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Tittel

The genesis, exploration, extraction and processing of skifer deposits in the caledonides of south-west Norway

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Fagområde	Dokument type	Forekomster
Geologi	Rapport	Vetlehagen Mon Norheim Kyte Skjotebane Istad
Råstofftype	**Emneord**	
Bygningstein	Skifer	

Sammendrag

Rapporten er en kopi av vedlegg til søknad om prospekteringsstøtte 1996.
Den viser områder med potensiale for skiferdrift, og viser geologiske faktorer som er knyttet til sonene med brytbar skifer.

THE GENESIS, EXPLORATION, EXTRACTION AND PROCESSING OF SKIFER DEPOSITS IN THE CALEDONIDES OF SOUTH-WEST NORWAY

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In association with

Voss Cementvarefabrikk L/L

Leonardo Programme

Voss og Omland Tiltakskontor

Norges Geologiske Undersolkelse

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THE GENESIS, EXPLORATION, EXTRACTION, AND PROCESSING OF SKIFER DEPOSITS IN THE CALEDONIDES OF SOUTH-WEST NORWAY.

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(Submitted for assessment 02.02.96)

Abstract - The aim of this report is to establish areas showing potential for skifer quarrying, identify geological factors that may be assigned to horizons of workable skifer, and to investigate the mining/quarrying and processing of slate/skifer in Great Britain in an attempt to suggest modernization of the currently employed methods at Voss Cementvarefabrikk. In addition to the surveys made in new areas, current operations such as Mon, Vetlehagen, and Norheim-Kyte were surveyed in order to assess their economic potential.

The new reserves identified by the author Bjorkhagen, Skjotebane, Istad, and those at or near the Mon-Vetlehagen operations have will be identified as where development could arise from these preliminary surveys.

Voss Skiferbrudde A/S and the conglomerate skifer workers seem to be in somewhat of a dilema, as far as the future of skifer production in Voss is concerned, namely in the method of extraction and processing. Techniques have not changed for over a century as was the case in the British operations at Penryhn and Delabole but subsequent rationalisation involving initial expenditure of significant capitol resulted in competative large scale slate/skifer operations. The author feels that a smaller, yet similar rationalisation of operations could ensure an industrious future for the Voss skifer quarries. The Voss Skiferbrudde A/S factory at Norheim-Kyte could be used as a model for all future processing of skifer with similar factorys being constructed at Mon and Istad or at a central point recieving sawn blocks from several quarries, abondoning the traditional single man operations seen today, ready to be split in a fashion not dissimilar to that at the British Delabole operation, thus reducing the percentage recovery of skifer tiles from blocks, therefore increasing production per tonne extracted.

The importance of modenisation/rationalisation is furthermore in evidance in the subject of available skilled workers, particularly in the future, where it is unlikely that the quarries will see a young workforce replacing the current workforce. Automation as has been suggested would reduce the number of men needed in the extraction and initial splitting of skifer blocks to manageable sizes (but not drasticly!). It is noted that some workers produce skifer only as a part-time source of income.

The subject of mining or quarrying the skifer deposits as discussed later results in the conclusion that it will be more economical to quarry skiffer than mine it. This has important implications for operations such as Mon with a relatively high stripping ratio which the author believes has a limited down-slope working life, as opposed to potential operation such as Istad, Bjorkehagen etc - areas of low stripping ratios and near horizontal strata. It must be appreciated that the fieldwork carried out in the summer of 1995 by the author centred significantly on the Mon-Vetlehagen quarries in order to establish the potential reserves between them, to (although purely academic) to discover the formational processes involved and to establish a framework for future studies by identifying the structural controls of workeable rocks - see previous chapters. Thus there is much potential for intensive additional studies at the suggested reserve areas, including the possibility of introducing diamond drilling on a large grid to establish the workability of skifer. Diamond drilling if done, must involve the production of large diameter samples for geological analysis and basic geotechnical engineering (0.15 m diameter samples). Again, the author hopes that Voss Cementvarefabrikk finds this report useful, or at the worst more useful than previous reports, and also the hope that the University of Wales, Cardiff can maintain a healthy relationship with the company for future student research.

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The slate industry has recieved a boost in recent years due to an increased interest in natural stone for achitectural purposes, leading to a niche market developing in higher priced prestige properties. There has also been some rationalisation in the face of competition from cheaper imports, together with increased mechanisation and improved productivity in most countries. The Norweigan slate/skifer market with its quartzite and phyllite schists is on the up, with the result of the re-opening of old quarries. It is this rationalisation that has led to the author to become involved in the Norweigan slate industry, namely Voss Cementvarefabrikk L/L a cooperative for independant quarry workers, through the Bergen based Comett Student exchange programme, for the summer of 1995.

The skifer quarries lie at Norheim-Kyte, Mon, and Vetlehagen just outside the town of Voss in south-west Norway. The areas are briefly described on the Geological Map of Voss (NGU report No. 1316-11). The skifer horizons belong to the Voss Nappe complex of Precambrian - Cambrian rocks, part of the Caledonian overthrust orogenic belt and lie within the Upper Bergsdalen Nappe.

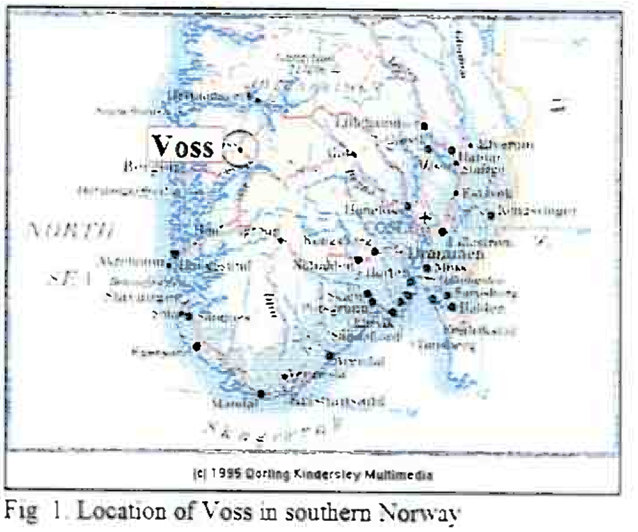


Fig. 1. Location of Voss in southern Norway

The intention of the placement is to produce detailed surveys of the quarries to determine a system in the occurence of economic and non-economic skifer. Quarrymen have found that some horizons contain veins of quartz, and other geological phenomena that make the stone unsuