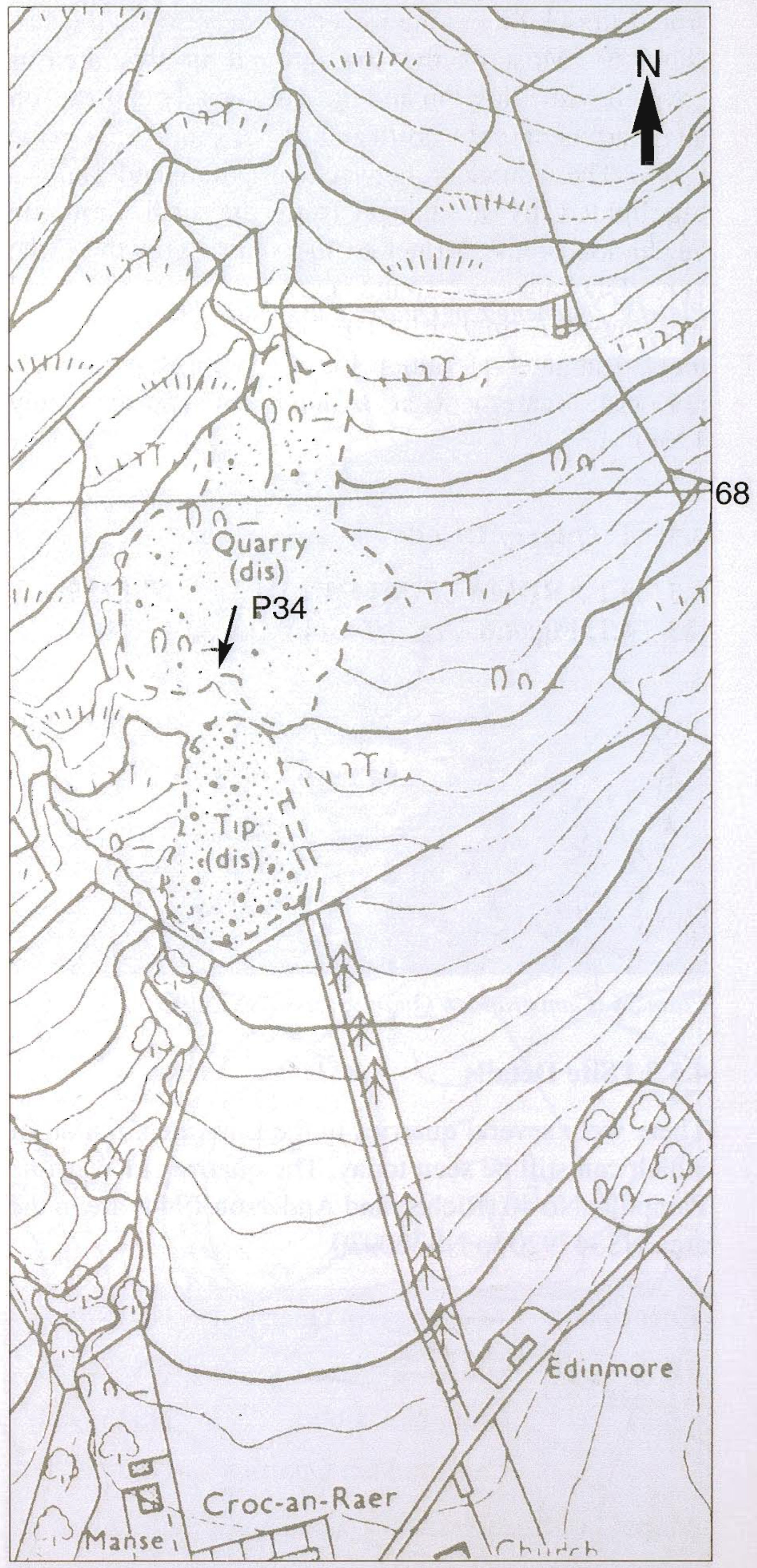


Fig. 4.9 Map of Edinmore Quarry based on OS NS06NE copyright 1980 1:5,000

4.5.3 LUSS QUARRIES NS347920 – NS360930

(Fig. 4.1, Fig. 4.3c, Fig. 4.10, Fig. 4.11 and Plates 35-36, Plates 60-61)

Several slate quarries have been worked in the hills to the west of the village of Luss on the west bank of Loch Lomond (Fig. 4.11).

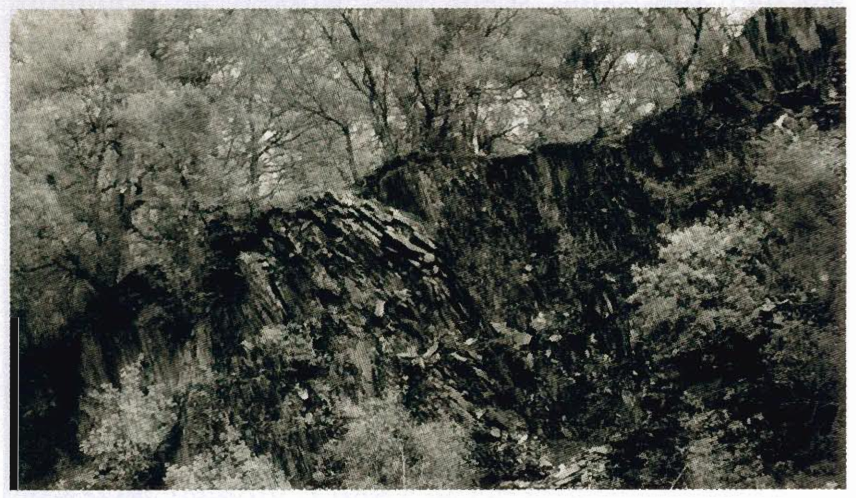


Plate 35 Auchengavin Quarry, Luss (NS347928)

Plate 36 Camstradden Quarry, Luss (NS355920)

4.5.3.1 Site Details

There were several quarries in the Luss area, not all of which can still be seen today. The quarries in Wartime Pamphlet No 40 (Richey and Anderson 1944) are in the area NS347920 to NS360930.

Location	Auchengavin Quarry	NS347928
	Old Quarries	NS357930
	Craig na Gaibhre	NS353924
	Camstradden Quarries	NS355920
Maps	O.S. 1:50000 Landranger Series Sheet 56	
	1:10000 NS 39SE and NS39 SW	
	BGS 1:50000 38 W	
Ownership	Sir Ivar Colquhoun of Luss	
Agents	Luss Estate office	

4.5.3.2 History

Records show that there was a slate quarry in the 15th century (Carr 1839) but Luss is a fertile area where farming was of much greater importance than the slate quarrying.

In the 18th century Statistical Accounts two slate quarries in the Luss area are mentioned (Stuart 1793). The larger of the two was on the Camstradden Estate, where *"10-20 hands"* worked, producing 250,000-360,000 slates annually. The second quarry was the Luss Quarry, also called the Auchengavin Quarry, on the estate of Sir James Colquhoun of Ross-Dhu House. Here 100,000 to 170,000 were exported annually. The workforce of *"10 hands"* were paid at 15 shillings per 1000 slates. The rate for transporting the slates from the quarries to the shore of Loch Lomond was 1s 4d per 1000.

Carr describes two types of slate; a light or greyish blue slate and a dark blue slate. The darker blue slate was reported as superior to the light coloured slate and hence sold at a higher price (Carr 1839).

Mineral statistics published anonymously gave the following production figures for Luss for the years 1883-1888 (1 ton represents approximately 1000 slates)

Year	1883	1884	1885	1886	1887	1888
Production (tons)	800	800	600	500	540	650

According to Smith (1835) the slates were *"not good quality and said to decompose after about 20 years"*.

Year	No of men	Full Size	Undersize	Source
1935	12	500,000	250,000	Richey and Anderson 1944

In 1951 only one worker was employed in the slate quarries. *"Production of roofing slates at Rosneath, Rhu and Luss had ceased in recent years due to competition from tiling"* (Campbell 1959).

Ownership

The Colquhoun family acquired the Luss estate in the mid 14th century and have been the principal landowners ever since. The second estate of any significance, the Camstradden Estate, became the property of a branch of the family in 1397. These two estates were merged in 1845 and have remained in the

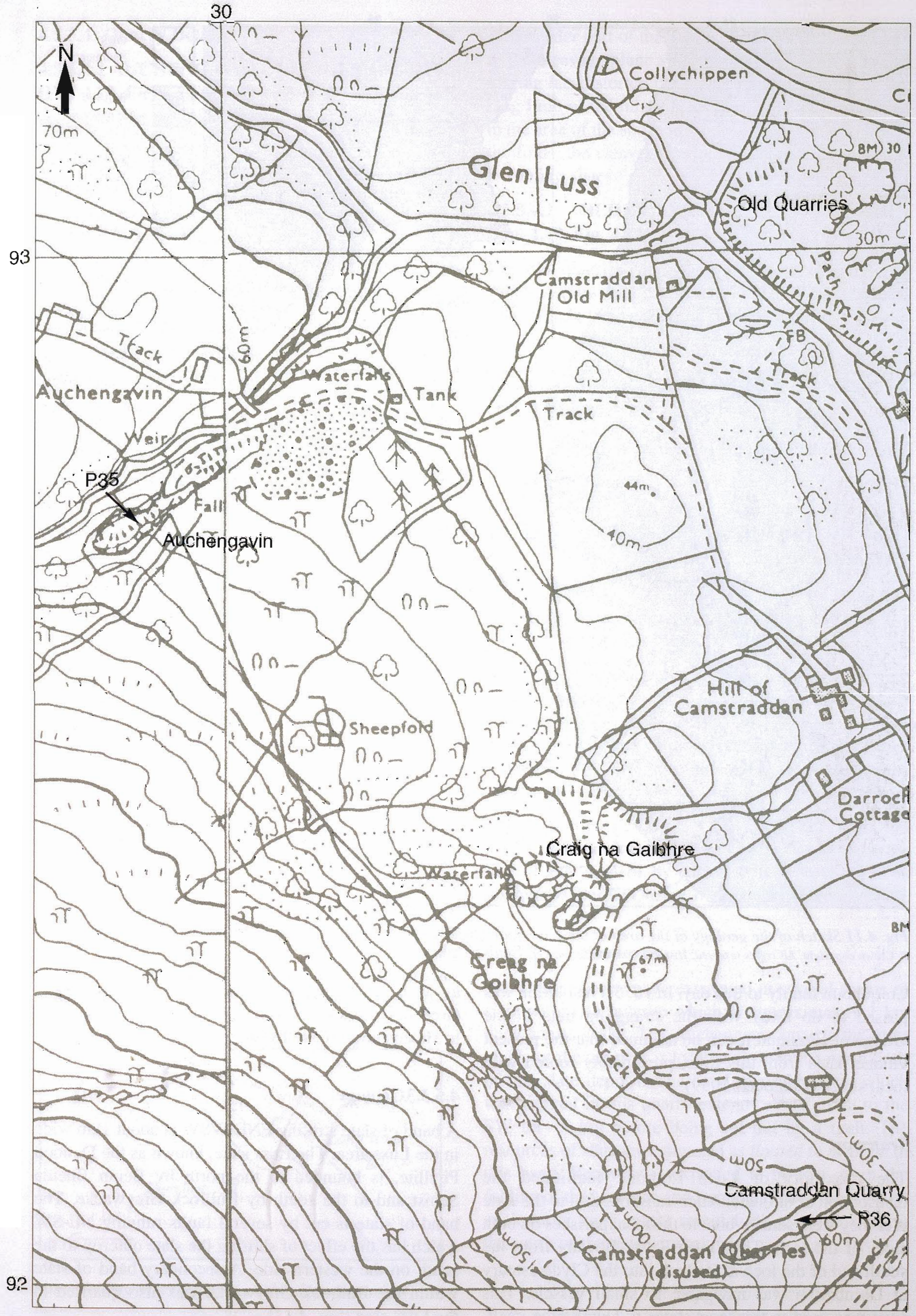


Fig. 4.10 Map of Luss Quarries based on OS NS3906SW & SE copyright 1976 & 1977 *1:5,000*

Fig. 4.11 Sketch of the geology of the area of the Luss Slate Quarries based on BGS Sheet 38W

Colquhoun family to this day. In 1875 a resolution was passed to do away with the straggling huts in the village of Luss and it can be assumed that the present village dates from this time, presumably roofed with local slates (Campbell 1959).

Transport

The proximity of Loch Lomond facilitated the distribution of the slate. After transportation to the slate pier they were sent by boat to the local parishes on both sides of the loch. The Leven River, flowing from the south end of the loch at Balloch into the Clyde estuary at Dumbarton was navigable to small vessels. This river was used to transport slates to Dumbarton itself, as well as Glasgow, Paisley, Port Glasgow and Greenock. Luss slates were also sent by a turnpike road to Helensburgh (Carr 1839).

4.5.3.3 Geology

A band of slate striking ENE-WSW is about 1km wide in the Luss area. The Luss slate, known as the Dunoon Phyllite, is bounded to the north by Beinn Bheula Schist and to the south by Bullrock Greywacke. The band of slate is cut by several faults running NE-SW which has the effect of shifting the slate outcrop to the south on the western side. A secondary band of slate within the Bullrock Greywacke was also quarried in the Luss area (Fig. 4.11).

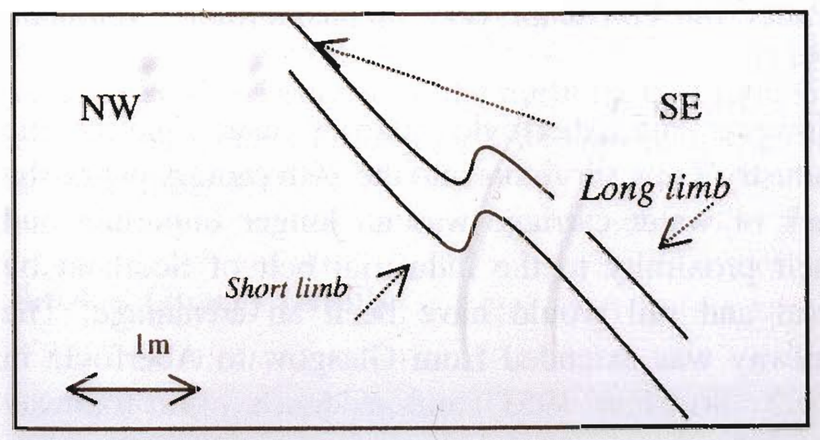
4.5.3.4 Quarry Details

4.5.3.4.1 AUCHENGAVIN QUARRIES NS347928 (Fig. 4.10, Fig. 4.11 and Plate 35)

Access	From the Luss by-pass A82 there is a narrow, rough farm track leading to a farm which lies within ½ km of the quarry on the opposite side of the Auchengavin Burn. The track divides at the burn, one branch crossing the burn to the farm while the other passes the entrance to the quarries.
Slate	Blue and blue-grey with some green, medium grained.
Cleavage	055°/60°- 80°.
Bedding	Intersection of bedding on the cleavage surface (ribboning) is clearly seen on some faces.
Joints	Irregular jointing.
Imperfections	Numerous quartz veins ranging from 1 to 10 cms in thickness some lensoidal in shape.

Workings

There were two quarries at this locality extracting slate from the same seam. Between the quarries there is a fault with a displacement of a few metres so that the newer working to the west is offset to the south. The western quarry at Auchengavin, which was in production at the time of the Richey and Anderson report (1944), is the one described below in more detail. The quarry was worked along strike in a SW-NE direction. It is over 100m long and about 10 wide at the entrance extending to 30m wide at the SW end. The SE is an overhanging face and at this the slate has collapsed. Where the quarry widens there is a large rock fall covering over half the quarry area. At the narrow part of the quarry is the remains of a shear zone and associated quartz veining. This has been removed at the wider part of the quarry. The NW face is parallel to the cleavage plane striking 055°/60° - 80°, however folding has distorted the planarity of this surface. The long limb of the minor folds have a planar surface but in the area of the short limb, close to the hinge zones of the folds, the cleavage surface is curved and unusable as roofing slates.



Minor folding super-imposed on the cleavage surface

4.5.3.4.2 OLD QUARRIES NS357930 (Fig. 4.10, Fig. 4.11)

The old quarries were a series of small workings, which are now very overgrown. The A82 Luss by-pass cuts through the eastern end of these quarries.

4.5.3.4.3 CRAIG NA GAIBHRE NS353924 (Fig. 4.10, Fig. 4.11)

There are two quarries at this location which are choked with debris.

4.5.3.4.4 CAMSTRADDEN QUARRIES NS355920 (Fig. 4.10, Fig. 4.11 and Plate 36)

A series of quarries were worked along strike on the hillside north of Craignahullie.

According to Richey and Anderson (1944) there were 5 or 6 benches each 15m - 25m (50 - 80ft) high and from 30 to 40m wide. At the time of their account, these working were already choked with debris and since then they have been back filled at the time of the construction of the Luss by-pass.

Other quarries described by Richey and Anderson (1944) were not located. Level Quarry was close to the line of the modern by-pass and has probably been obliterated. Purple Quarry, if still there, was not visited.

4.5.3.5 Resources

The Luss quarries were excavated in several seams of slate within an outcrop which is approximately 1 km wide across strike. The Auchengavin quarry, the most viable of the quarries is located close to the north limit of this slate deposit. The band of usable slate which was worked in this quarry extends along strike to the SW for ½ km before being cut out by a fault. The resources of slate are estimated as *limited* to *medium* in this band. Recovery is expected to be low given the folding of the cleavage and frequent quartz veins. More exploratory work might reveal further usable slate to the south of the present workings

4.5.4 ABERFOYLE QUARRIES

NN502029 - NN508033

(Fig. 4.1, Fig.4.3d, Fig. 4.12, Fig. 4.13 and Plates 37-38)

The Aberfoyle slate quarries are situated in the Queen Elizabeth Forest Park in the Trossachs, a National Scenic Area.

Plate 37 Aberfoyle, lower level quarries (NN506031)

4.5.4.1	**Site Details**
Location	In the Achray Forest 2.4km NW of Aberfoyle covering an area from NN502029 to NN508033 at a height of 250-350 m.
Maps	OS 1:50000 Sheet 57 1:25000 Sheet NN 50 1:10000 Sheet NN 50SW BGS 1:63360 Sheet 38
Access	Leaving the A821 2km north of Aberfoyle, there is good forestry road leading to the quarries.
Ownership	Forestry Commission.

4.5.4.2 History

Historically the area was owned by the Graham family, the Earls of Menteith, until the end of the 17th century. The land then passed to the Dukes of Montrose who continued to be the landowners until the 1930s. The Forestry Commission began to acquire land in the area in 1928, including eventually the slate quarries (Strachan 1953).

One of the earliest records of Aberfoyle slate is in the 1625 accounts of the Masters of Works when it was mentioned as the source of the roofing slates for Stirling Castle. However the quarries were only intermittently worked in the 17th and the 18th centuries, *"Slate of good quality which is wrought whenever there is a demand for it"* (Graham 1793). Even in the 19th century, the acme of slate production elsewhere, only a small workforce was employed,

Plate 38 Aberfoyle West Quarry (NN506029)

albeit on a more regular basis. In 1843 Rev. Allan Graham described the slate as *"excellent quality and regularly wrought"* giving employment to 20 men (Graham 1843). According to the mineral statistics for 1858-59, 1.4 million slates were produced and the price at the quarry face was 45 shillings per 1000 slates. This was comparable to the Ballachulish slates at 50 shillings per 1000 (Hunt 1860). The distance from markets was always seen as a major problem, *"The lack of water carriage and the distance of a market render the consumpt very inconsiderable"* (Graham 1843).

However the Aberfoyle quarries were one of the industry's few survivors into the 20th century, when the lack of water carriage was no longer important and their proximity to the industrial belt of Scotland by road and rail would have been an advantage. The railway was extended from Glasgow to Aberfoyle in 1882 (Strachan 1953) and evidence of a tramway servicing the quarries is seen on old OS maps. Between the wars, the slate quarries maintained a work force of over 30 men. Production came to a standstill during World War 2 but Aberfoyle was one of four

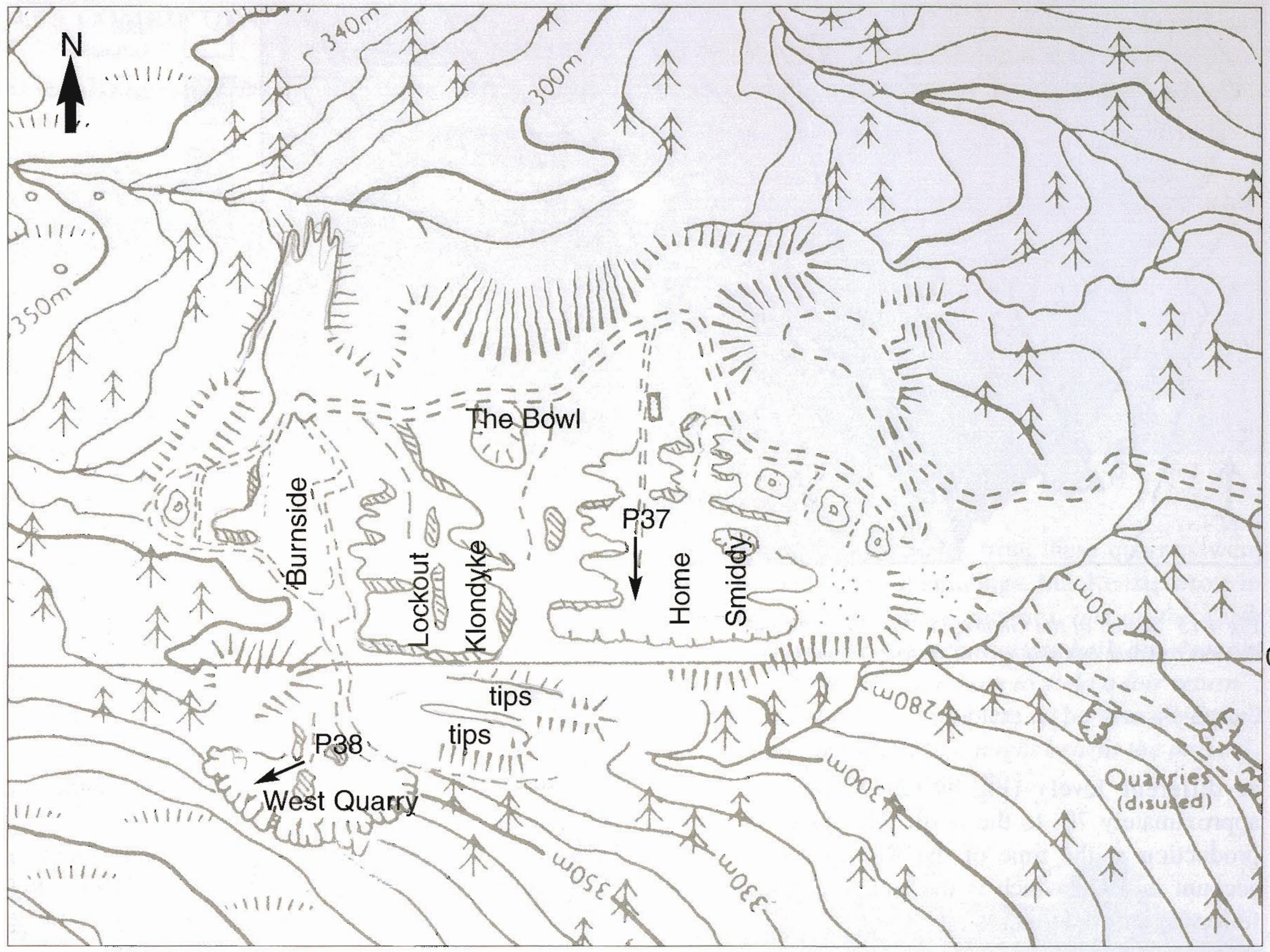


Fig. 4.12 Map of the Aberfoyle Slate Quarries based on Richey and Anderson (1944) and OS NS50SW copyright 1978 updated by the author's survey in 1997 *1:5,000*

quarries reopened when the Scottish Slate Company came into being in 1947. The other chosen areas were Ballachulish and two quarries on the slate islands of Luing and Seil, Cullipool and Balvicar respectively. This revival was short lived; Aberfoyle was closed in 1954 and production concentrated on the Cullipool and Balvicar quarries for the next few years after which they too closed.

4.5.4.3 Geology

Aberfoyle gives its name to the band of slate from the east of Loch Lomond to Glen Shee NW of Perth. This band of slate is bounded to the north by Ben Ledi Grit and to the south by Leny Grit, as shown in Fig. 4.2, 4.13 & Table 4.1.

4.5.4.4 Quarry Details

4.5.4.4.1 Slate Description	
Colour	From the waste tips it can be seen that different coloured slates were produced including blue, grey, green and purple.
Cleavage	Cleavage surfaces are rough with a well defined grain, sometimes with a slight sheen. Others have a silky texture.
Thickness	Samples collected have a thickness of 5-14mm but often tapering.
Sizes	From the size of the offcuts it is assumed that only small slates were produced.
Imperfections	Frequent small quartz veins cross the slates sometimes delimiting different coloured bands. No pyrites were observed.
Bedding	Although the bedding has an overall trend subparallel to the cleavage (as noted in the West Quarry below) there are many examples of bedding features cutting across slate at a high angle indicating minor folding.

4.5.4.4.2 Workings

The workings cover an area approximately 0.75 x 0.5 km (40 ha) and were subdivided into different quarries

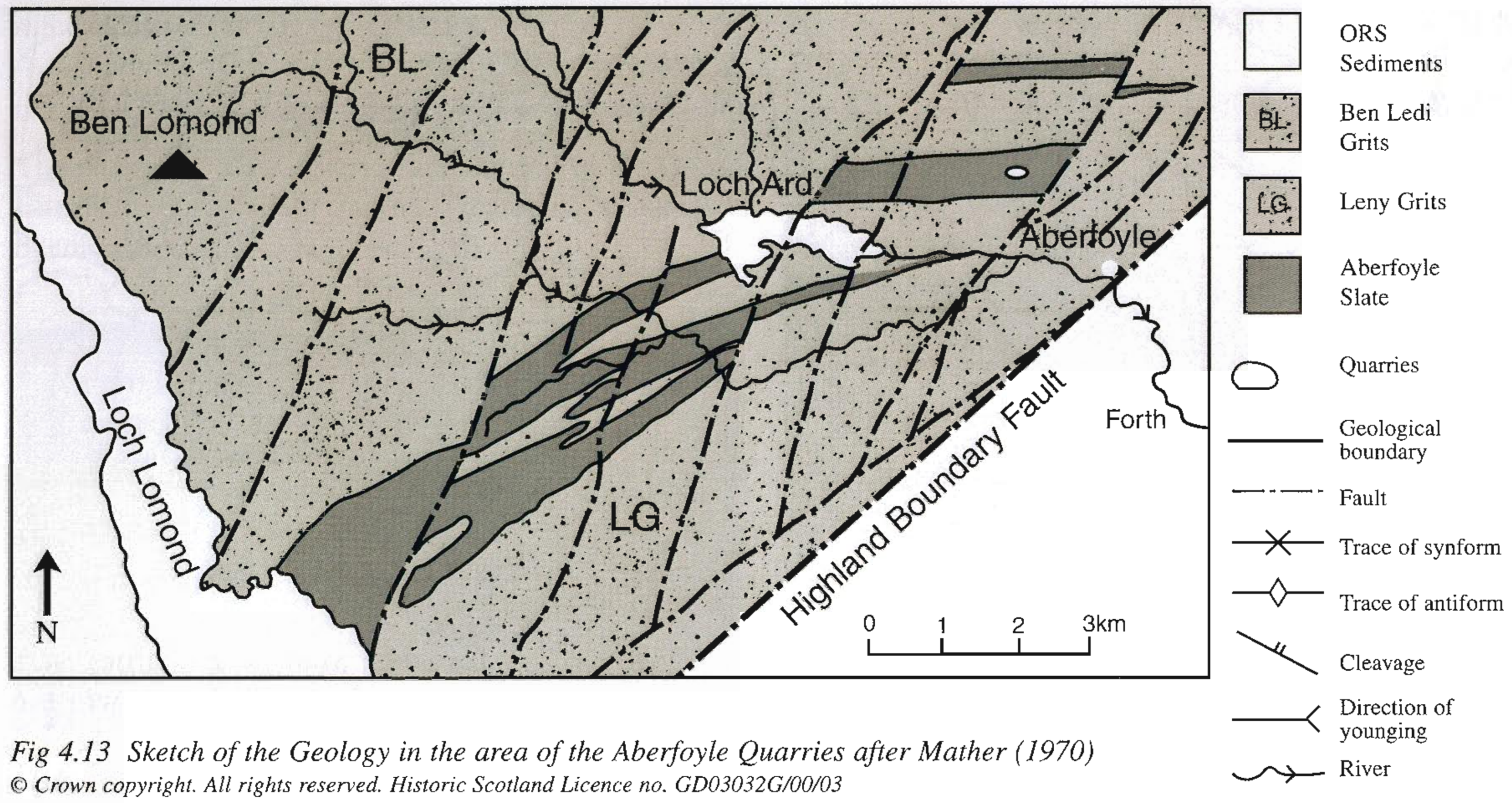


Fig 4.13 Sketch of the Geology in the area of the Aberfoyle Quarries after Mather (1970)

at different levels (Fig. 4.12). Cleavage dips at approximately 70° to the north. The quarries were in production at the time of the Richey and Anderson account in 1944 which is the source of much of the following information.

Low level **NN506031**

The main workings were at this level in seven different seams with varying colours in the Smiddy, Home and Klondyke quarries. However, even in 1944, the division between the quarries was obscure and they were already heavily blocked with debris. A further ten years of production has added significantly to the debris and the only evidence of the various seams is from the different colour off-cuts in the waste tips (Plate 37).

Medium Level **NN504031**

The Lockout and Burnside quarries at this level are still recognisable. The exposed faces are covered with numerous quartz veins and there is little of the smooth homogeneous surface needed to produce good slate. This of course is why the face is still there and probably was not typical of the producing seam.

High Level **NN506029**

The so-called West Quarry is at the highest level but on the south side of the quarry. A seam 10m wide and 15m high was worked, but production had already ceased at the time of the Richey and Anderson report. The large irregular holes for explosives suggest that drilling was by hand i.e. no compressed air was used at the time this seam was in production. The cleavage is steep and colour bands align with cleavage suggesting that bedding and cleavage are almost parallel. The slate at this level was predominantly purple with some green (Plate 38).

Weathering

There is very little rusty weathering due to the absence of pyrites. However there is some limonite staining on the pillaring faces due to the break down of chlorite. Some penetration of moisture along cleavage planes was noted.

All faces have suffered weathering, the slate giving a dead sound when hit with a hammer. On splitting, the cleavage surface is flaky indicating frost damage. Toppling, the collapse of the faces due to the steeply inclined cleavage giving way with time, has occurred in places.

4.5.4.5 Resources

To produce even a limited supply of Aberfoyle slate from the present quarries would involve removing the weathered surfaces of the present faces and a massive operation to clear old tips. For a more substantial supply, the best possibility is to prospect for new seams or the continuation of old seams in the high ground to the south and west of the present quarry.

4.5.5 COMRIE QUARRIES

NN709188 - NN716197

(Fig. 4.1, Fig. 4.3e, Figs. 4.14 to 4.16 and Plates 39 to 42)

Plate 39 Aberuchill Quarry near Comrie as seen from Drummond Quarry (NN716197)

Plate 40 Aberuchill Quarry. View of south face (NN709188)

The Aberfoyle Slate Belt crosses the hills to the WSW of Comrie. Several slate quarries were worked in the valley of the Allt Glas which cuts through these hills.

4.5.5.1 Site Details

Location	Aberuchill Quarry	NN716197
	Drummond Quarry	NN709188
	Aberuchill Quarry and Drummond Quarry are situated 12km. SW of Comrie. The former is on the eastern slope of Allt Glas, a tributary of the Water of Ruchill, and the latter is on the western slope .	
Maps	O.S. 1:50000 Landranger Series Sheet 52	
	1:10000 NN71 NW	
	BGS 1:63360 BGS Sheet 47	
Access	A well maintained farm track, starting at Aberuchill Castle, leads directly to the quarries 6km away. The path starts in a SW direction, skirts the southern slopes of Dun Dubh before turning NNW along the east slope of Allt Glas to Aberuchill Quarry. Drummond Quarry is 1km from this path across boggy terrain to the west on the other side of the valley.	
Ownership	Aberuchill Quarry is on the Aberuchill Estate, Comrie.	
	Drummond Quarry is on the Drummond Estate. It passed from the Perth to the Ancaster families and is now owned by the Countess of Ancaster.	

4.5.5.2 History

It is assumed that the slates from these quarries were primarily used for local buildings. MacKenzie wrote in 1838 *"There are two slate quarries, one on the Perth and another on the Aberuchill estate both are wrought though not extensively and seen to yield a fair return"*. Lack of transport was a problem as he also suggested that *"a canal or railroad [ ] might benefit the parish"*. The railroad duly arrived in 1893.

Plate 41 Horse Engine house on the Aberuchill Estate roofed with slates from the quarry

Plate 42 Drummond Quarry near Comrie as seen from the road leading to Aberuchill Quarry

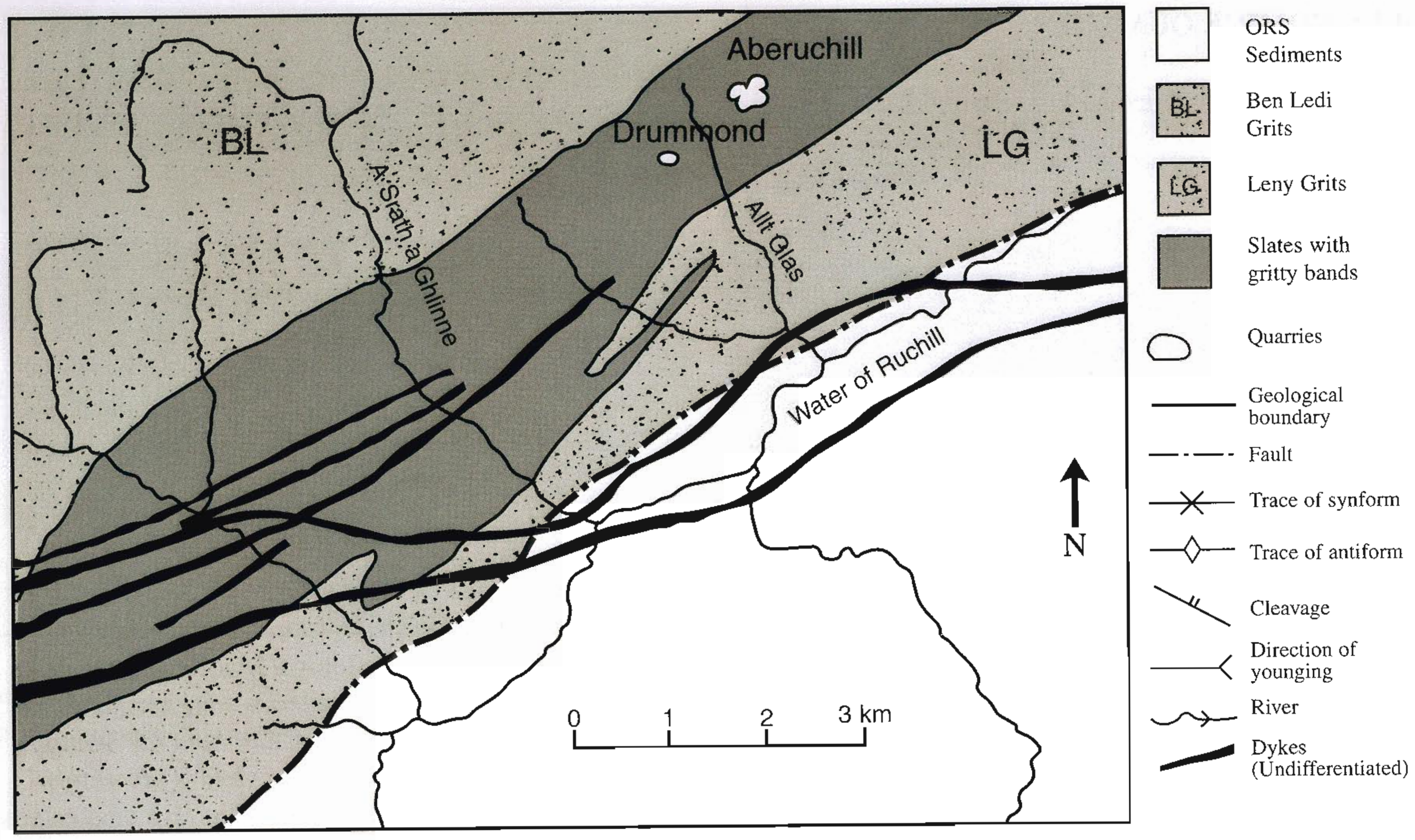


Fig. 4.14 Sketch of the geology in the area of the Comrie Quarries after Anderson (1946)

4.5.5.3 Geology

The slate in the area is called Aberfoyle Slate and is bounded to the north by Ben Ledi Grit and to the south by Leny Grit (Table 4.1 and Fig. 4.14). Locally the line of the Highland Boundary Fault follows the Water of Ruchill which flows into the River Earn at Comrie 2km to the south of the quarries (Anderson 1946). Leny Grit forms the rough hills immediately to the north, which give way to the slate band, stretching from Loch Lubnaig north of Callander NE towards Comrie. Slate is well exposed in the valleys of streams flowing south into the Water of Ruchill, such as the Allt Glas.

4.5.5.4 Quarry Details

4.5.5.4.1 Slate Description	
Colour	Blue and green slate with occasional purple tint.
Grain Size	Coarse grain is often associated with the green slate, grading into the finer grey blue slate.
Cleavage	230°-245°/40°-60° The cleavage is distorted in the vicinity of quartz veins.
Bedding	Frequent ribboning (the intersection of bedding on the cleavage surface) is generally at an angle of 45° to cleavage, giving an attractive appearance to the slate.
Imperfections	No pyrite, but quartz veins are frequent at some locations ranging in size from a few millimetres to 50mm.
Weathering	Chlorite appears in the quartz veins suggesting that it is vulnerable to weathering. Little rusty weathering was seen in the tips.

4.5.5.4.2 Workings

Aberuchill Quarry NN716197
(Fig. 4.3e, Fig. 4.14, Fig. 4.15, Plates 39-40, Plate 62)

This quarry lies at a height of between 400m and 500m OD and has been worked 200m into the hillside along strike. The lower level of the quarry is dominated by tips. The remnant of the working face is only seen at the upper level. This part of the quarry is 100m x 100m and 20m high. Irregular jointing is seen on the cleavage face on the south side of the quarry although some vertical joints show a general pillaring trend. Many joints cut diagonally across the face. The north side of the quarry is overhanging and slumping has occurred. This part of the quarry was not worked due to the frequency of quartz veins, which destroy the cleavage. Outwith the main part of the quarry is an area to the north with folding and frequent quartz veins.

Drummond Quarry NN709188
(Fig. 4.14, Fig. 4.16, Plate 42)

The workings are 50m x 50m in area and 20m high with the tips spilling over on to the lower ground to the west. There is a higher proportion of green slate than found at Aberuchill Quarry. As before, there is a strong association between this green slate and quartz veins. Bedding features, highlighted in the green slate, are seen to be at a low angle to cleavage. The chlorite in the quartz veins is dark green to black in colour, showing some rusty weathering when crumbled. Frequent minor folding is seen in the larger blocks of the quarry.

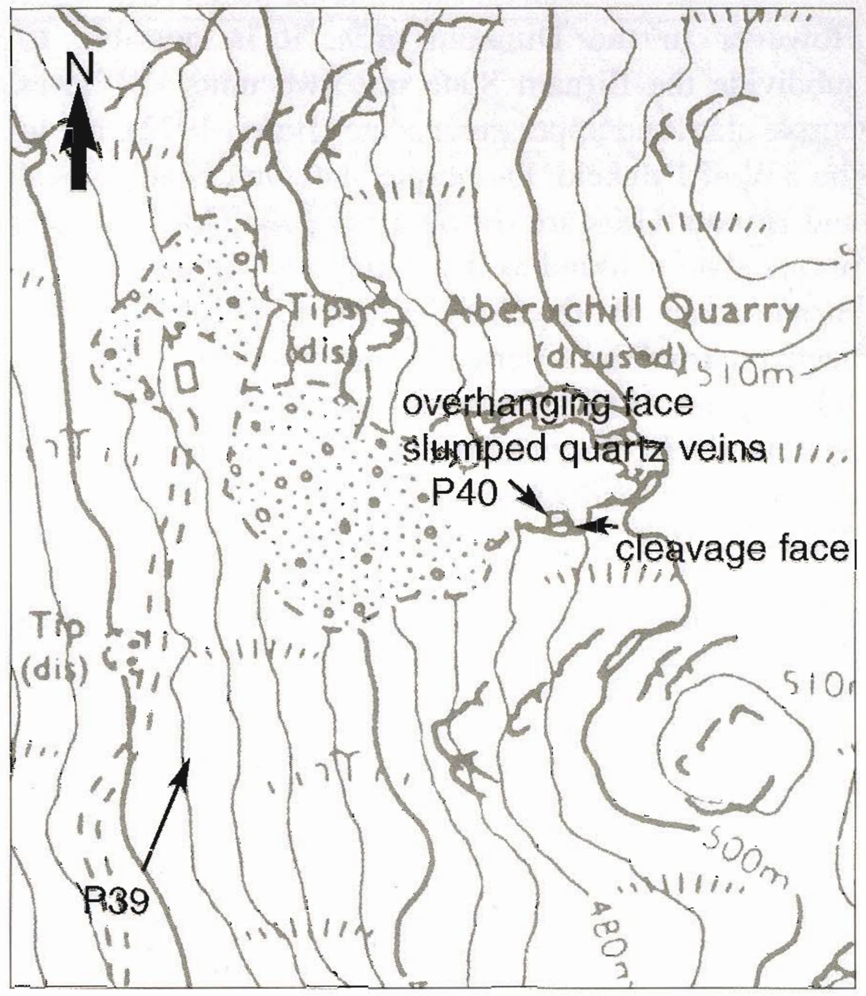


Fig. 4.15 Map of Aberuchill Quarry based on OS NN71SW copyright 1991 1:5,000

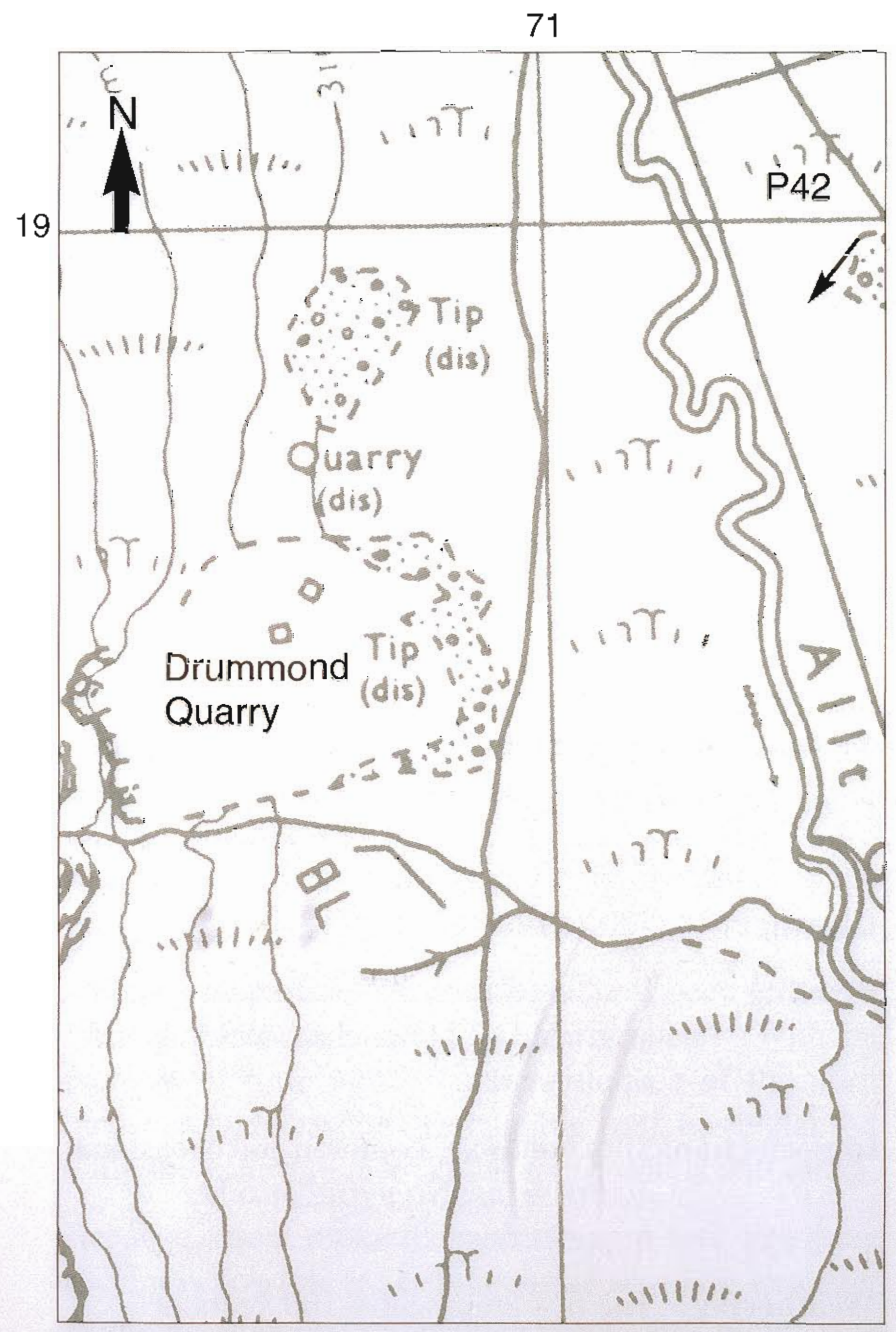


Fig. 4.16 Map of Drummond Quarry based on OS NN71SW copyright 1991 1:5,000

4.5.5.5 Resources

The band of slate continues along strike in both directions, so that further exploitation of resources should be possible. The Aberuchill quarry could be extended to the ENE into the hillside and in the Aberuchill and to the WSW in the Drummond quarry along strike.

4.5.6 LOGIEALMOND NN950322
(Fig. 4.1, Fig. 4.3f, Fig. 4.17, Fig. 4.18 and Plates 43 to 44, Plate 63)

To the north of the Almond is a row of hills where slate is exposed, namely Craig Lea (532m) and Crochan Hill (506m). Slate quarries are found on the southern slopes of these hills from the Small Glen to Glen Shee.

Plate 43 Craiglea Quarry. South Quarry Logiealmond (NN950322)

Plate 44 Craiglea Quarry, North Quarry Logiealmond

4.5.6.1 Site Details

Location	Craiglea Quarry	**NN950322**
Maps	O.S. 1:50000 Landranger Series Sheet 52	
	O.S. 1:10000 NN93 SE	
	BGS 1:63360 BGS Sheet 47	
Ownership	Earl of Mansfield, Scone Palace.	
Access	To the west of Harrietfield on the B8063, there is a minor road leading north to Logiealmond Lodge. From Logiealmond there is a good service road leading to the quarry	

4.5.6.2 History

The slate quarries located along the southern slopes of the Logiealmond Hills range in size from small holes in the ground to large workings. Two of these quarries are mentioned specifically in the historical records, namely Glenshee and Craiglea. The former probably only produced sporadically while the latter already had a regular annual production in the late 18th century.

At the end of the 18th century most houses in the area were thatched even though slate was being produced locally (Baxter 1792). He refers to a quarry near the Forest of Glenartney. Craiglea Quarry is on the estate of Logiealmond. A *"valuable blue slate quarry was let at 50 guineas yearly. 500,000 slates are sold annually a 13/4 per thousand"* (Stirling 1794). The slates produced were transported by road.

In the 19th century the Glenshee slate quarry was feeling the competition from Craiglea as it was *"but little worked owing to the greatly superior quality of the Craiglea quarry"*. Production at Craiglea had increased to 1,200,000 slates of superior quality in 1837 (Maxtone 1837). In 1859 Hunt reports 90,000 tons of slate sold at 35 shillings per thousand. Production at Craiglea ceased at the beginning of World War 1. It was surveyed in the 1950s but the report said re-opening was not justified (Porteous 1954).

4.5.6.3 Geology

The slate belt in the Logiealmond area lies approximately 5km north of the Highland Boundary Fault which in this area follows the line of the Almond River (Fig. 4.17). The geology is comprised of three formations; the oldest are the Birnam Grits to the SE, followed by the Birnam Slate and the younger Dunkeld Grit to the NW (Table 4.7) (Harris 1972, Harris & Fettes 1972). This is similar to the geology described in greater detail for the Dunkeld area (Section 4.5.7.3). However in the Dunkeld area, it is possible to subdivide the Birnam Slate into two units i.e. lower purple slate and upper green slate (Harris 1972), but to the SW of Dunkeld, the purple slate unit is attenuated and Birnam Grits are overlain by green slate. Instead, purple slate is found as discontinuous units within the Birnam Grits. At the Craiglea Quarry purple slate has been quarried in a series of downward-facing folds (Shackleton 1958). The main part of the quarry has been worked in a synform with a gentle limb to the SE dipping at 25° and a steep limb to the NW (Richey and Anderson 1944).

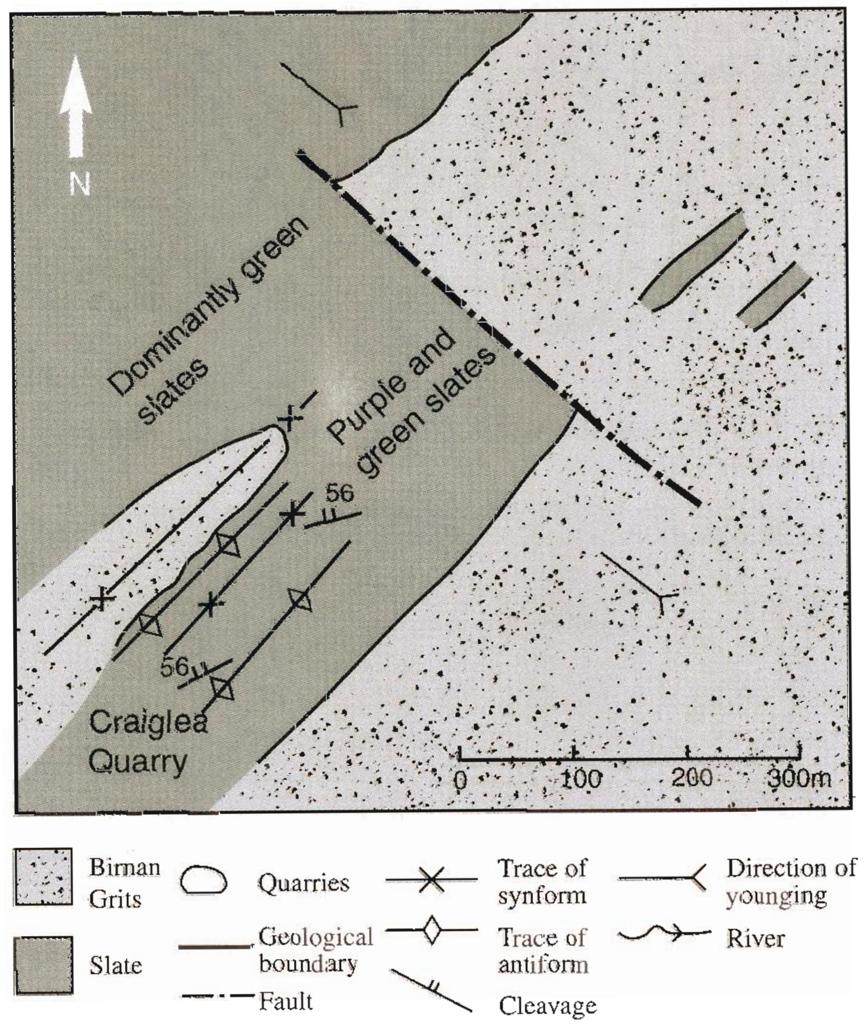


Fig. 4.17 Sketch of the geology in the area of the Logiealmond Quarries after Harris & Fettes (1972)

4.5.6.4 Quarry Details

4.5.6.4.1 Slate Description

Colour	Blue and green coarse grained. slate with occasional purple tint.
Cleavage	220°/60°.
Bedding	Bedding structures are frequent, such as graded bedding, cross-bedding and ripple marks.
Imperfections	Silty bands are common and occasional quartz veins. No pyrite or other imperfections.
Weathering	The tips after nearly 100 years of exposure show very little rusty weathering.

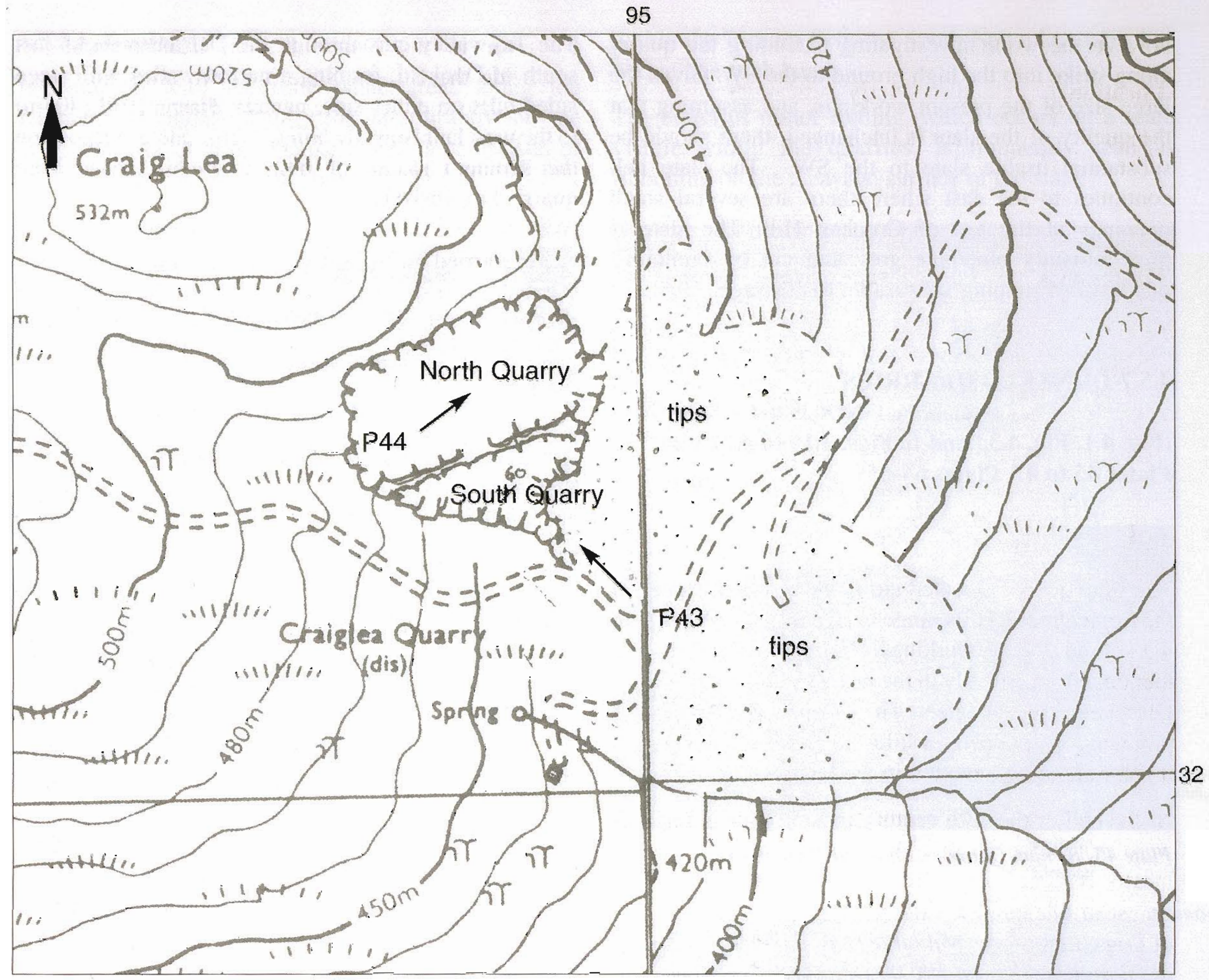


Fig. 4.18 Map of Craiglea Quarry based on OS NN93SE copyright 1983 *1:5,000*

4.5.6.4.2 Workings

CRAIGLEA QUARRY **NN950322**
(Fig. 4.3f, Fig. 4.17, Fig. 4.18 and Plates 43 to 44)

The overall size of the quarries is estimated at 200m by 150m and over 50m high. There are two workings, the smaller quarry to the south and the larger to the north. The entrance to the smaller quarry is directly from the access road and the entrance to the larger quarry is through the north face of the smaller. This access is at first bench level of the larger quarry, the latter having been worked 10-15m below this.

The tips in the south quarry here have been left in an unstable state and rock falls are frequent. With the passage of time most of the north face of the north quarry, which was the overhanging wall, has collapsed. Only the cleavage face on the south side is still intact.

Because recent rockfalls have exposed less weathered rock, it is possible to see that purple slate was extracted from the middle of the quarry and green/blue slate extracted from either side. This colour change is due to bedding and the quarry is located at the core of a fold. This is one of a series of downward-facing folds Shackleton (1958) with gently inclined long limb to the SE and steeply inclined limb to the NW.

4.5.6.5 Resources

The Craiglea quarry produced a very durable slate, a local examples of this can be seen on the barn at Upper Frances Field (now called Kipney) which was built at the end of the 18th century (Plate 30a). The roof is in need of repair due to nail sickness but the slates are re-usable. Bonellas Cottage, adjacent to the farm, is the only remaining example of the row of quarriers' cottages. It was re-roofed within the last few years using the original slates with a loss of only 10% (Plate 30b).

Resources within the confines of the present quarry are *limited*. The quarry has been worked to a considerable depth and the tips left in an unstable slate. In addition the band of slate gives way to grit to the NW and to the SE of the present quarry, therefore it would not possible to extend the quarry across strike. It should however be worth investigating extending the quarry along strike into the high ground to the SW. Given the large size of the present workings, and assuming that the quality of the slate is unchanged, there should be substantial usable slate to the SW. The slate belt continues to the east where there are several small openings at the top of Crochan Hill. The slate is predominantly blue/blue grey and cut by numerous quartz veins running subparallel to cleavage.

4.5.7 DUNKELD QUARRIES
NO039404 – NO047411

(Fig. 4.1, Fig. 4.3g and h, Figs. 4.19 to 4.21 and Plates 45 to 47, Plates 64-65)

Plate 45 Birnam Quarries, Dunkeld (NO039404)

Plate 46 Overall view of the Newtyle Quarries as seen from Birnam Hill (NO045413)

Plate 47 Newtyle Quarry, Dunkeld

The Tay valley cuts through the Dalradian rocks just south of Dunkeld, forming a narrow valley with steep sided hills on either side, namely Birnam Hill (404m) to the west and Newtyle Hill (317m). Slate outcrops on the southern slopes of both these hills have been quarried extensively.

4.5.7.1	**Site Details**	
Maps	O.S. 1:50000 Landranger Series Sheet 52	
	1:10000 NO04SW	
	BGS 1:63360 BGS Sheets 47 & 48	
Location	Birnam	NO037403 to NO039405
	Newtyle North	NO045413
	Newtyle South	NO047411
Access	Access to the Birnam quarries is 500m south of the intersection of the A9 and the B867 to Blackfoot. There is a bridge under the railway which gives access to the quarries. The road leading to the lower level quarries is well maintained; however the path mention by Richey and Anderson (1944) which used to zig-zag up the hillside to the higher level quarries is but a faint outline in the bracken.	
	The Newtyle Quarries are located approximately 3km south of the bridge at Dunkeld within 100m of the A984 to Coupar Angus. Several tracks give access to the quarries from the road.	

4.5.7.2 History

Both the Newtyle and the Birnam quarries were producing slates at the end of the 18th century. Of the Newtyle quarries Innerarity wrote in 1791: *"quarries of excellent blue slate which are sold on the spot at £1 the thousand and are carried a considerable distance"*.

Robertson wrote of the Birnam slates at the same time *" In the hill of Birnam is abundance of slate that splits into plates of a convenient size and thickness of a deep blue colour bordering on violet and exceedingly beautiful"*.

In the 19th century both quarries were in production, Newtyle producing 200,000 monthly. The proximity of the Newtyle quarries to the Tay probably gave them an advantage over those at Birnam but this would have reversed when the railway line reached Dunkeld. Both quarries were in production until the early 20th century. Mechanical drill holes suggest that Newtyle North was in production in the 1930s.

4.5.7.3 Geology

In common with the other slate areas along the Highland Boundary Fault, the stratigraphy of the Dalradian Rocks in the Dunkeld area is comprised of grits and slates (Fig. 4.19, Harris 1972)

Dunkeld Grit	*youngest*
Upper Birnam Slates (mainly green)	↑
Lower Birnam Slates (purple)	
Birnam Grits with Purple Slates.	*oldest*

However the Dunkeld area does not follow the general trend found to the SW, i.e. the slate is not located in the core of a downward facing synform, bounded by younger grits on both sides. In this area, the grit and slate formations are right-way-up, dipping to the NW and belong to the same limb of a major fold (Harris 1972). The main quarries of the area are in the Birnam slate which are divided into two subgroups; the older purple to the SE and the younger green to the NW.

Repetition of slate bands in the area was seen as folding (OS Sheet 48), (Anderson 1946, Shackleton 1958). This was also the interpretation used by Richey and Anderson (1944). However in the revision of the geology of the area by Harris (1972) this repetition is partly explained by reverse faults. Of greater significance is the recognition of purple bands of slate within the Birnam Grit; the South Newtyle quarry lies within one such band.

The effect of minor folding, which occurs on a scale visible within the quarries, is frequently seen as ribboning on the cleavage surface of the slate.

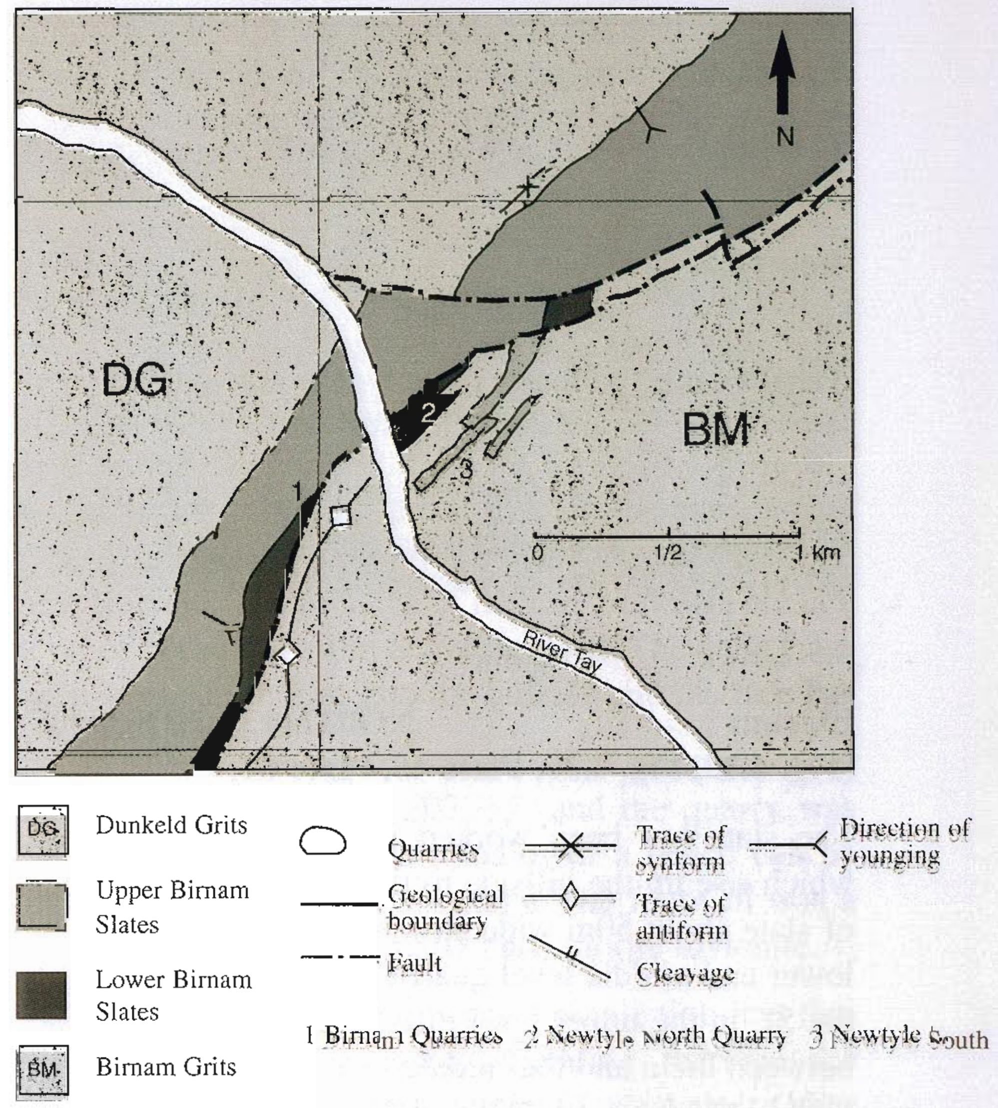


Fig. 4.19 Sketch of the geology in the area of the Dunkeld Quarries after Harries (1972)

Extracts from Mineral Statistics for Perthshire (Hunt, Geological Survey 1850s)

Quarry	Location	Owner	Price (1/- =5p)	Slates
Aberfoyle	Aberfoyle	Duke of Montrose	45/-	1,400,000
Aberuchill	Comrie	Sir David Dundas	35/-	200,000
Craiglea		Earl of Mansfield	35/-	90,000
Glenshee		Duke of Atholl	28/-	90,000
Birnam	Dunkeld	Sir W Stewart	35/-	300,000
Dalbeaty	Newtyle	Sir W Stewart		100,000

Extract from Mineral Statistics published anonymously from 1882-1888 for Birnam

Year	1882	1883	1884	1885	1886	1887	1888
Tons	75	300	300	700	700	200	200

Table 4.6 Production figures for Highland Border slate in the 19th century

4.5.7.4 Quarry Details

4.5.7.4.1 Slate Description

Colour	Grey, purple and green slate, medium grained with frequent coarser grained bands.
Cleavage	210°/50°
Bedding	Bedding features such as silt bands are frequent.
Imperfections	Quartz veins are common, especially in the green slate.
Weathering	Chlorite often weathers leaving a green sheen on the surface.
	Light brown staining is noted on freshly cleaved surfaces.

4.5.7.4.2 Workings

Birnam NO037403 – NO039405
(Fig. 4.19, Fig. 4.20, Plate 45, Plate 64)

The slate has been worked in a series of openings, which rise up the hillside to the SSW. There is a band of slate about 50m wide striking at around 200° in the lower and middle level quarries. This band is offset to the SE in the upper level quarries, probably by a fault between them and the middle level quarries.

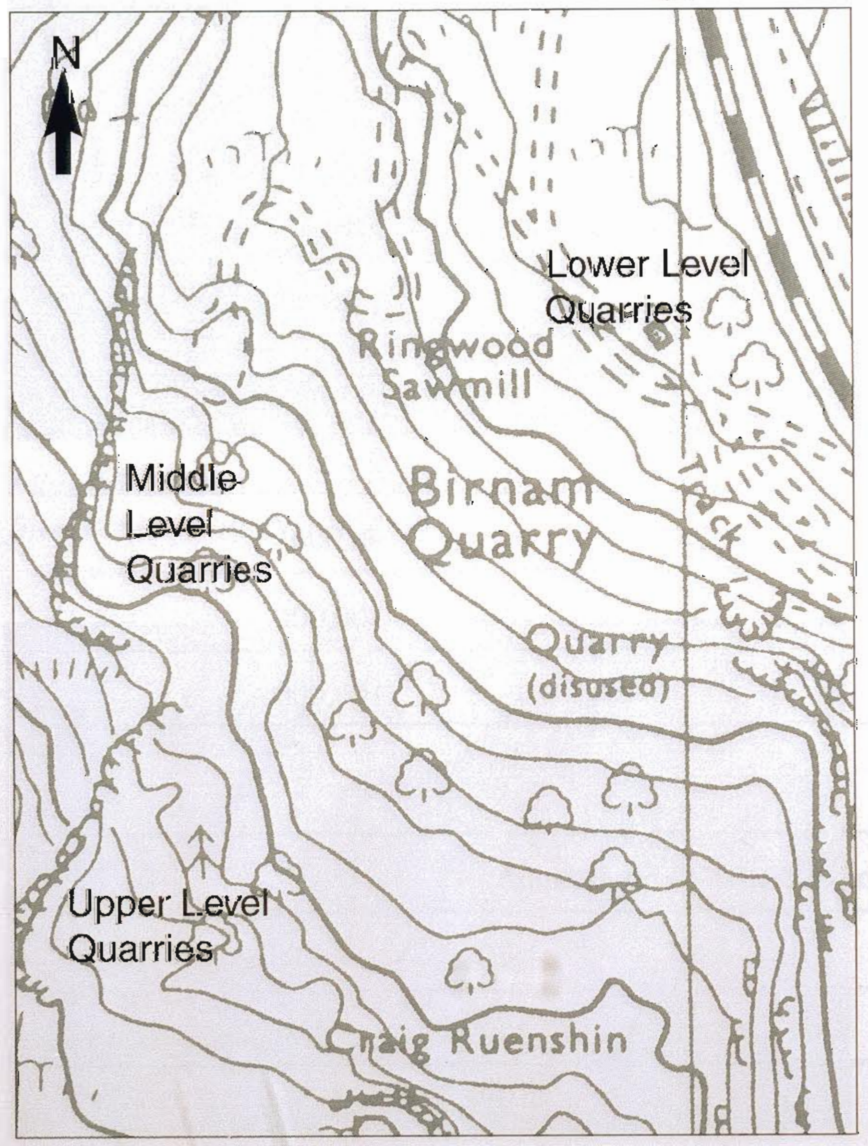


Fig. 4.20 Map of the Birnam Quarries based on OS NO04SW copyright 1983 1:5,000

Lower Level Quarries NO039405

The lowest working, 100m x 50m in area, is adjacent to the railway line at a height of 80m. According to Richey and Anderson (1944) this area was worked below ground level but it has now been filled in.

Middle Level Quarries NO038404

The floor of the next quarry is at a height of 150m, and is 50m x 30m in extent. The quarry was worked along strike for 200m leaving a cliff face rising to 70m above the level of the floor. The remaining face on the NW side of the quarry appears gritty with some yellow weathering as seen from the floor of the quarry. Today most of this area is filled with towering heaps of spoil, some of which has recently been used probably as road fill. This operation has left the tips in an unstable state.

Examining the tips, it can be seen that there is a decrease in the proportion of green slate and a corresponding increase in purple to the SE.

Upper Level Quarries NO037403

Several small-scale quarries were stepped up the hillside from 210m to 240m. A band of slate was worked along strike for 200m. Although the slate in the quarry face to the NW is comprised of coarse green slate with bands of grit, it can be seen from the tips that the band of purple slate to the SE was worked. This suggests that only the green slate is left above present ground level.

Three quarries were identified at this level, the lowest of which is a small opening about 20m long and 7m wide. A narrow band of good slate 3m wide is surrounded by coarser grained slate with many quartz/chlorite veins. Folding was observed in this quarry.

The second quarry of this group is an extension of the first but with access at a higher level.

The third quarry of this group, the highest working in the Birnam area, is located at a height of 240m with a face rising a further 10-15m. The quarry, worked along strike, was limited to the NW by a shear zone. The recovery rate was also affected by folding as can be seen in a promontory in the centre of the quarry which was left intact due to folding. The remaining face has collapsed along former joints. Jointing along cleavage is frequent as well as a set of nearly vertical joints which occur at 0.5m intervals probably following the pillaring line. The barrow run can still be identified and the remains of a shelter can still be seen in this quarry. All the upper level quarries are very overgrown with bracken and trees such as silver birch and larch.

Resources

Most of this area has been worked back to the NW as far as the coarser grained green slate. Numerous quartz veins within this green slate would make the recovery rate very low. The better quality green slate and the purple lie to the SE, but further resources are presumably below the present ground level. Extension of the band of slate may be found in the flat ground to the north of Craig Ruenshin.

Newtyle North NO045413
(Fig. 4.19, Fig. 4.21, Plate 46)

This is the largest of the quarries on the east bank of the Tay. The present quarry is 100m along strike and 70m across strike. The entrance to the quarry is on the south side and it has been worked into the hillside 30-40m high. The tips are extensive, stretching to the north and south of the entrance for 400m. They have been landscaped on the riverside of the road.

The north west face of the quarry is overhanging and slumping has occurred. Here the rock is rotten and crumbling with clayey bands and bands of weathered yellow powder.

On the SE side of the quarry there is a band of silvery grey with some greenish grey slate which has weathered in places to a silvery green sheen. There are numerous narrow veins of quartz.

The remains of a bench can be seen in the upper part of the quarry. At this level slate has been extracted from the axis of a fold leaving a hole 20m deep with an overhanging arch. Here folded coarse sandstone has been left in place, while the purple slate in the core of the fold has been wrought. Above this cave the remains of another bench is found within 20-15m of the top of the quarry.

Jointing is parallel to cleavage at 1-2m intervals. Other joints cut across the cleavage surface are fairly widely spaced. It was not possible to take sufficient measurements to determine a pattern.

Newtyle South NO047411
(Fig. 4.3h, Fig. 4.19, Fig. 4.21, Plate 47)

Here slate has been extracted along a narrow seam approximately 20m wide. The workings probably began near the road but this lower level is now choked with debris. There have been a few sinkings which are now flooded. The remains of the last workings are at a level of 100m OD, 40m above the road. The quarry has been worked for 70m into the hillside and the face has a height of 20m.

The cleavage is regular 202°/55° and the quarry was worked along strike. The remains of a bench can be seen at the NE end of the quarry. The footwall was a fault now marked with quartz and chlorite mylonite.

Much of the slate in the tips has a purple tint; it is fine grained with micas visible. Bedding features are frequent, often at a high angle to cleavage. Other bedding structures, such as graded bedding and ripple

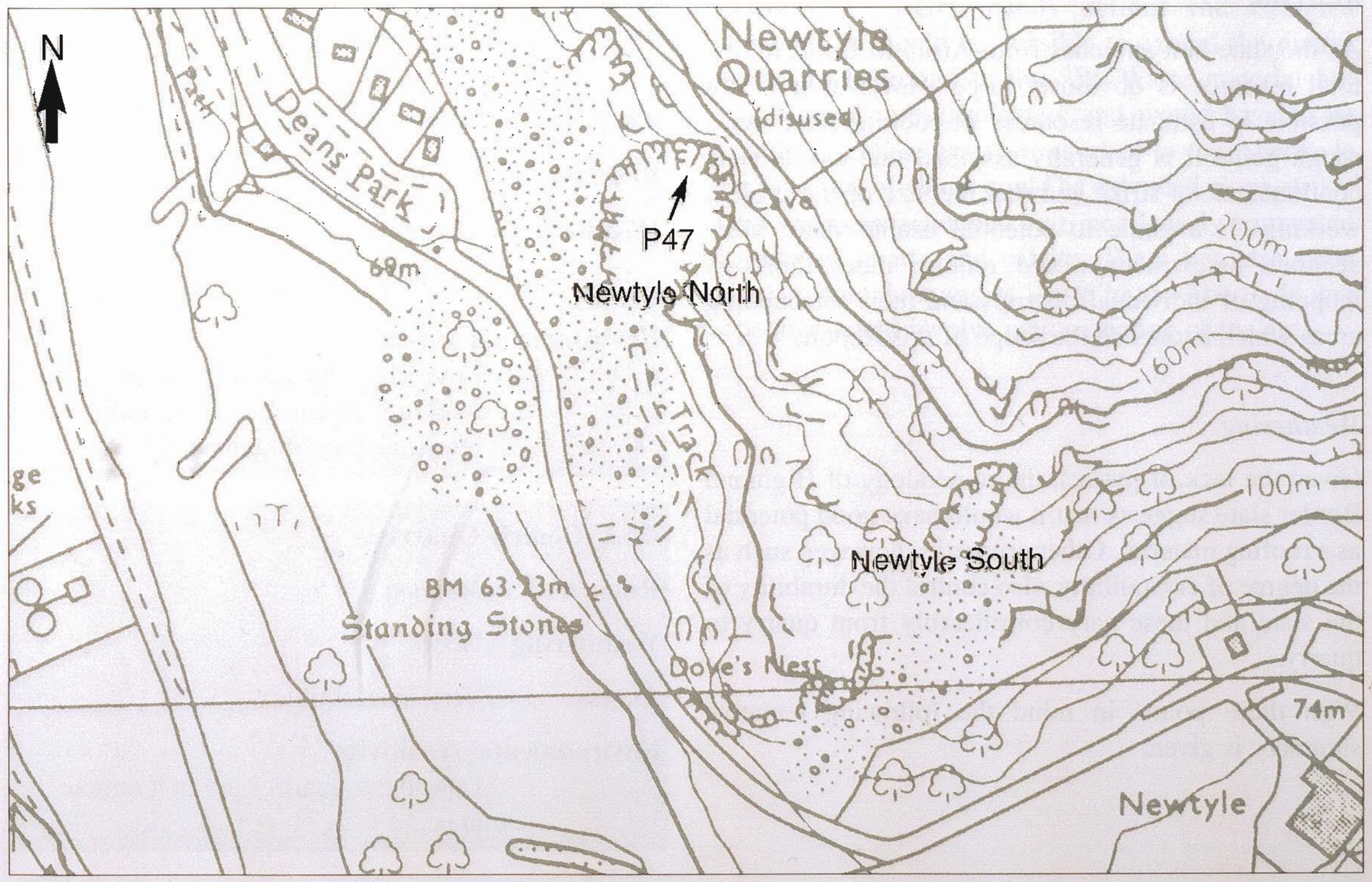


Fig. 4.21 Map of the Newtyle Quarries based on OS NO04SW copyright 1983 1:5,000

marks, are present. Generally the green slate is coarser grained with pebbles of quartz and some brown weathering. Quartz veins are common, often associated with mylonitic chlorite.

Resources

According to Harris' (1972) geological map of the area the outcrop of purple slate in the North Newtyle Quarry does not extend much beyond the present confines of the quarry. Similarly the band of purple slate in the Birnam Grit worked in Newtyle South does not extend much beyond the present quarry area. There is limited potential for further exploitation in this area.

An alternative band of purple slate in the Birnam Grit lies between Newtyle North and Newtyle South (Harris 1972). This band, which extends from the valley floor up the hillside to 275m before being cut out by a fault, is worth further examination. The outcrop of lower Birnam Slate seen in Newtyle North is repeated to the north due to a reverse fault. From the map it can be seen that a few small quarries have been worked in this band in the past and this deserves further investigation.

4.6 Summary

Giving a general summary for a slate area as diverse as that of the Highland Border has severe limitations, and the following should be read in conjunction with individual quarry reports.

Reserves

As the slate belt stretches from Arran to Dunkeld, the total resource is obviously large. However it is not possible to estimate resources of roofing slate. As a rough guide it is generally assumed that usable slate continues along strike and that the size of the present workings is a guide to potential usable slate. More accurate assessment would require more thorough mapping of individual quarries and their surrounding areas which is outside the scope of this Report.

Weathering

Given the lack of pyrites, the mineralogy of Highland Border slate suggests that it would have good potential as a roofing material. Other properties however, such as the degree of crystallinity, also control the durability of the slate and these vary considerably from quarry to quarry.

With these points in mind the following tentative summary is given:

4.6.1 Arran Quarries

Resources *Limited*

Weathering Good

Access Very inaccessible

Environmental sensitivity
Low; these quarries are in a remote area.

4.6.2 Bute Quarries

Resources *Medium*

Weathering The quality of this slate is very variable.

Access Edinmore and Ardmaleish are accessible but Hilton is not accessible.

Environmental sensitivity
Low; these quarries are in a remote area

4.6.3 Luss Quarries

Reserves *Limited to medium.*

Weathering Medium

Access Reasonably accessible

Environmental sensitivity
Medium. Although these quarries are hidden, the area around Loch Lomond is one of outstanding natural beauty and a tourist area

4.6.4 Aberfoyle Quarries

Resources *Medium*

Weathering Medium - good

Access Accessible

Environmental sensitivity
Low. There are already extensive workings in this area and a more recent history of quarrying

4.6.5 Comrie Quarries

Resources *Medium*

Weathering Good

Access Very inaccessible.

Environmental sensitivity
Low, these quarries are in a remote area

4.6.6 Logiealmond

Resources *Limited to medium*

Weathering Good

Access A good track leads to the Craiglea Quarries

Environmental sensitivity
Low, these quarries are in a remote area

4.6.7 Dunkeld Quarries

Resources *Variable*, see quarry reports

Weathering Medium - good

Access A good road leads to the lower level quarries at Birnam. Upper level quarries at Birnam are inaccessible. The Newtyle quarries are close to the road

Environmental sensitivity
Birnam, low

Newtyle: medium, these quarries are close to several houses

4.7 Conclusion

The Highland Border quarries proposed for further investigation are Logiealmond (Craiglea) and Aberfoyle for the following reasons:

Other uses: The green slate of Craiglea and some of the Aberfoyle have attractive bedding features which suggest that the slate could be used for architectural purposes other than roofing, such as flooring and cladding.

Mineralogy: The mineralogy of Highland Border slate indicates lower durability than other Scottish slate in that there is a higher proportion of chlorite. In addition Aberfoyle has lower than average quartz content. However the iron ore mineral present is in the oxidised form of haematite and there is no graphite. The presence of small amounts of calcite in the absence of pyrite/pyrrhotite is not considered deleterious.

Crystallinity: The crystallinity of the Craiglea slate is high as measured by the intensity of XRD peaks and FWHM of between 0.12 and 0.14 2θ. The crystallinity of Aberfoyle is low to medium and FWHM is 0.16 2θ.

Size of slates: The Craiglea slate is fine to medium grained and would produce a slate 9-10mm thick. Because the waste tips have been left in a very unstable condition, it was not possible to assess the effect of density and orientation of jointing on the size of the slates. The Aberfoyle slate is finer grained and the commercial thickness is estimated as 8mm. Joints are widely spaced and would not limit the size of slates.

Recovery: Grit bands delimit the Craiglea quarry, but it should be possible to extend the quarry into the high ground to the SW. Waste material has been dumped indiscriminately and would have to be cleared. Several seams were worked in the Aberfoyle quarries some of which could be extended along strike. These seams are separated by zones densely permeated by veins of quartz and calcite. There has also been indiscriminate dumping of waste in the Aberfoyle and reopening would involve major clearing of the area.

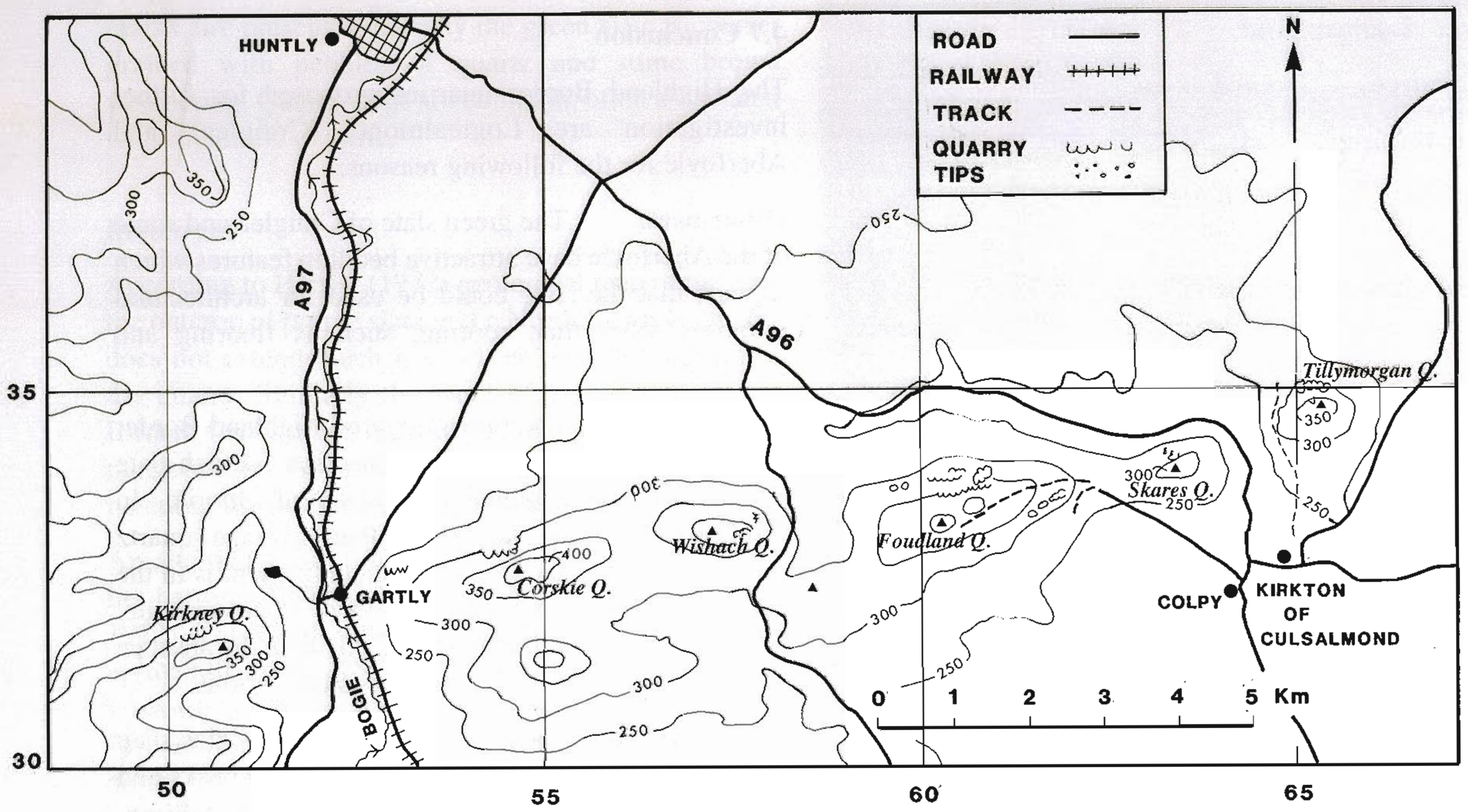


Fig. 5.1 Map showing the location of the Slate Hills

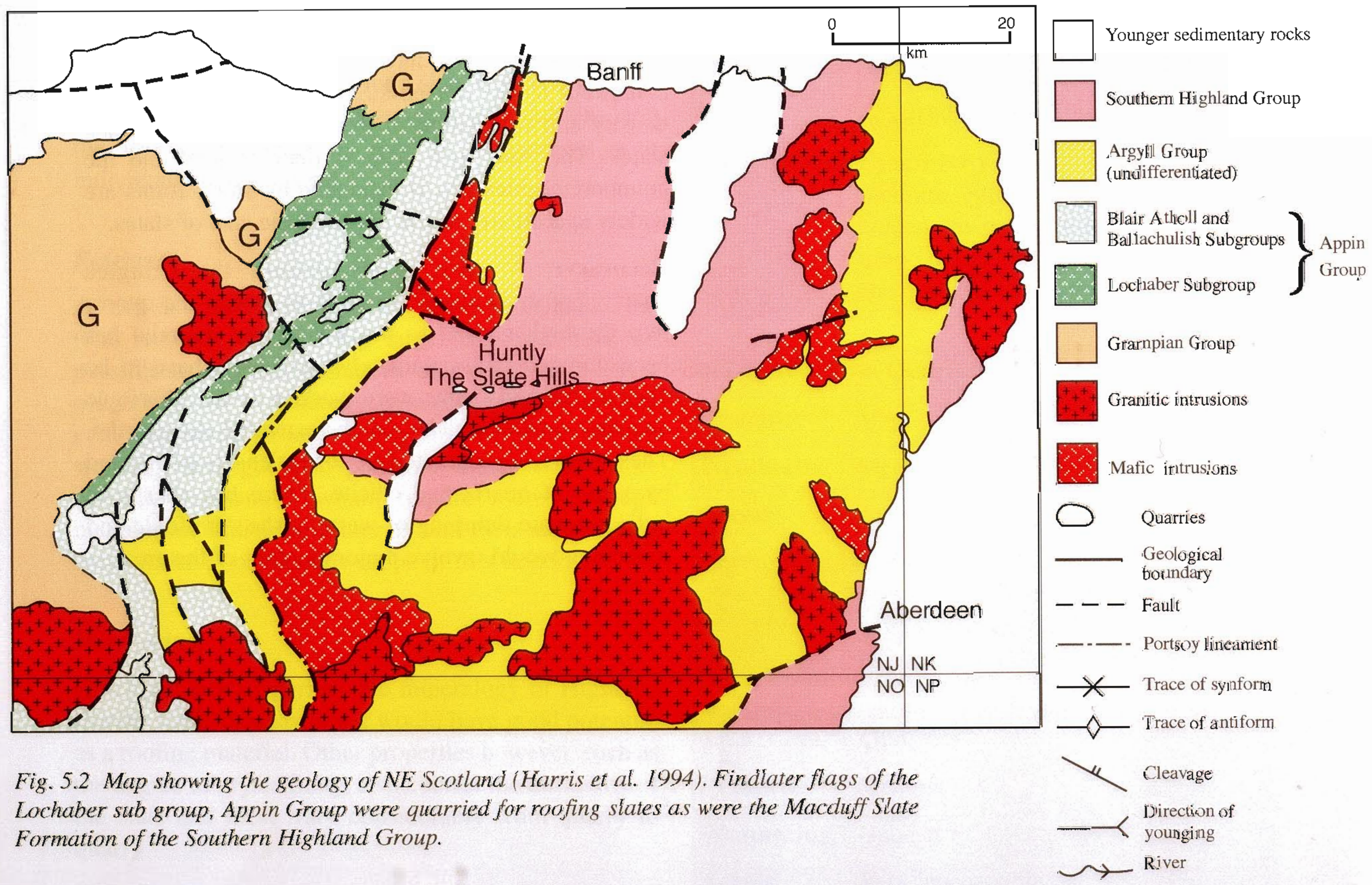


Fig. 5.2 Map showing the geology of NE Scotland (Harris et al. 1994). Findlater flags of the Lochaber sub group, Appin Group were quarried for roofing slates as were the Macduff Slate Formation of the Southern Highland Group.

5 THE MACDUFF SLATE QUARRIES

5.1 Introduction

Slate has been wrought in two areas in the NE of Scotland, namely the Macduff Quarries in Buchan and the Keith Quarries in Banffshire. Macduff Slate is named after the type location on the coast, although the quarries themselves are located several kilometres inland near Huntly. Slate was extracted from the so called slate hills of Kirkney, Corskie, Wishach, Foudland, Skares and Tillymorgan (Fig. 5.1). Of these, the most important quarries in the 19th century were on the Hill of Foudland and the name "Foudland" is sometimes used as a generic term for slates from the area. Numerous slate quarries are dotted around the countryside but only those mentioned in the War Pamphlet No 40 (Richey and Anderson 1944) report are considered in this Report.

The second group of quarries is located together in the Keith area in Banffshire, stretching from north of Keith to Dufftown. These slates were extracted from an older formation called the Findlater Flags.

5.1.1 Location

Macduff slate was quarried in a row of hills stretching from east to west approximately 8km south of Huntly in Aberdeenshire.

Maps O.S. 1:50000 Landranger Series Sheet 29
1:10000 NJ53 SE & SW, NJ63SW & SE
BGS 1:63360 Sheet 86

Slate quarries on the following hills are described below:

Quarry	Grid Reference
Kirkney	NJ503317 to NJ510320
Corskie	NJ533328 & NJ544328 to NJ549329
Wishach	NJ577331 to NJ579334
Foudland	NJ590327 to NJ620340
Tillymorgan	NJ646345 to NJ659351

5.1.2 Topography

The area around Huntly in Aberdeenshire is called the Buchan platform. It is an area of relatively low relief with gently undulating low hills. The country is covered in a thick blanket of glacial deposits with rounded hills formed by psammites and occasional conglomerates. To the south of this area the slate hills form an east-west ridge rising to a height of approximately 400m (Fig. 5.1) which stand out in contrast to the easily eroded, basic intrusion of the Insch mass nearby. In fact these slate hills mark the aureole of the thermally altered rocks. In Quaternary time, these slate hill were sites of erosion while ice sheets flowed E and NE across Buchan, depositing a mantle of boulder clay on the lower ground (Hall & Connell 1991). The barren infertile ground at the tops of the slate hills is in sharp contrast to the rich farmland in this famous whisky producing area. For this reason, slate was quarried on the high ground to avoid the problems associated with an overburden of glacial deposits.

In contrast to the rolling country of the Buchan platform, the area to the west is less regular. Deeply dissected valleys run NNE-SSW between ridges made up of steeply dipping competent lithologies such as quartzite (Read 1923).

5.2 Geology

The schists of the north east of Scotland were divided by Read (1923) into the Keith and Banff divisions separated by the Boyne Line, which he interpreted as a major structural discontinuity. These divisions are subdivided into numerous small groups, mapped from the excellent exposure along the coast of the Moray Firth from where most of the formations derive their local names. However, some of these group names are no longer used as they represent different metamorphic grades rather than different lithologies e.g. the Boyndie Bay Group near Banff (Fig. 5.2) is now considered part of the Macduff Slate Formation, but at a higher metamorphic grade (Stephenson & Gould 1995). The formations in this part of Scotland have since been correlated with equivalent formations in the rest of the Grampian area, despite the presence of the major shear zone and a different metamorphic history, and the Banff and Keith subdivisions are no longer used. The two formations from which roofing slates were extracted are the Findlater Flags and the Macduff Slate. The former has been correlated with the Lochaber

Subgroup of the Appin Group by Treagus and Roberts (1981) and the later has been assigned to the Southern Highland Group (Harris and Pitcher 1975, Harris *et al.* 1994).

5.2.1 Stratigraphy

The Macduff slate formation, part of the Southern Highland Group, is comprised of fine-grained distal turbidites with slump deposits. The Findlater Flags are part of the Lochaber Group and consist of psammites and semipelites (Table 5.1).

5.2.1.1 Macduff Slate

The Macduff formation outcrops over a large part of the NE of Scotland. It stretches along the coast from Banff (NJ685640) through Macduff (NJ715645) to Gamrie Bay (NJ800650), a distance of 10km. It can also be traced to the south into the Strathbogie area south of Huntly (NJ525400). The Macduff Slate, consisting of 1700m of distal turbidite deposit (Stephenson & Gould 1995), is very uniform over this large area with only occasional bands of grit. The slates are well-cleaved and dark blue in colour.

5.2.1.2 The Findlater Flags

The Findlater Flags are exposed along the coast from West Sands (NJ538674) to west of Crathie Point (NJ549675). Located on this part of the coast is the Castle of Findlater (NJ5446674) from which the group gets its name. The formation continues inland into the Aultmore district almost to the Isla River at Keith (NJ430528). The strike is to the north-east and dips are generally high near the coast, but decrease to 20° in the Keith area (Read 1923).

Slate was quarried at several localities of which the following are but a few examples:

- Craighead Quarry is a small working (NJ347511) west of Mulben.
- An unnamed quarry (NJ426526) in a stream embankment at Newmills north of Keith.
- A large quarry called Tarrymount (NJ411585) in the Aultmore area.
- Cnoc Fergan Quarry (NJ143225) (Plates 66 to 67) north of Tomintoul is a small quarry, which was used almost exclusively to roof the village of Tomintoul (per. com. local slater).
- A small quarry (NJ370358) near Auchindoun Castle but the waste tips of several workings on the slopes of the Hill of Mackalea (NJ370382) marked on the OS map NJ33NE are now overgrown with gorse.

The Findlater Flags are silvery grey in colour and are quartzose. They separate into flags approximately 15mm thick due to development of mica on the plane surface. The flags are rich in quartz and become progressively more so from the coast towards Keith (Read 1923).

Group	Subgroup	Keith Area	Macduff Area
Southern Highland			*Macduff Slate*
			Whitehill Grit
Argyll	Tayvallich		Boyndie Limestone
	Crinan		
	Portsoy Lineament tectonic discontinuity		
	Easdale		
	Islay		
Appin	Blair Atholl		
	Ballachulish		
	Lochaber	*Findlater Flags*	

Table 5.1 Stratigraphy of the NE Grampian area modified from Stephenson and Gould 1995

5.2.2 Structure

The structure of the Buchan area is dominated by broad, open upright folds with axes striking NNE such as the Turriff Syncline. This structure folds an older set of folds which vary from upright and open in the centre to tighter and isoclinal on the limbs. The Macduff slate group occupies the core of this Turriff Syncline, where the primary folds are upright and upward facing with strong, steep, axial planar cleavage (Fig. 5.3, Stephenson and Gould 1995).

To the west of the Turriff Syncline there is a major monoform, the Boyndie Syncline (Sutton and Watson 1956). There is considerable debate as to whether this is a primary or later fold, but whatever the timing its existence accounts for the older rocks, such as the Findlater Flags, outcropping to the west (Treagus and Roberts 1981, Johnson & Stewart 1960, Fettes 1970).

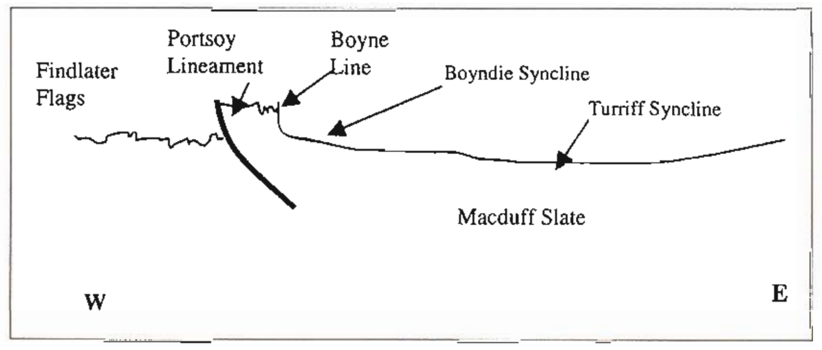


Fig. 5.3 Cartoon showing the cross section of the Macduff slate formation within the major structure in the Buchan and Banff area.

5.2.3 Metamorphism

Between the Macduff Slate and the Findlater Flags outcrops there is an area of intense deformation, the Portsoy Lineament. There are many esoteric interpretations as the significance of this shear zone but suffice to say that it defines the Buchan Block to the east as a separate unit with a different metamorphic history.

The Buchan area is a classical one, first used to describe metamorphism with a higher geothermal gradient than that found in Barrovian metamorphism (Barrow 1893). Superimposed on the regional metamorphism in the Huntly area is contact metamorphism due to the emplacement of the Insch and Boganclough Igneous Intrusions. This has had the benefit of hardening the slate. However, closer to the intrusion on the southern slopes of the slate hill there is a gradual change from unaltered slate to a spotted slate, a hornfels which is no longer capable of being split along planes of cleavage. Most of the slate quarries are located on the north slopes of the hills where the slate, although often spotted, is still capable of being split along cleavage.

5.3 History

The Macduff slate quarries are subdivided into groups which share a common history as follows:

- The Strathbogie Quarries

  The quarries on the hills of Kirkney, Corskie and Wishach.
- The Foudland Quarries
- Skares Quarries
- The Tillymorgan Quarries

5.3.1 Ownership

Strathbogie Quarries

The land on which the Strathbogie quarries lie was given at the time of Robert the Bruce to the Gordon family, originally from Huntly in Berwickshire. This line died out in 1836 and ownership passed to the Dukes of Richmond, although the estate has subsequently been broken up (Blaikie 1834).

Foudland Quarries

In the 19th century the greater part of the Hill of Foudland was owned by Mr. Gordon of Newton in the parish of Culsalmond, with a much smaller part belonging to Major Leslie of Balquhain. Inverurie (Blaikie 1834).

Tillymorgan Quarries

At the time of peak production in the 19th century, the Hill of Tillymorgan was owned by Mr. Leith Lumsden of Clova and Mr. Fraser of Williamston. The former estate was broken up in 1866, although most of the quarries remained in one lot. The Williamston Estate is still intact and owned by the Fraser family (per. com. Mr. Burnett).

5.3.2 Production

The Corskie quarries were the first in the area to start production in 1700, followed by those at Tillymorgan in 1750 and Foudland in 1754 (Blaikie 1834). Production was at its peak during the early part of the 19th century, with typical annual outputs as estimated by Blaikie of:

Strathbogie	400,000 - 500,000 slates
Foudland	800,000 - 900,000
Tillymorgan	300,000

Little is recorded of the Hill of Skares quarries, but their small size suggests very limited production.

Macduff slates were small, with typical sizes of 12" x 9" (305mm x 225mm) and 9" x 6" (225mm x 150mm). At the time of peak production they sold at 40 - 50 shillings per thousand at the quarry, with transport cost increasing the price to £4 at Elgin, for example, where Easdale slate at the same time sold for £3 per thousand.

Most of the quarries appear to have closed during the period 1850 - 1870, as the development of railways enabled slate from other parts of Great Britain to be sold competitively in the area. Local tradition suggests that the Foudland quarries remained in production till the end of the 19th century, but there are no official records to support this. The Kirkney quarry in Strathbogie was used for roadstone in the 1920s and 30s.

5.3.3 Working Practices

The custom of letting and subletting quarries on short leases led to their being worked in a very unsystematic manner. A subtenant would take the quarry on a one-year lease at a rate per thousand slates on condition that he opened new quarries or removed rubbish from old. If he was successful in finding a good quarry, the price for the slates was reduced at the end of the year or a new subtenant found.

This understandably led to poor working practices and little effort was spent on cutting drains, making roads and removing rubbish. Evidence of this can still be seen today, where rubble has been allowed to accumulate close to workings and the remains of numerous small openings suggest transience. At one point quarrymen were brought from Wales to train the local workforce at the Foudland quarries, but this does not seem to have halted their decline (Blaikie 1834).

5.3.4 Transport

The turnpike roads, newly developed in the early 1800s, provided the first means of transport for slate. The Aberdeenshire Canal was opened in 1805 - 1807, and there are records of slate being carried from Inverurie to Aberdeen. However, this traffic went into steep decline with the coming of railways, and the Canal was closed following the opening of the Great North of Scotland Railway. The railway extended progressively from Aberdeen in the 1840s and 50s to Huntly and then to Keith. It should have facilitated the transport of slate, but in fact heralded the decline of local quarries by allowing slate from Wales and the west of Scotland to be cheaply imported.

5.4 Description of Macduff Slate (Plate 68)

The Macduff slate is remarkably homogeneous across the area covered by the quarries.

5.4.1 Hand Specimen

Slate	Blue grey and occasionally green slate, medium with occasional silty bands.
Cleavage	Flat with a rough surface.
Bedding	Bedding features common.
Weathering	Slight rusty weathering along non-cleavage surfaces.

5.4.2 Mineralogy

The mineralogy was determined by thin sections, XRF and XRD analyses as follows:

Major minerals	Quartz, White mica and Chlorite (Appendix 1)
Minor Minerals	Haematite, Apatite and Ilmenite
Graphite	None detected
Carbonate	None detected
Reduced iron/Total Iron Fe^{2+}/Fe_{total}	MK-4 28% MF-11 29%
Crystallinity	Medium

Formula

Formulae for a sample from the Kirkney quarry were determined by electron microprobe analysis.

White mica
MK-4 $Na_{0.32}K_{0.63}Fe_{0.15}Al_{1.88}(Al_{0.99}Si_{3.01}O_{10})(OH)_2$

Chlorite
MK-4 $Fe_{2.47}Mg_{1.63}Al_{1.64}(Al_{1.37}Si_{2.63}O_{10})(OH)_8$

Using the formulae above, the mineral composition of a selection of slates was determined (see Appendix 1).

5.4.3 Weathering

The mineralogy is homogeneous over a large area. Most chemical weathering is due to the presence of reduced iron, especially in the presence also of carbonates. In Macduff slate the iron ore mineral is present in the oxidised form of haematite, and no carbonates were detected, which makes the slate resistant to chemical weathering.

No water absorption figures are available for fresh

slate. It was noted however that local roofs (Plate 48) have much lichen and algae on the surface, suggesting that water absorption is higher than for fine-grained slates such as Ballachulish. The reduced iron present in chlorite makes it the most vulnerable mineral in Macduff slate, and traces of chloritic weathering were found. This concurs with Blaikie's account where green slate, which has a higher chlorite/haematite ratio, was considered less durable.

5.4.4 Fabric

A selection of slates, from tips and from silty bands left *in situ*, was collected from each of the slate hills and their fabric examined under the SEM:

Shape of Cleavage Domains	Anastamosing and often discontinuous
Spacing of Cleavage Domains	Spacing ranges from 16μm to 30μm with an average value of 26μm
Microlithons	Very little fabric
Alignment	13-30% with an average value of 21%
FPS Value	5-10 with an average value of 9

This equates to a potential minimum commercial thickness of ~7-8mm (Research Report Chapter 4). It is worth noting that the fabric of a sample collected from the dressing area was not exceptionally good, as had been expected, but was actually at the lower range of the values shown above.

5.5 Quarry Appraisals

5.5.1 KIRKNEY QUARRIES

NJ503317 to NJ510320

(Fig. 5.1, Fig. 5.4a, Fig. 5.5, Plate 49)

Plate 49 Kirkney Quarry. The overhanging face has collapsed with time, along the pillaring line (NJ503317 to 510320)

5.5.1.1 Site Details

Location	The Kirkney Quarries are located on the Hill of Kirkney (height 442m), the most westerly of the slate hills.
Maps	O.S. 1:10000 NJ 53 SW
Access	From Whitlumbs, on the minor road to the clachan of Kirkney which joins the A97 100m south of Gartly Station, there is access to the quarries across the fields. A discontinuous track can be seen on the hillside, which probably serviced the quarries in their day. There is no vehicular access.
Ownership	Forestry Commission since 1929.

5.5.1.2 Quarry Details

Slate	Blue-black and some green and grey medium grained.
Bedding	Green to blue banding.
Cleavage	075°/56° Cleavage surface is regular.
Imperfections	Silty bands and occasional quartz veins.
Weathering	Weathering surface a lighter grey; very little rusty weathering.

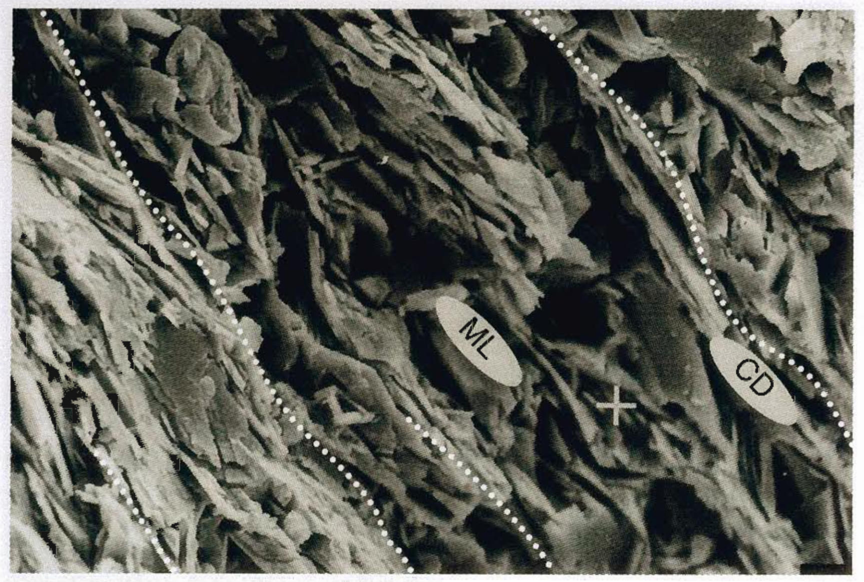
5.5.1.3 Workings

The main quarries are situated on the north slopes of the Hill of Kirkney in the area NJ503317 to NJ510320 at a height of 380m. There appear to have been two seams worked along strike ENE (075°). There are two main clusters of quarries each 500m long with a gap of 500m between them. The older workings are at a lower level and have been partly obliterated by the tips from later workings at a higher level. Individual quarries can be identified each with its own entrance/drain, usually on the north side, and accompanying tips (Fig. 5.5b). On the south side of the quarries the face is overhanging or has collapsed with time, often along pillaring lines (Plate 49). The remains of several shelters can be seen with an area nearby where the slates were dressed. None of the quarries has been worked to greater than 10m depth.

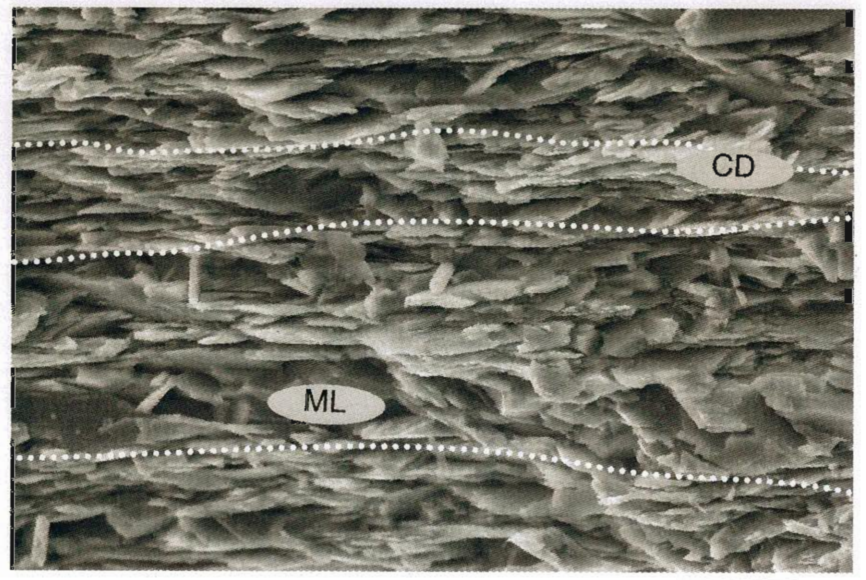
Of less significance is a second set of workings found on the south side of the hill at a height of 350m. They are located in the area NJ500313 to NJ516317

5.5.1.4 Resources

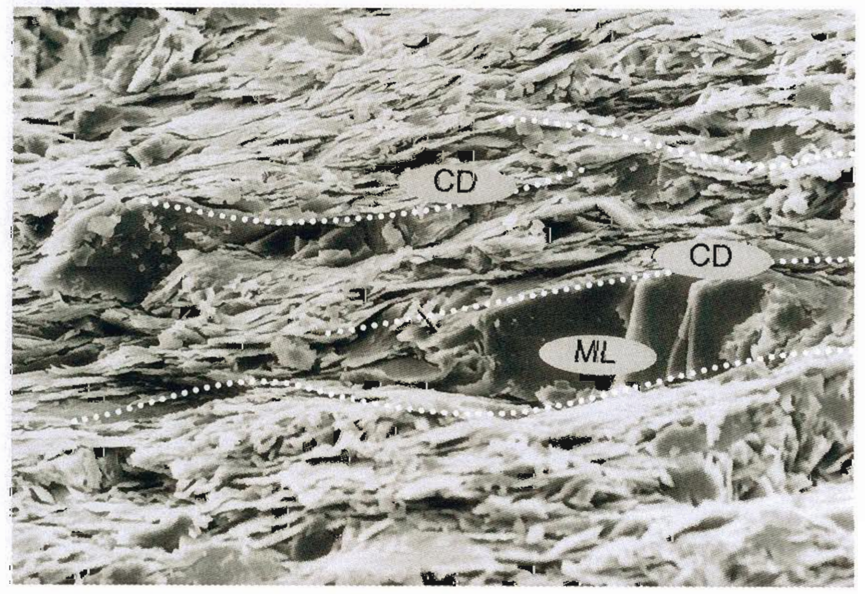
The slate deposits are *very large* in this area. The seams of slate have only been worked between bands of siltier



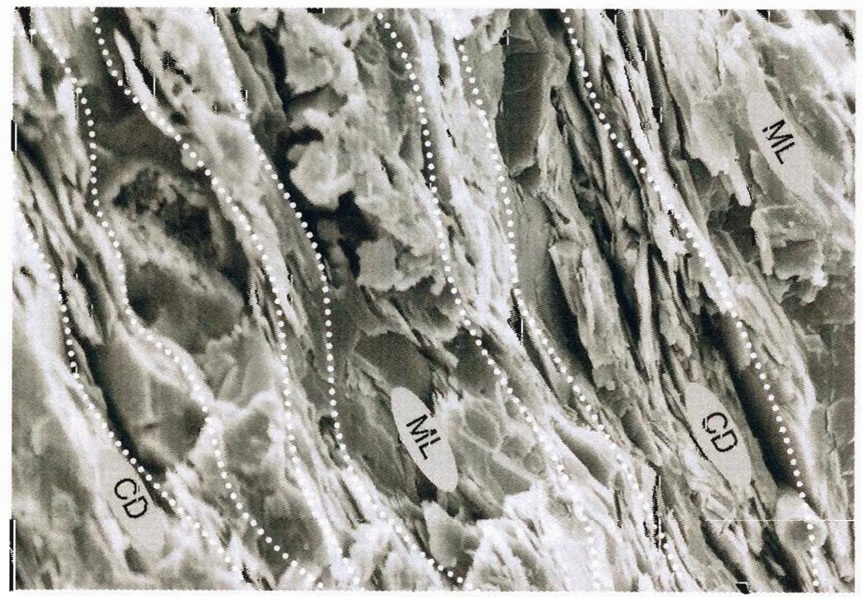
a) KIRKNEY QUARRIES 20.0µm
MK-2
Finely spaced, discontinuous slight anastomosing around microlithons. This slate has the potential to be split to 6.00 - 7.00mm.



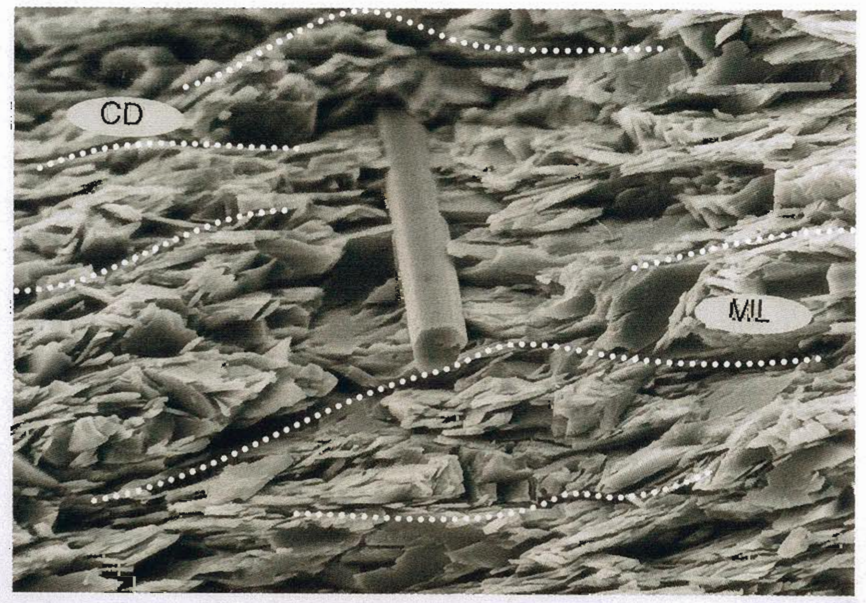
d) WISHACH QUARRIES 20.0µm
MW-1
Straight continuous cleavage domains make up a high proportion of the slate giving it the ability to be split 5.5 - 6.00mm.



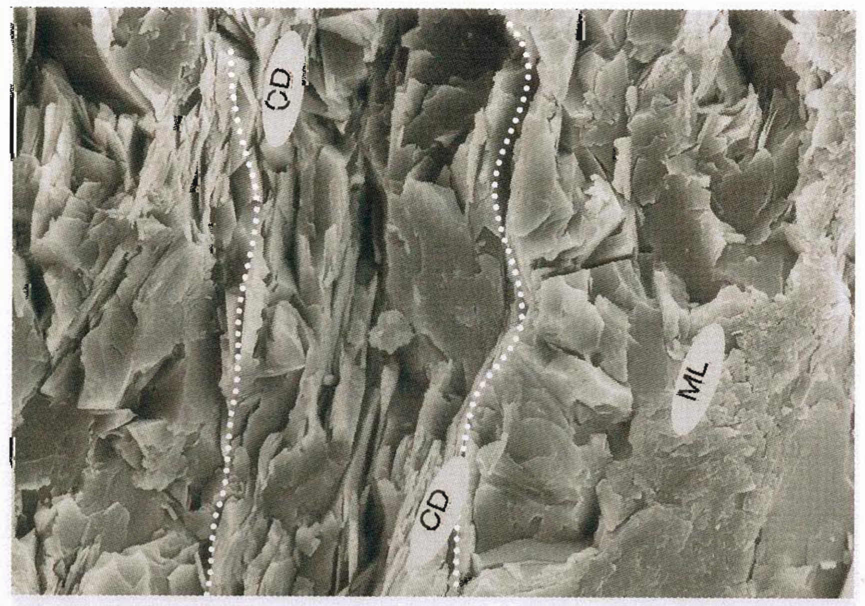
b) CORSKIE QUARRIES 50.0µm
MC-2
Cleavage domains are irregular and widely spaced, discontinuous and anastomising. Estimated thickness is approximately 8mm.



e) FOUDLAND QUARRIES 20.0µm
MF-2
Fairly widely spaced, slightly anastomising around microlithon with some development of fabric estimated thickness 6.0mm.



c) Corskie Hill HAINING QUARRIES
MH-2 20.0µm
Cleavage domains are irregular, discontinuous and anastomising. This slate has the potential to be split to 7mm. The crystal centre field is tourmaline.



f) TILLYMORGAN QUARRIES
MT-4 20.0µm
Widely spaced, discontinuous irregular cleavage domains limit the thickness of a slate to 8mm.

Fig. 5.4 Fabric of Macduff slate

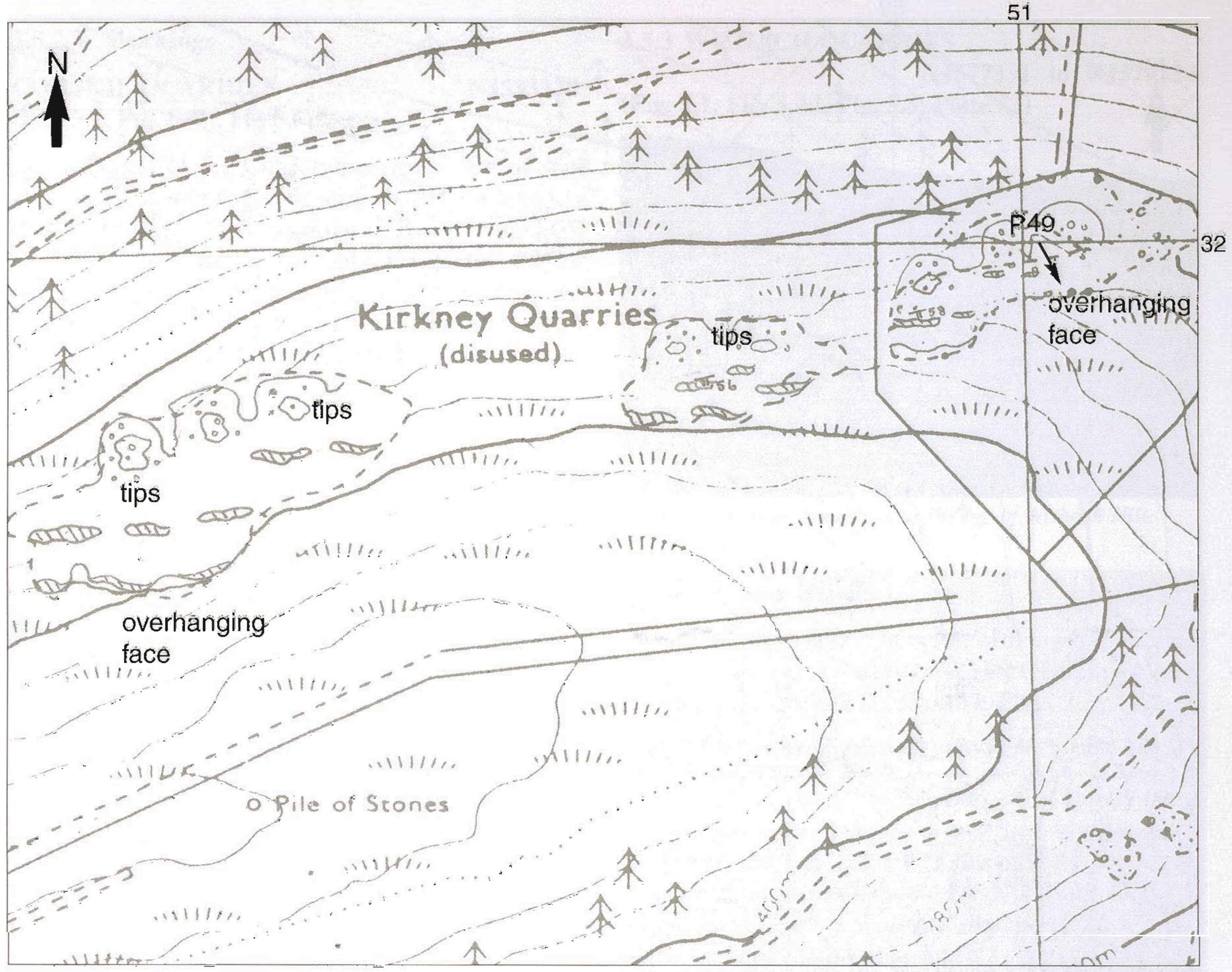


Fig. 5.5 Map of the Kirkney Quarries based on OS NJ53SW copyright 1992. A similar layout was found in many of the quarries located on the north slopes of the hills. *1:5,000*

rock, and resources are expected to be at least *medium* in size. The quarries were also only worked superficially and further exploitation is possible to greater depth. Assuming no change in the quality of the slate, further extraction should also be possible along strike.

5.5.2 CORSKIE QUARRIES
NJ533328 and NJ544328 to NJ549329
(Fig. 5.1, Fig. 5.4b and c, Fig 5.6, 5.7, Plate 50)

Plate 50 Haining Quarry near the top of the Hill of Corskie (NJ544328 to NJ549329)

Located on the Hill of Corskie are the Corskie, Haining and Roughouster Quarries.

5.5.2.1 Site Details

Location	The Corskie and the Haining Quarries are situated on the north slopes of the Hill of Corskie (420m) following a line stretching ENE. The Corskie Quarries are at the western end of this line at 280m. The largest of the workings is located at NJ533328 with several smaller quarries in a line to the west. The Haining Quarries are near the top of the hill in a line stretching from NJ544328 to NJ549329. Roughouster Quarries consist of two small workings located at NJ551331 300m ENE of the most easterly of the Haining Quarries.
Maps	O. S. 1:10000 NJ 53 SW
Access	There is an entrance into the Gartly

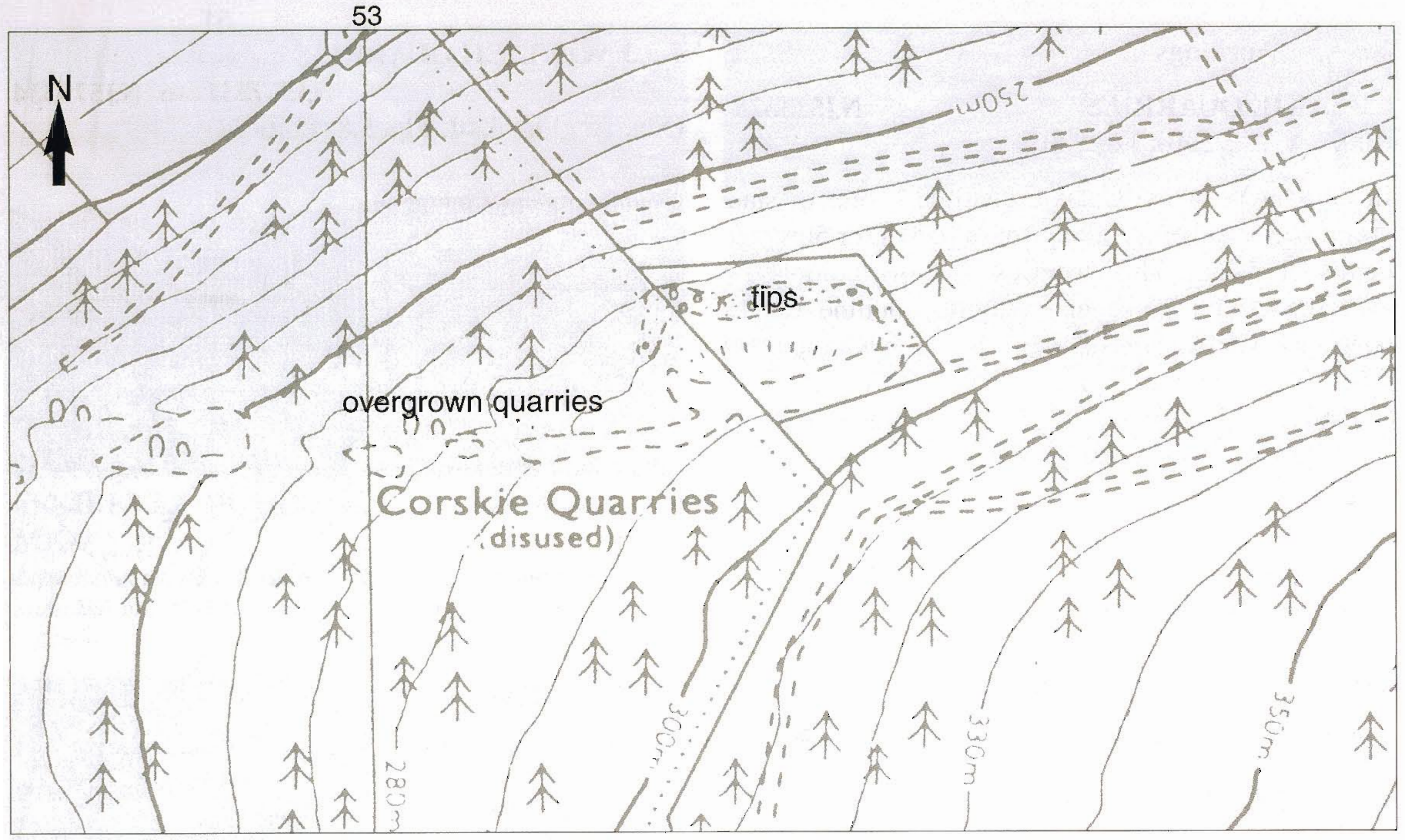


Fig. 5.6 Map of the Corskie Quarries based on OS NJ53SW copyright 1992 *1:5,000*

	Moor Forest 1.5km east of Gartly Station. 200m along this track it divides, the westerly branch leading to the Corskie Quarries 200km further on.
	The Haining Quarries can be reached on foot by using a series of fire breaks and forestry paths to reach the top of the hill. Alternatively, there is a well maintained forest track to a radio mast at the top of the hill, from which a rough track gives vehicular access close to the quarries. There is no path to the Roughouster Quarries.
Ownership	Corskie and Roughouster Quarries; Forestry Commission since 1946
	Haining Quarries; Mr. J. Cooper, 7 Dubford Ave, Bridge of Don, Aberdeenshire.

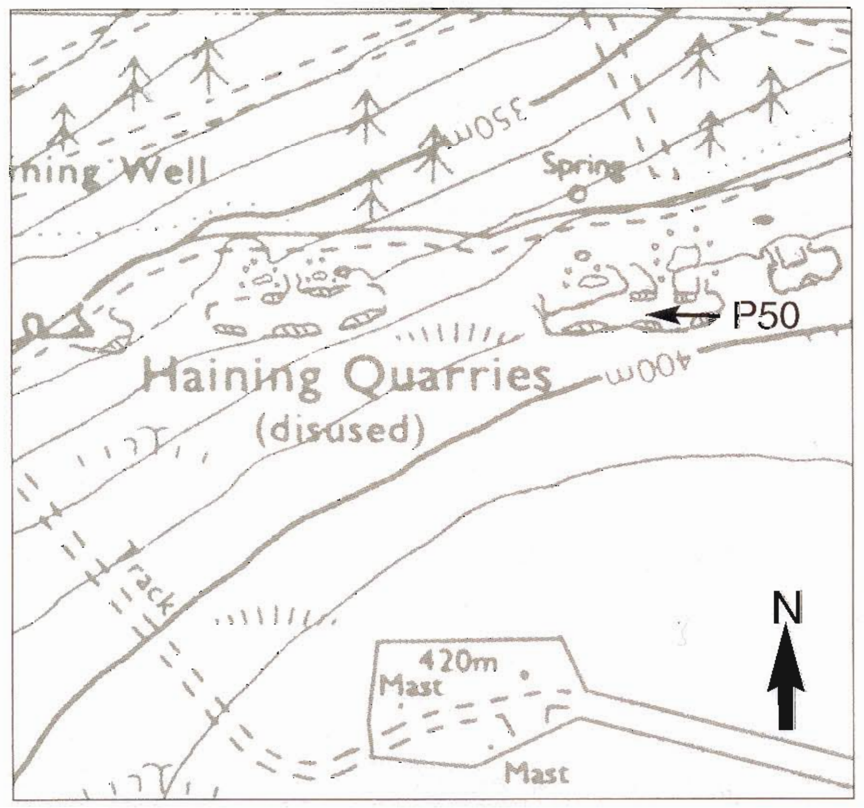


Fig. 5.7 Map of the Haining Quarries based on OS NJ53SW copyright 1992 *1:5,000*

5.5.2.2 Quarry Details

Slate	Blue grey in colour, fairly coarse grained. Green slate estimated as 10% in the Corskie tips.
Cleavage	070°/70°
Bedding	Frequent banding at low angle to cleavage estimated as 20°.
Weathering	Slate in the Corskie tips showed slight rusting along jointing and occasional chloritic sheen. In the largest of the Haining workings a band of slate had weathered to a yellow substance. Elsewhere there was very little weathering.

5.5.2.3 Workings

CORSKIE QUARRIES **NJ533328**
(Fig. 5.1, Fig. 5.4b, Fig 5.6)

In the largest of the Corskie quarries a vein of slate 20m wide was worked along strike (070°) for 50m to a depth of 5-7m. This working is now completely overgrown with gorse and only the outline of the quarries is visible, similar to that found in Kirkney Hill (Fig.5.5.b). Samples were collected from the tips. Several smaller openings, also overgrown, can be identified to the west along strike.

HAINING QUARRIES **NJ544328 – NJ549329**
(Fig. 5.1, Fig. 5.4c, Fig 5.7, Plate 50)

A vein of slate was worked at intervals along strike (070°) for approximately 500m. About five or six quarries were identified ranging in size from 10m to 50m. They follow the same pattern of working as described for Kirkney but on a smaller scale.

5.5.2.4 Resources

Slate deposits are very large, covering most of the Hill of Corskie, indicating *large* resources. Resources within the area of the quarry are estimated as *medium*, assuming no change in the quality of the slate along strike. It should also be possible to extract slate at greater depth than worked previously.

5.5.3 WISHACH QUARRIES
NJ577331 to NJ579334
(Fig. 5.1, Fig. 5.4d, Fig. 5.8, Plate 51)

Plate 51 Wishach Quarry near the top of Wishach Hill (NJ579334)

5.5.3.1 Site Details

Location	A group of small workings are located near the top of Wishach Hill in the area NJ577331 to NJ579334.
Maps	O.S. 1:10000 NJ53SE
Access	From the A96 7km SE of Huntly there is a minor road over the moors to Insch. After following this road for 3km there is an entrance into the forest to the west. The quarries are within a kilometre of this entrance, through dense undergrowth at the time of writing.
Ownership	Forestry Commission since 1946.

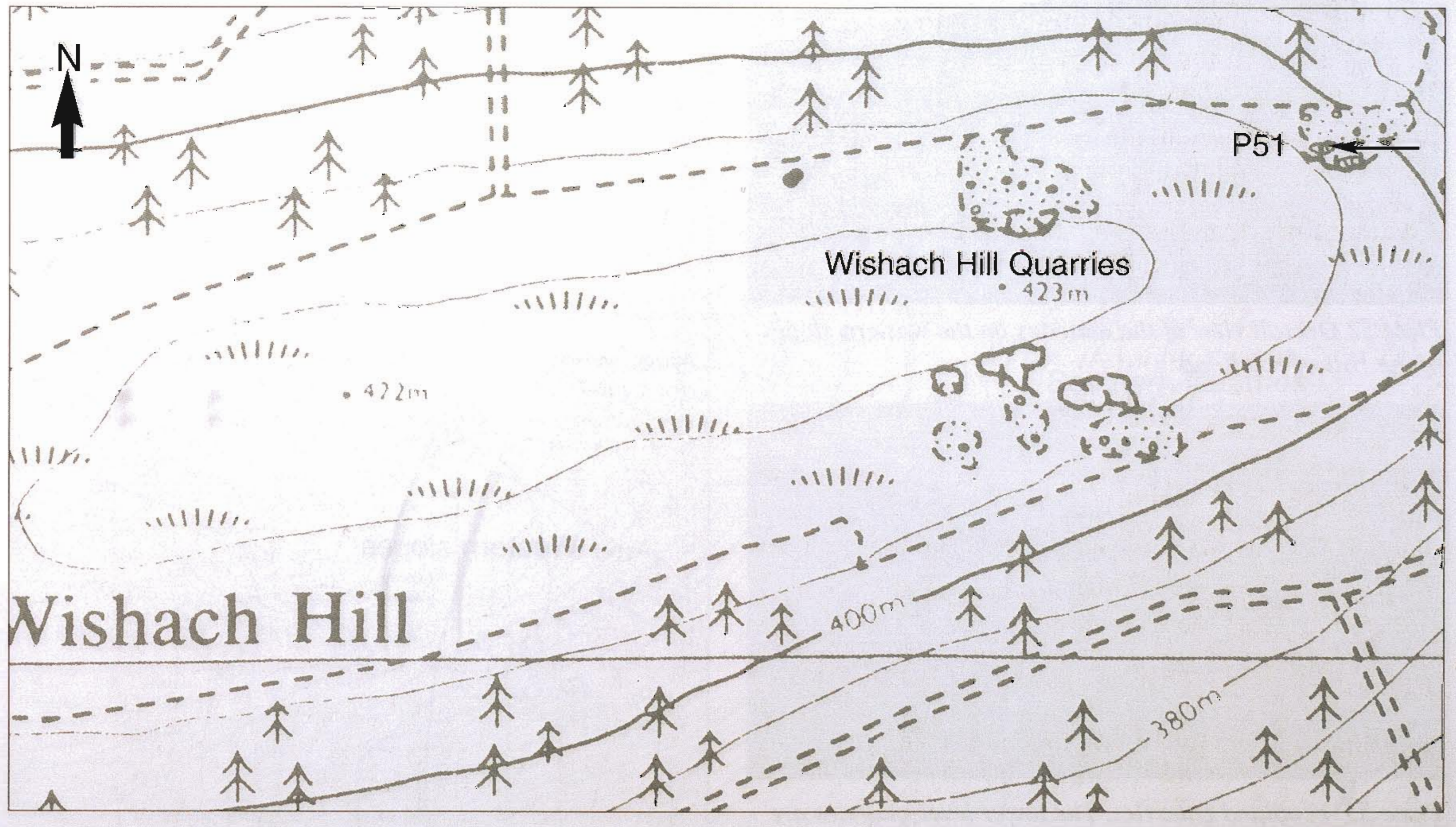


Fig. 5.8 Map of the Wishach Quarries based on OS NJ53SE copyright 1993 *1:5,000*

5.5.3.2 Quarry Details

Slate	Blue grey, medium grained with frequent grit bands, usually green.
Bedding	Conspicuous banding at 45° to cleavage.
Cleavage	68°/54°
Imperfections	Silty bands and occasional quartz veins.
Weathering	Weathering surface is a lighter grey; very little rusty weathering was observed

5.5.3.3 Workings

Several small quarries, each less than 50m in length, were worked close to but not at the brow of the hill. A typical quarry on the north side of the brow of the hill is 30m long, 5m wide and 3-5m deep.

5.5.3.4 Resources

The seams of slate have never been worked to more than 10m and there are plenty of resources available for future exploitation within the confines of each quarry and continued along strike.

5.5.4 FOUDLAND QUARRIES
NJ590327 to NJ620340
(Figs. 5.1, Fig. 5.4e, Fig. 5.9, Plates 52 and 53)

Plate 52 Overall view of the quarries on the western slopes of the Hill of Foudland

Plate 53 Foudland Quarries. The lower level quarries are choked with debris (NJ597337 to 610339)

The Foudland Quarries, on the hill of that name, are located on the northern boundary of the parish of Insch.

5.5.4.1 Site Details

Location	The Foudland Quarries are located on the Hill of Foudland (467m), a broad ridge of barren heathland. The whole of the high ground is dotted with quarries and they are even found at a lower level than usual on the western slopes where glacial deposits are absent. This group of quarries covers an area of 3km² from NJ590327 to NJ620340.
Maps	O.S. 1:10000 NJ53SE and NJ63SW
Western Slopes	
Access	From the A96 8km south-east of Huntly there is a minor road leading to the Glens of Foudland and Clinkstone Farm. A farm track leading to the quarries starts at the south end of the Clinkstone farmyard. A single working is located 1km along this track at NJ591336 and a group of quarries 300m further on at NJ591333.
Ownership	The single quarry at NJ591336 in on Forestry Commission land. The rest of this group is owned by Mr Alan Wilson of Clinkstone Farm.
Crest and remaining slopes	
Access	100m south of the intersection of the A920 and the A96 at Kirkton of Culsalmond there is a minor road signposted to the farms of Colby and Jericho. The first of the quarries is located about 3km along this road. The road continues to the summit of the hill and most of the quarries can be reached easily on foot from there.
Ownership	Mr S Leslie, Warthill, Meikle Wartle, Aberdeenshire.

5.5.4.2 Quarry Details

Slate	Dark grey rough texture with spotting found in the south and upper level quarries.
Cleavage	060°/60° - 70°, cleavage is regular over a large area.
Bedding	Green silt bands; bedding/cleavage lineation is at low angle indicating that bedding and cleavage surfaces are almost parallel
Jointing	Frequent jointing parallel to the cleavage surface Jc and also parallel to the pillaring surface Jr.
Weathering	Slight rusting was noted along joints, occasionally with a chloritic sheen.

5.5.4.3 Workings

Three seams of slate were worked on the Hill of Foudland:

- The Southern quarries on the south side of the hill.
- The Upper Level quarries follow the ridge to the top of the hill and continue to Clinkstone Farm.
- The Lower Level quarries on the north slopes close to the old road.

It is not known whether accessibility or quality of slate was the reason for the location of the quarries. Two of the seams are practically joined at the top of the hill, which suggests the former was the main reason, but some badly weathered slate was found at one location between the upper and lower level quarries which tends to support the latter.

Southern Quarries NJ615333 to NJ620337

Extensive workings approximately 70m wide stretch 500m along the south slope at a height of 400m. As the regional cleavage dips to the south, the slate was extracted directly into the hillside thus avoiding the problem of the overhanging face as observed in quarries on the north sides of the hills.

Upper Level Quarries NJ611336 to NJ615338

On the north slope of the hill at 400m (200m NE of the WT Station mast) a group of quarries stretch for 400m along strike. More recent quarries higher up the hill obscure older workings, but it is still possible to

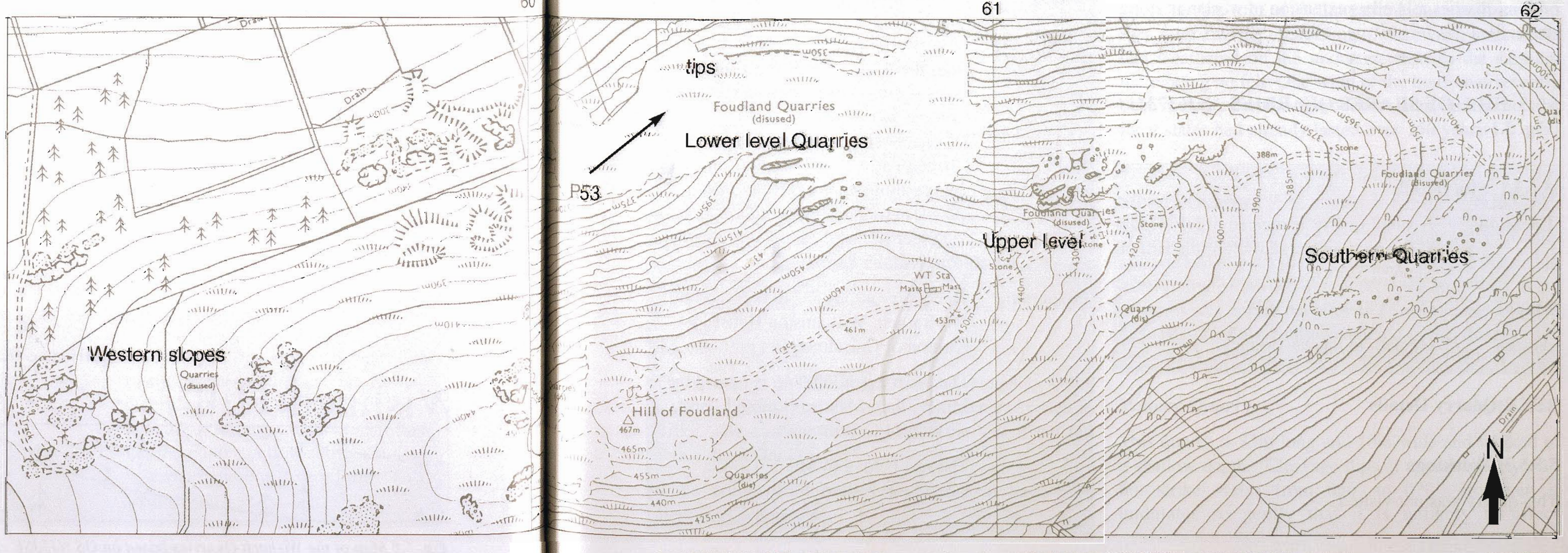


Fig. 5.9 Map of the Foudland Quarries based on OS NJ53SE &NJ63SW copyright 1993 & 1983 1:10,000

recognise 4-5 individual workings. As the regional cleavage dips to the south this face is overhanging in individual quarries and has collapsed in many cases.

Several small workings were visited on the west slope, close to the brow of the hill.

Lower Level Quarries NJ597337 to NJ610339

The most extensive quarries are found at a lower level on the north slopes of the hill stretching over 800m along strike and up to 300m wide. This is probably due to the proximity of the old road through the Glens of Foudland. Individual quarries are stepped upwards from west to east, the size of the workings increasing in the same direction, judging from the size of the tips (Plate 53). The lower level quarries in this group are very overgrown, but at the upper level it is possible to recognise individual workings.

The quarries on the western slopes with access from Clinkstone Farm are a continuation of the two seams seen at the brow of the hill. They consist of several small opening and are not always worked along strike.

Apart from variation in the amount of spotting, the slate is remarkable uniform over this large area.

5.5.4.4 Resources

The workings in the Foudland area are among the largest in the area and many of the quarries are covered in tips. But none of the workings reached any great depth and there is great potential for further exploitation of the resources within the confines of present quarries as well as extension of workings along strike.

5.5.5 HILL OF SKARES QUARRIES NJ637341 (Fig. 5.1)

5.4.5.1 Site Details	
Location	A small quarry is located at NJ637341 to the north of the summit of the Hill of Skares (324m).
Maps	O.S. 1:10000 NJ63SW
Access	No path to these workings.

5.5.5.2 Quarry Details

5.5.5.3 Workings

This quarry was not visited

5.5.5.4 Resources

Assuming the quality of the slate is similar to that on the adjacent hills there are also substantial resources available on this hill.

5.5.6 TILLYMORGAN QUARRIES NJ646345 to NJ659350 (Fig. 5.1, Fig. 5.4f, 5.10, Plate 54)

Plate 54 Siberia Quarry - Hill of Tillymorgan (NJ652347)

5.5.6.1 Site Details	
Location	A group of quarries is located at the top and on the north side of the Hill of Tillymorgan from NJ646345 to NJ659350
Maps	O.S. 1:10000 NJ 63 SW & NJ 63 SE
Access	Access to the quarries is from the N, S and W but none is suitable for vehicles. Shortly after turning east on the A920 from the A96, 10km SE of Huntly, there is the small village of Kirkton of Culsalmond. Access to the westernmost quarries is through Kirkton Farm, 300m north of this village along 'Cadgers Road'. The quarries are located about 3km along a rough farm track heading northwards from Kirkton Farm.
Ownership	The quarry at NJ652346 is owned by Mr. Barnett, Williamston House, Kirkton of Culsalmond The quarry at NJ658346 is owned by Mr. William Massie, Gouksell Farm, Kirkton of Culsalmond. The rest belong to Mr. G. Cowie, Greystone, Fisherford, Inverurie.

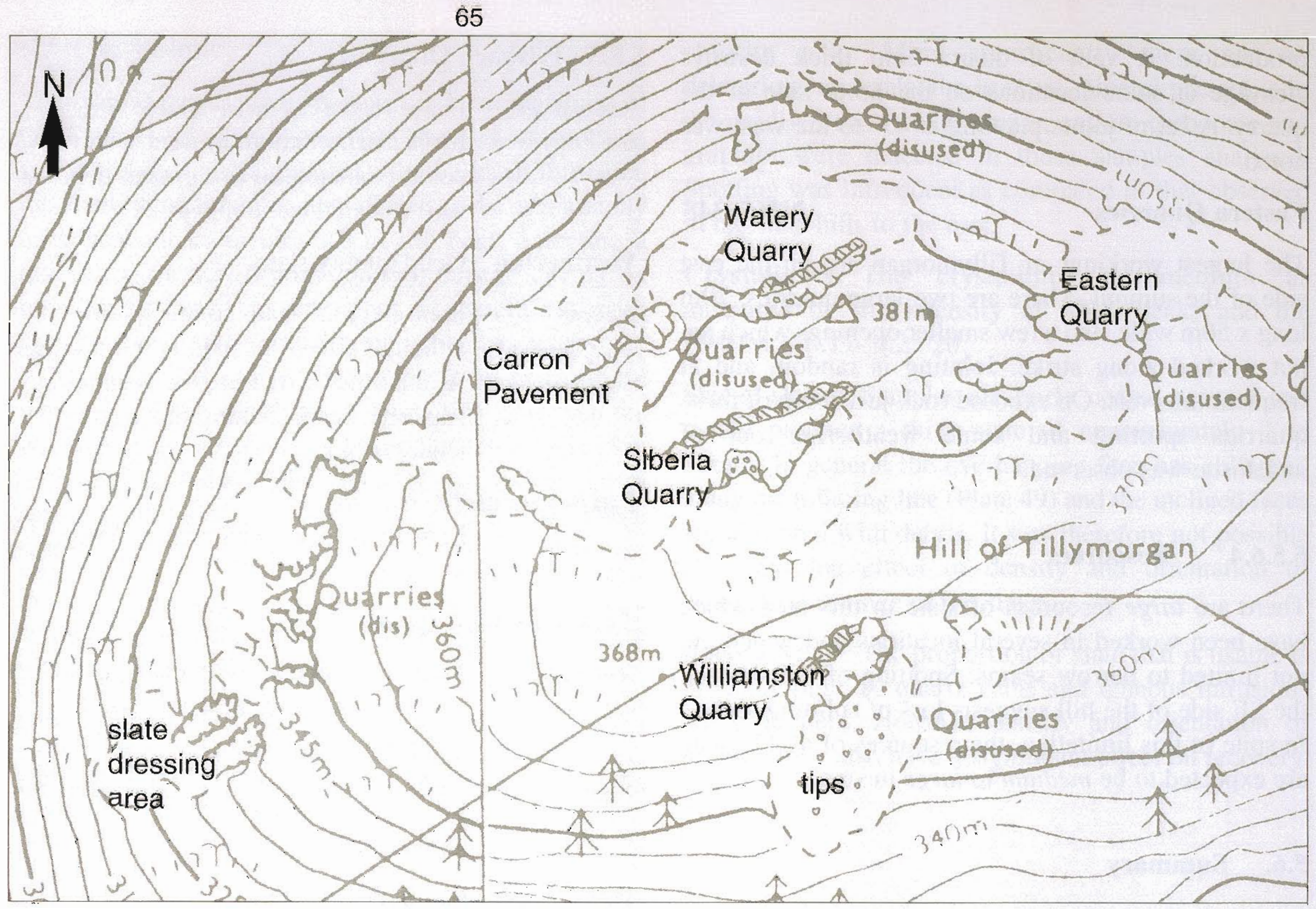


Fig. 5.10 Map of the Tillymorgan Quarries based on OS NJ63SW copyright 1983. Quarry names taken from a map prepared by Beattie (a surveyor) in 1866 1:5,000

5.5.6.2 Quarry Details	
Slate	Blue grey with slight sheen. Blue slate was used preferentially as can be seen from the dressing areas where green slate was discarded. Grains of white mica are visible. Spotting is often seen in quarries on the south side of the summit.
Cleavage	060°/40°-50°
Imperfections	Quartz veins are more frequent than seen in the north Macduff quarries.
Jointing	Jointing along the cleavage plane J_0 and perpendicular to this plane J_1 is common. There is also frequent jointing pitching at 45° on the cleavage surface.

5.5.6.3 Workings

The workings at Tillymorgan are unsystematic, being worked directly into the hillside without reference to strike. The quarries cover most of the top of the hill above the 320m contour.

Some of the quarries on Beattie's map have been identified as follows:

Williamston Quarry NJ653346

Slate was extracted to a depth of 5m in a quarry approximately 50m x 20 m in area and 5-10m wide. This quarry on the Fraser Estate was not in use at the time of Blaikie's report. It may well be the source of slates for the roof of Williamston House built in 1815 (per. com. owner). According to the owner, large slates had weathered on the underside next to the sarking; there being no felt. One wing of the house has recently been re-roofed with *better* Welsh slates, but by then the local slates had already lasted over 150 years.

Siberia Quarry NJ652347

This is a large quarry about 100m long and 50m wide and worked to a depth of 5-10m. Cleavage is dipping at a lower angle than usually found in the area (44°). A set of joints was noted pitching at 45° to the west. (Plate 42). The faces are badly weathered in this quarry.

Watery Quarry NJ652358

This quarry is 85m long and 10m wide and worked to a shallow depth. Cleavage dips at approximately 40°, but strike varies from 056° to 070°. However, it undulates so gently that it is unlikely to affect production. A vein of quartz 5cm thick destroys cleavage at some locations on the north side of the quarry. A set of joints pitching at 45° to the west was noted.

Eastern Quarries **NJ656348**

The largest workings at Tillymorgan are on the east side of the summit. There are two large quarries, 70m long x 50m wide, and a few smaller openings which are not worked along strike. Jointing is random and at frequent intervals. On exposed rock just south of these quarries spotting and some weathering out of andalusite was observed.

5.5.6.4 Resources

There are *large* resources of slate in this area which have been worked in several locations and which are not limited to narrow seams. Spotting of the slate on the SE side of the hill suggests loss of splitting ability. In spite of this limitation, the resources of usable slate are expected to be *medium* to *large* in size.

5.6. Summary

5.6.1 Kirkney Quarries

Reserves	*Large* resources are available for further exploitation. The present workings could be increased to a greater depth as well as extended along strike.
Weathering	Good quality slate.
Access	Poor, no roads lead to these quarries.
Environmental Sensitivity	Low, these quarries are fairly remote from all habitation.

5.6.2 Corskie Quarries

Resources	*Large* resources are available for further exploitation. Present workings could be increased to a greater depth as well as extended along strike.
Weathering	Good quality slate with only slight weathering of chlorites observed.
Access	Medium. The forestry road leads to the lower level quarries and another track leads to the top of the hill which is fairly close to the higher level quarries.
Environmental Sensitivity	Low, these quarries are remote from all habitation.

5.6.3 Wishach Quarries

Resources	*Large* resources are available for further exploitation. Present workings could be increased to a greater depth as well as extended along strike
Weathering	Good quality slate.
Access	Poor. No road leads to this quarry although a forestry road is fairly close. At the time of writing, the vegetation was very dense making this quarry inaccessible.
Environmental Sensitivity	Low, these quarries are very remote.

5.6.4 Foudland Quarries

Resources	Many of the quarries in this area are covered with large tips. The depth of workings are greater than observed elsewhere in the Slate Hills. However, *large* resources are available for further exploitation.
Weathering	Good quality slate.
Access	Medium; there is a good track to the top of the hill close to the high level quarries, but many of the other workings are quite some distance from any vehicular access.
Environmental Sensitivity	Low, these quarries are fairly remote from all habitation.

5.6.5 Tillymorgan Quarries

Resources	Many of the quarries in this area are covered with large tips, but *large* resources are available for further exploitation.
Weathering	Good quality slate.
Access	Poor. No roads lead directly to the quarries.
Environmental Sensitivity	Low, these quarries are fairly remote from all habitation.

5.7 Conclusions

There are large resources of slate on the north slopes of the Slate Hills. Apart from the intensity of spotting, which depends on the proximity to the Insch Intrusion, the quality of the slate was found to be remarkably homogeneous from one hill to the next. Selecting a quarry for further exploitation will depend largely on other factors such as access etc. In general, quarries that have at least rudimentary vehicular access are those worked extensively in the past and hence those which have the problem of large tips covering the working area. Hence a decision on further investigation will need to balance the advantage of easier access against the need to clear larger volumes of waste material.

With this in mind, of the several quarries in the area suitable for further investigation the group chosen in this Report is Kirkney Hill.

Mineralogy: The mineralogy is ideally suited to producing a durable slate, in that the quartz content is moderately high and there is a high white mica to chlorite ratio. More significantly there are no deleterious minerals, the iron ore mineral present is in the oxidised form of haematite, and no carbonate and graphite were detected in those samples analysed. Spotting was infrequent as compared to that observed in the slate hills to the east.

Crystallinity: The crystallinity is medium as measured by the intensity of XRD peaks and the FWHM is 0.17- 0.23 2θ.

Size of slates: Samples are fairly coarse grained and would produce a thick slate of approximately 7 to 10mm. In general the overhanging face has collapsed along the pillaring line (Plate 49) and the inclined faces are obscured with debris. It was therefore not possible to assess the effect of density and orientation of jointing on the size of the slates.

Recovery: The proportion of slate that is usable is probably high, as quartz veins and igneous intrusions are infrequent. However density and orientation of jointing may also have a significant effect on recovery.

APPENDIX 1

MINERAL COMPOSITION (PERCENT WEIGHT) OF SCOTTISH SLATE SAMPLES AS CALCULATED FROM XRF DATA

Ballachulish Slate

Quarry		Total	Quartz	White mica	Chlorite	Pyrite	Albite	Apatite	Dolomite	Clay
East Laroch	Standard	99.6	34.6	26.3	21.2	2.7	4.5	0.2	6.5	3.8
	EL3	99.2	17.2	44	13.6	6.2	10.1	0.1	0	7.9
	EL4	99.1	23.8	43.4	13.1	5	4.6	0.1	0	9.1
	EL6	100.5	40	27.4	17.7	5.1	4.1	0.1	0	6
	EL7	102	28	32.5	22.1	5.4	6	0.2	0	7.9
	EL8	99.1	36.2	29.4	22.6	1.7	8.8	0.2	0.1	0
	EL9	99.6	30.3	29.8	24.9	9.6	4.9	0.1	0.1	0
	EL10	99.6	34.6	26.3	21.1	2.7	4.5	0.2	6.5	3.8
West Laroch	WL1	99.7	37.1	34.5	19.9	1.5	3.8	0.1	0	2.7
	WL3	99.4	33.5	30.5	21.9	1.1	10.1	0.2	0	2.1
	WL5	99.5	32.9	33.9	25.4	2.5	2.5	0.1	0.1	2
Khartoum	K1	97.3	22.4	40.4	19.3	3.6	6.3	0.1	0	5.1
	K2	99.5	32.6	39	12.1	4.1	5.6	0.2	0	5.9
	K3	100.1	35	37	11.4	5.3	5	0.1	0	6.3
Used slate	BX-1	99.2	29.2	38.5	18.9	3.4	7	0.1	0.1	1.8
	Mean	**99.6**	**31**	**33.6**	**19.6**	**3.9**	**5.8**	**0.1**	**1**	**4.3**
	St. Dev.	**1.0**	**6.5**	**6.3**	**4.3**	**2.3**	**2.4**	**0**	**2.4**	**3**

Easdale Slate

Seil		Total	Quartz	White mica	Chlorite	Pyrite	Albite	Apatite	Dolomite	Clay
Balvicar	SB1	99.1	32.7	32.7	21.8	1.6	8.4	0.4	1.5	0.0
	SB2	93.1	33.9	28.0	20.0	0.8	8.9	0.3	1.2	0.0
	SB3	100.2	24.3	27.4	17.1	0.5	11.4	1.3	18.2	0.0
	SB4	96.7	17.8	28.9	18.9	0.7	16.4	0.5	13.3	0.0
Breine Phort	SB5	98.7	17.9	45.4	12.7	5.7	13.7	0.4	1.8	1.1
	SB7	98.9	38.2	33.2	10.2	3.7	12.1	0.4	0.0	1.1
	SB-6	97.3	24.3	44.0	9.9	2.8	15.8	0.3	0.3	0.0
	SB8	98.9	23.3	41.3	10.4	5.0	13.9	0.4	3.1	1.4
Easdale Island	EE2	98.8	21.1	35.6	9.6	6.9	10.8	0.3	7.6	6.9
	EE3	101.0	20.5	40.4	4.7	8.9	9.0	0.3	8.3	8.9
Used Slate	EX-1	102.1	30.8	39.2	5.7	8.2	12.6	0.2	3.1	2.3
	EE1	104.0	22.3	48.3	11.7	10.4	10.1	0.5	0.7	0.0
	Mean	**100.0**	**24.8**	**40.9**	**9.3**	**6.5**	**12.3**	**0.3**	**3.1**	**2.7**
	ST Dev	**2.2**	**6.6**	**5.0**	**2.8**	**2.6**	**2.2**	**0.1**	**3.2**	**3.3**

SB-1-SB-4, Pyrite based on sulphur XRF, chlorite based on residual Fe.

Seil		Total	Quartz	White mica	Chlorite	Pyrite	Albite	Apatite	Dolomite	Clay
Balvicar	SB1	98.2	33.3	32.7	19.3	2.6	8.4	0.4	1.5	0.0
	SB2	92.8	34.0	28.0	19.5	0.8	8.9	0.3	1.2	0.0
	SB3	90.4	28.0	27.4	3.6	0.5	11.4	1.3	18.2	0.0
	SB4	89.4	20.6	28.9	9.0	0.7	16.4	0.5	13.3	0.0

Value of chlorite based on the amount of residue Al

Luing		Total	Quartz	White mica	Chlorite	Pyrite	Albite	Apatite	Dolomite	Clay
Toberonochy	LT1	87.8	27.9	30.7	12.1	3.8	11.4	0.2	1.6	0.0
	LT2	99.9	21.0	37.2	7.1	7.8	9.7	0.4	7.0	9.6
	LT3	88.7	27.4	36.4	10.7	5.2	7.0	0.2	1.7	0.0
Port Mary	LP1	95.5	26.1	33.7	20.6	2.5	10.9	0.4	1.4	0.0
& Rubha na	LP3	96.6	25.6	31.6	19.0	7.1	11.6	0.3	1.3	0.0
hEasgainne	LP5	99.3	19.1	41.3	15.6	5.4	13.5	0.3	0.6	3.5
	LP6	98.8	31.1	37.0	8.6	5.8	12.0	0.4	0.0	3.8
Cullipool	LC1	99.4	24.4	41.5	6.6	5.9	12.7	0.4	4.6	3.3
	LC2	98.3	30.1	38.0	11.0	5.5	9.6	0.4	0.5	3.2
	LC-3	98.5	27.7	39.0	10.9	5.7	11.4	0.4	0.9	2.5
Tir na Oig	LT5	100.4	22.8	37.5	8.6	6.5	17.0	0.3	5.2	2.6
Black Mill Bay	LB1	95.4	27.8	32.1	13.0	2.4	12.4	0.6	7.1	0.0
	LB2	97.8	25.4	29.7	3.0	5.8	4.6	0.5	28.8	0.0
	LB3	97.6	20.1	37.0	13.2	7.1	15.3	0.4	2.8	1.7
	Mean	**96.7**	**25.5**	**35.9**	**11.4**	**5.5**	**11.4**	**0.4**	**4.5**	**2.1**
	St Dev	**3.9**	**3.6**	**3.7**	**4.8**	**1.6**	**3.1**	**0.1**	**7.4**	**2.6**
Belmahua		**Total**	**Quartz**	**White mica**	**Chlorite**	**Pyrite**	**Albite**	**Apatite**	**Dolomite**	**Clay**
	BB1	99.0	38.0	21.7	16.5	5.2	10.7	0.3	4.1	2.5
	BB2	98.5	25.8	30.3	13.2	6.9	10.9	0.4	4.7	6.2

Highland Border Slate

		Total	Quartz	White mica	Chlorite	Haematite	Albite	Apatite	Calcite	Clay
Arran	A3	98.5	30.8	34.5	8.5	5.4	14.3	0.2	4.9	2.1
	A5	98.0	30.9	53.6	4.6	3.8	5.8	0.2	-0.9	2.4
	A6	98.7	30.2	47.8	4.6	5.8	10.2	0.2	0.0	1.8
Bute	B1b	99.1	5.4	47.3	7.4	6.5	15.7	0.6	16.1	1.6
	B1	99.6	16.0	39.0	5.0	7.6	12.5	0.4	19.1	1.2
	B3	96.8	13.3	38.5	16.5	5.0	7.3	0.4	15.8	3.7
	B5	90.5	25.7	46.2	5.5	7.6	5.3	0.3	0.0	10.3
	B2-	98.6	33.7	32.3	8.3	2.2	10.9	0.3	10.8	1.6
Luss										
Auchengavin	LS1	99.3	22.7	51.1	8.5	5.8	6.7	0.2	0.0	4.3
	LS2	102.7	32.1	50.4	10.3	3.6	2.8	0.3	0.0	3.1
Aberfoyie										
	AB-5	97.9	15.4	43.6	12.3	7.0	16.9	0.6	0.5	1.5
	AB3	98.6	19.5	28.8	16.8	4.5	16.9	0.4	0.1	11.6
	AB4	97.8	15.7	43.8	12.4	7.1	16.4	0.6	0.5	1.3
	AB-6	98.6	25.2	32.3	14.2	2.5	15.8	0.3	0.8	7.5
	Mean	**98.2**	**19.0**	**37.1**	**13.9**	**5.3**	**16.5**	**0.5**	**0.5**	**5.5**
	Std Dev	**0.4**	**4.6**	**7.7**	**2.1**	**2.2**	**0.5**	**0.1**	**0.3**	**5.0**
Comrie										
Aberuchil	AU1	98.2	22.4	31.8	15.3	5.3	21.0	0.6	0.6	1.2
	AU2	99.2	22.8	43.7	12.7	6.8	12.6	0.6	0.0	0.0
	AU-3	98.8	23.8	37.8	12.9	4.0	18.9	0.5	0.9	0.1
Drummond	DR1	95.3	23.8	36.5	13.4	2.6	9.1	0.3	0.4	9.3
Logiealmond										
Craiglea	CR1	99.1	22.0	31.3	17.6	5.6	13.9	0.6	0.4	7.8
	CR2	98.8	25.7	39.0	12.6	6.4	12.8	0.4	0.5	1.3
	Cr3	98.6	18.9	39.7	15.9	5.5	13.6	0.5	0.7	3.8

Dunkeld		Total	Quartz	White mica	Chlorite	Haematite	Albite	Apatite	Calcite	Clay
Birnam	DB1	98.6	28.6	48.0	11.8	5.3	4.1	0.4	0.3	0.0
	DB2	100.6	27.1	46.0	10.4	5.9	10.6	0.4	0.1	0.0
	DB3	99.3	22.5	54.7	6.8	7.9	6.9	0.4	0.0	0.0
Newtyle	DN1	99.4	24.8	40.2	17.4	2.7	13.9	0.3	0.1	0.0
	DN2	98.8	24.5	43.5	13.1	5.3	11.6	0.6	0.3	0.0
	DN3	101.0	18.3	58.7	13.4	3.9	6.0	0.6	0.1	0.0
	DN4	98.4	22.8	44.3	13.5	3.7	12.6	0.5	1.0	0.0
Used slate	DX-1	97.6	23.0	37.3	13.1	3.0	14.9	0.4	2.5	3.3
	Mean	**99.2**	**24.0**	**46.6**	**12.4**	**4.7**	**10.1**	**0.4**	**0.6**	**0.4**
	ST Dev	**1.1**	**3.1**	**7.1**	**3.0**	**1.7**	**3.9**	**0.1**	**0.8**	**1.2**

Macduff Slate

		Total	Quartz	White mica	Chlorite	Haematite	Albite	Apatite	Calcite	Clay
Kirkney Hill	MK2	98.6	24.9	46.4	17.6	4.8	4.6	0.3	0.0	0.0
	MK4	98.4	22.5	41.5	14.6	7.6	5.4	0.3	0.0	6.5
Corksie Hill	MH1	99.6	18.6	47.3	9.7	6.1	10.4	0.3	0.0	7.3
	MH-2	100.2	18.4	49.8	7.9	7.0	9.5	0.3	0.0	7.1
	MC-1	97.2	19.2	47.2	16.6	5.7	4.5	0.5	0.0	3.5
Wishach Hill	MW-1	100.2	26.3	50.9	15.4	5.3	2.6	0.3	0.0	-0.4
	MX-2	99.5	26.8	40.9	17.8	4.3	3.5	0.3	0.0	5.8
	MX-3	99.2	28.4	40.7	16.5	3.6	2.1	0.2	0.0	7.8
Hill of Foudland	MF-1	99.2	21.1	46.4	12.9	5.1	5.5	0.3	0.0	7.8
	MF-11	98.8	25.0	40.9	15.0	5.1	4.7	0.3	0.0	7.7
Tillymorgan Hill	MT-2	101.9	18.7	40.6	13.2	5.4	6.6	0.4	0.0	17.0
	MT-6	100.5	25.1	41.5	13.4	5.9	6.6	0.3	0.0	7.7
	Mean		**22.9**	**44.5**	**14.2**	**5.5**	**5.5**	**0.3**	**0.0**	**6.5**
	Std Dev		**3.6**	**3.9**	**3.0**	**1.1**	**2.5**	**0.1**	**0.0**	**4.4**

APPENDIX 2
PLATES OF USED ROOFING SLATES FROM SELECTED QUARRIES

Plate 55 Ballachulish slate from a used-slate dealer estimated at over 100 years old

Plate 56 Toberonocy slate from a local building

Plate 57 Belnahua slate collected from a building on the island

Plate 58 Easdale slate from a used-slate dealer

Plate 59 Easdale slate from a used-slate dealer estimated at over 100 years old

Plate 60 Luss slate from a local farm building

Plate 61 Luss slate collected by CCUS Dundee University

Plate 62 Aberuchill slate from a local building

Plate 63 Craiglea slate from a local farm building

Plate 64 Birnam slate collected from the quarry

Plate 65 Dunkeld slate from a used slate dealer estimated at over 100 years old

Plate 66 Cnocfergan flagstone from a house in Tomintoul

Plate 67 Cnocfergan flagstone from a house in Tomintoul

Plate 68 Foudland slate from Greystone Farm near the Tillymorgan quarries

Plate 69 Easdale slate from a building close to a quarry on the Island of Kerrara

Plate 70 Flagstone collected from the Kings Old Building in Stirling Castle

Plate 71 Coarse-grained siliceous slate from Castle Tiorom

BIBLIOGRAPHY

Anderson J G C. 1946 The geology of the Highland Border, Stonehaven to Arran, *Transactions of the Royal Society of Edinburgh* **61** 479-515.

Anderton R. 1985 Sedimentation and tectonics in the Scottish Dalradian, *Scottish Journal of Geology* **21** 407-436.

Anderton R. 1988 Dalradian slides and basin development: a radical interpretation of stratigraphy and structure in the SW and Central Highlands of Scotland, *Quarterly Journal of the Geological Society of London* **145** 669-678.

Bailey E B & Maufe H B. 1916 The Geology of Ben Nevis and Glencoe and the Surrounding Country, *Memoirs of the Geological Survey of Great Britain Publishers.* HMSO, Edinburgh.

Bailey E B. 1934 West Highland Tectonics: Loch Leven to Glen Roy, *Quarterly Journal of the Geological Society of London* **94** 462-523.

Bailey E B & Maufe H B. 1960 The Geology of Ben Nevis and Glencoe and the Surrounding Country (2nd edition of the above).

Barrow G. 1893 On an intrusion of muscovite-biotite gneiss in south-east Highlands of Scotland and its accompanying metamorphism. *Quarterly Journal of the Geological Society of London* **49** 330-358.

Baxter C. 1792 The Parish of Comrie, *Old Statistical Account* **12** 268-278, *Editor* Sir John Sinclair.

Blaikie J. 1834 Essay III on the slate quarries of Aberdeenshire, *Prize Essays and Transactions of the Highland Agricultural Society* **10** 98-106.

Bowes D R & Wright A E. 1973 Early phases of Caledonian deformation in the Dalradian of the Ballachulish district, Argyll. *Geological Journal* **8** 333-344.

Bremmer D. 1869 *The industries of Scotland: their rise, progress and present condition. Publishers* Black, Edinburgh.

Campbell A. 1959 The Parish of Luss, *Third Statistical Account.* **6** 145-154 *Editors* Dilke M S & Templeton A A. *Publishers* Collins, Edinburgh.

Carmichael I. 1951 The Parish of Lismore and Appin, *Third Statistical Account,* **9** 160-168 *Editor.* Macdonald C M.

Carmichael J 1837 An account of the principal marble, slate, sandstone and greenstone quarries in Scotland. *Prize Essays and Transaction of the Highland and Argricultural Society* **5** 398-416.

Carr R. 1839 The Parish of Luss, *New Statistical Account* **8** 155-168 *Publishers* Blackwood, Edinburgh.

Craig R. 1845 The Parish of Rothesay, *New Statistical Account* **5** (Bute) 95-120. *Publishers* Blackwood, Edinburgh.

Crockett R N. 1975 Slate, *Mineral Dossier 12. Publishers.* Mineral Resources Consulting Committee, London.

Cunningham J H. 1843 Geognostical Account of Banffshire, *Transactions of the Highland Agriculture Society* **14** 447-502.

Easdale Slate Co. 1909 *Easdale the roof of the World*

Fairweather B. 1994 *The 300-year story of Ballachulish slate, Publishers.* Glencoe and North Lorn Folk Museum, Glencoe, Fort William.

Fettes D J. 1970 The structural and metamorphism state of the Dalradian rocks and their bearing in the age of emplacement of the basic sheet, *Scottish Journal of Geology* **6** 108-118.

Fettes D J. 1971 Relation of cleavage and metamorphism in the Macduff Slates, *Scottish Journal of Geology* **7** 248-253.

Geikie A. 1901 *The Scenery of Scotland viewed in connection with its Physical Geology* (3rd Edition).

Gibbons W & Harris A L. 1994 *A revised correlation of Precambrian rocks in the British Isles London* Special Report No 22. *Publishers* Geological Society, London.

Graham P. 1793 The Parish of Aberfoyle, *Old Statistical Account* **12** 1-18. *Editor* Sir John Sinclair.

Graham R C. 1843 The Parish of Aberfoyle, *New Statistical Account* **10** 1150-1160 *Publishers* Blackwood Edinburgh.

Gunn W. 1903 The Geology of North Arran, South Bute and the Cumbraes, *Memoirs of the Geological Survey, Sheet 21 Publishers.* HMSO, Glasgow.

Hall A J. 1982 Gypsum as a precursor to pyrrhotite in metamorphic rocks. Evidence from the Ballachulish Slate in Scotland. *Mineralium Deposita* **17** 401-409.

Hall A J. 1986 Pyrite-pyrrhotine redox reaction in nature. *Mineralogical Magazine* **50** 223-229.

Hall A J, Boyce A J & Fallick A E. 1988 A sulphur isotope study of iron sulphides in the Late Precambrian Dalradian, Easdale Slate Formation, Argyll, Scotland. *Mineralogical Magazine* **52** 483-490.

Hall A M & Connell E R. 1991 The glacial deposits of Buchan, north-east Scotland. *Glacial deposits in Great Britain and Ireland Editors* Ehlers J, Gibbard P L and Rose J.

Harris A L. 1972 The Dalradian Rocks at Dunkeld, Perthshire, *Bulletin of the Geological Survey of Great Britain* **38** 1-10.

Harris A L & Fettes D J. 1972 Stratigraphy and structure of Upper Dalradian rocks and the Highland Border. *Scottish Journal of Geology* **8** 253-264.

Harris A L & Pitcher W S. 1975 The Dalradian Supergroup *A correlation of Precambrian rocks in the British Isles, Editor* Harris A L *Publishers* Geological Society London Special Report No 6.

Harris A L, Haselock P J, Kennedy M J & Mendum J R. 1994 The Dalradian Supergroup in Scotland, Shetland and Ireland. *A revised correlation of Precambrian rocks in the British Isle,s Editiors* Gibbons W & Harris A L *Publishers* Geological Society London Special Report No 22.

Hewison J K. 1845 The Isle of Bute in the olden Times Vol. II *Publishers* William Blackwood, Edinburgh.

Hickman A H. 1975 The stratigraphy of the Late Precambrian metasediments between Glen Roy and Lismore, *Scottish Journal of Geology*, **11** 117-142.

Hunt R. 1853-81 Mineral Statistics (annual volumes).

Innerarity W. 1791 The Parish of Caputh, *Old Statistical Account* **12** 485-509.*Editor* Sir John Sinclair.

Johnson M R W. & Stewart F H. 1960 Dalradian Structures in north-east Scotland. *Transactions of the Edinburgh Geological Society* **19** 29-64.

List of Quarries under the Quarries Act 1894, **1906, 1908 & 1912**

MacIntyre W J. 1951 The Parish of Kilbrandon and Kilchattan, *Third Statistical Account* **9** 202-207. *Editors* MacDonald C M, *Publishers* Collins, Glasgow.

MacKenzie W. 1838 The Parish of Comrie, *New Statistical Account* **10** 578-593 *Publishers* Blackwood, Edinburgh.

Marshall D N. 1955 *History of Bute, Publishers.* Bute Print, Rothesay

Mather J D. 1970 The Biolite Isograd and the Lower Greenschist Focies in the Dalradian Rocks of Scotland. *Journal of Petrology* **11** 253-75

Maxtone A. 1837 The Parish of Foulis Wester. *New Statistical Accounts* **10** 249-261 *Publishers* Blackwood, Edinburgh.

McGregor G. c1845 The United Parish of Lismore and Appin. *New Statistical Accounts* **7** 247-251 *Publishers* Blackwood, Edinburgh.

McNaughton A. 1845 The Parish of Kilbride, *New Statistical Account* **5** (Bute) 1-39 261 *Publishers* Blackwood, Edinburgh.

McNicol D. 1790 The Parish of Lismore and Appin, *Old Statistical Account* **20** 345-364 *Editor* Sir John Sinclair.

McPherson F. 1843 The Parishes of Kilbrandon and Kilchattan *New Statistical Accounts* **7** 71-81. *Publishers* Blackwood, Edinburgh

Neumann H. 1950 Pseudomorphs after pyrite in the Ballachulish Slates, *Mineralogy Magazine* **29** 234-238.

Peach B N, Kynaston H & Muff H B. 1909 The Geology of the seaboard of Mid Argyll, *Memoirs of the Geological Survey of Scotland, Publishers.* HMSO, Glasgow.

Porteous J. 1954 The Parish of Logiealmond, *Third Statistical Account* **27** 540-542 Editor Taylor D B.

Read H H. 1923 The Geology of the country round Banff, Huntly and Turriff. *Memoirs of the Geological Society, Sheets 86 and 96 Publishers* HMSO Edinburgh.

Richards, Moorehead and Laing Ltd. 1995 *Slate Waste Tips and Workings in Britain, Publishers* HMSO for the Department of the Environment.

Richards A J. 1995 *Slate Quarrying in Wales Publishers* Gwasg Carreg Gwalch, Wales.

Richey J E & Anderson J G C. 1944 *Scottish Slates Wartime Pamphlet No 40. Publishers* Geological Survey of Great Britain.

Roberts J L & Treagus J E. 1977 The Dalradian rocks of the Loch Leven area, *Scottish Journal of Geology* **13**, 165-184.

Robertson J. 1791 The Parish of Little Dunkeld, *Old Statistical Account* **12** 397-424 *Editor* Sir John Sinclair.

Shackleton R M. 1958 Downward-facing structures of the Highland Border, *Quarterly Journal of the Geological Society of London* **113** 361-392.

Smith G. 1835 Account of the principal slate quarries in Scotland. *Transactions of the Highland and Agricultural Society* **4 Series 2** 94-97.

Smout T C. 1986 *A Century of the Scottish People 1830-1950 Publisher.* Collins, London.

Stephenson D & Gould D. 1995 British Regional Geology: The Grampian Highlands (4th edition), *Publishers* HMSO for the British Geological Survey, London.

Stewart F. 1792 The Parish of Jura and Colonsay *Old Statistical Account* **20** 368-385 *Editor* Sir John Sinclair.

Stirling 1794 The Parish of Foulis Wester, *Old Statistical Account* **12** 437-452 *Editor* Sir John Sinclair.

Strachan W. 1953 The Parish of Aberfoyle *Third Statistical Account* **27** 579-587 *Editor* Taylor D B.

Stuart J. 1793 The Parish of Luss., *Old Statistical Account* **9** 83-116 *Editor* Sir John Sinclair.

Sutton J & Watson J V. 1956 The Boyndie Bay Syncline of the Dalradian rocks of the Banffshire coast, *Quarterly Journal of the Geological Society of London* **112** 103-128.

Treagus J E & Roberts J L. 1981 The Boyndie Syncline: a D1 structure in the Dalradian of Scotland, *Geological Journal* **16** 125-135.

Trewin N H, Kneller B C & Gillen C. 1987 *(editors) Excursion Guide to the Geology of the Aberdeen area. Publishers.* Scottish Academic Press Ltd, Edinburgh.

Tucker D G. 1976 The Slate Quarries of Easdale, Argyllshire, Scotland, *Post-Medieval Archaeology* **10.**

Tucker D G. 1977 The Slate Islands of Scotland; The History of the Scottish Slate Industry, *Business History* **19** 8-35.

Wright A E. 1988 *The Appin Group in Later Proterozoic Stratigraphy of the Northern Atlantic Regions, Editor* Winchester J A. Blackie, Glasgow.

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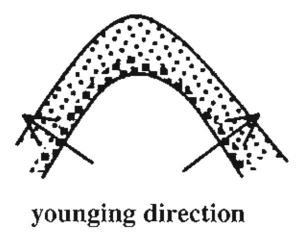
GLOSSARY

Only a selection of geological terms are given in this glossary. For further information the following reference is recommended. *Glossary of Geology Editors* Gary M, McAfee J &Wolf C L. Publishers American Geological Institute Washington D C.

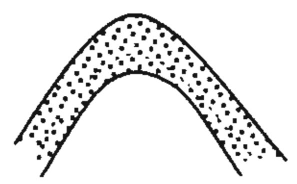
Alluvium A general term for clay, silt, sand and gravel deposited in recent geological time by a stream or other body of running water.

Amphibole Family of rock forming minerals, mainly silicates of calcium, magnesium and iron. A common constituent of some igneous and metamorphic rocks.

Anticline A fold defined in terms of the age of the strata with older rocks in the core.



Antiform A fold defined in terms of its orientation with limbs that close upwards forming an arch.



Aureole A zone around an igneous intrusion in which the country rock shows the effects of contact metamorphism.

Axis See fold

Bedding Natural layers formed during deposition of sediments

Caledonian orogeny A name commonly used for the early Palaeozoic deformation in Europe which created an orogenic belt the Caledonides extending from Ireland and Scotland northeastward through Scandinavia.

Chlorite A group of platy minerals, usually green, found in low grade metamorphic rocks

Cleavage The tendency of a rock to split along secondary aligned fractures produced by deformation or metamorphism

Cleavage domain See slaty cleavage

Competent Said of a rock which is able to withstand the pressures of folding without change in original thickness

Conglomerate Sedimentary rocks consisting of water worn pebbles bound together in a sandy matrix

Cross bedding A sequence of inclined sedimentary beds deposited by flowing wind or water

Dip The inclination of a planar surface relative to the horizontal

Dolerite Medium-grained basic igneous rock

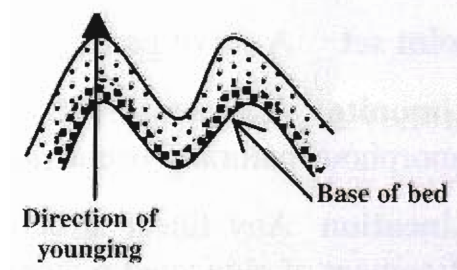
Dyke Tabular igneous intrusion which cuts across the planar structures of the country rock.

Epidiorite Metamorphosed basic igneous rock. A field term that is not generally used now having been replaced by terms such as metadolerite.

Facies, metamorphic A distinctive metamorphic mineralogy and the particular set of pressure and temperature conditions leading to it.

Facies, sedimentary A particular type of sedimentary rock and the set of conditions leading to it.

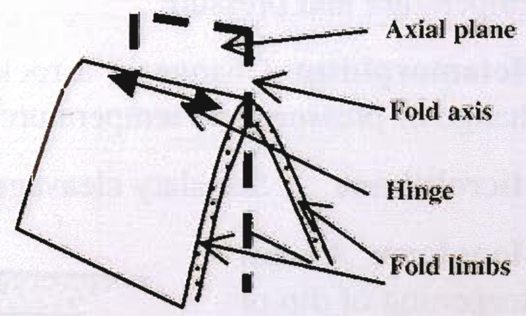
Facing direction Direction perpendicular to the fold hinge in which the beds of a fold become younger.



Fault Fracture in the rock along which there has been an observable amount of displacement

Fold axis Line bisecting a fold

Fold axial surface or plane Surface bisecting a fold and containing the fold axis and the hinge.



Fold hinge The line of maximum curvature of a fold

Graded bedding Vertical progression of grain sizes within a sediment layer from coarse to fine or *vice versa*

Greenschist A low grade metamorphic facies named for the common presence of green minerals such as chlorite

Greywacke Fine to coarse-grained sandstone with angular fragments of quartz, feldspar and rock fragments in a clayey matrix.

Hinge See fold

Hornblende A silicate mineral usually acicular or fibrous in form

Hornfels A fine-grained rock composed of a mosaic of equidimensional grains without preferred orientation and typically formed by contact metamorphism. Porphyroblasts are often present.

Illite A white mica

Inclined fold A fold with inclined axial surface, One limb of the fold dips more steeply than the other, also called an asymmetric fold

Isoclinal fold Both limbs of the fold are essentially parallel to each other regardless of the dip of the axial plane

Joint A fracture in the rock without any displacement

Joint set A set of parallel joints

Limonite A general field term for a group of brown amorphous naturally occurring hydrous ferric oxides

Lineation Any linear structure such as the parallel alignment of elongated minerals

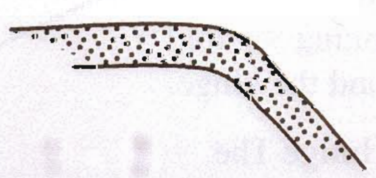
Marble Metamorphosed limestone

Metamorphic grade Measure of the intensity of metamorphism usually expressed in terms of temperature and pressure

Metamorphism Change in a rock brought about by change of pressure and temperature

Microlithons See slaty cleavage.

Monoform A local steepening of dip of layered rocks in areas where the bedding is relatively flat.



Open fold A fold with limbs at a wide angle, between 70° and 120°

Orogeny The process of development of mountains and of the rocks within the mountains

Overturned fold A fold with inclined axial surface and one limb tilted beyond the vertical. Both limbs dip in the same direction but not at the same angle

Phengite A white mica

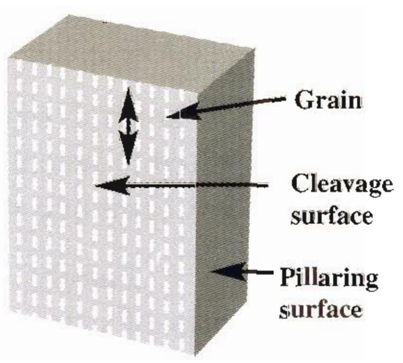
Phyllite A low grade metamorphic rock intermediate in grade between a slate and a mica schist

Phyllosilicate A silicate mineral such as white mica in which silica tetrahedra are linked together in sheets. Individual sheets are bound together by inter-layered cations

Pelite A mudstone or its metamorphic equivalent

Pillaring line The intersection of the pillaring surface with the cleavage surface

Pillaring surface The surface perpendicular to the cleavage surface and parallel to the grain of a slate



Pluton An igneous intrusion which has crystallised at depth

Porphyroblast A large crystal in a metamorphic rock with a fine-grained matrix

Prograde metamorphism Change in a rock due to an increase in pressure and temperature

Psammite A sandstone or arenite, or the metamorphic derivative of an arenite

Pyrites Any of various metallic looking sulphides of which iron sulphide (pyrite) is the commonest.

Pyrrhotite A reddish-brown iron sulphide, softer and more easily weathered than pyrite.

Quartzite Metamorphosed quartz-rich sandstone

Recumbent fold A fold with an axial surface which is essentially horizontal.

Reserve The quantity of a mineral that has been located and can be exploited economically

Resource Reserve plus that quantity of a mineral known or believed to exist but not exploitable

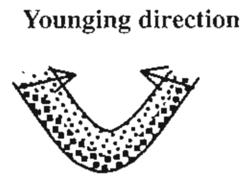
Retrogressive metamorphism Change in a rock due to a decrease in pressure and temperature

Sill Tabular igneous intrusion parallel to bedding

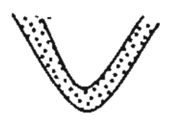
Slaty cleavage The ability to split a rock along closely spaced planar surfaces called cleavage domains which are made up of platy minerals. The areas between the cleavage domains are called microlithons

Strike Direction in which a planar surface such as a joint is horizontal

Syncline A fold defined in terms of the age of the strata with younger rocks in the core.



Synform A fold defined in terms of its orientation with limbs that close downwards forming a trough.



Tabular A body which has two dimensions much greater than a third

Terrane A general term used to describe a group of rocks which have a common geological history together with the area in which they outcrop.

Till Glacial deposit made up of stones and clay

Turbidite The deposits laid down by a turbidity current characterised by graded bedding.

Turbidity current A current caused by increased density due to a load of suspended material

Whinstone A quarry term for a hard compact rock usually basalt

White mica A general term for a group of phyllosilicates characterised by perfect cleavage. The group includes muscovite, phengite and illite, each representing variation in the chemical composition.

Younging The direction in which the order or succession of rocks gets younger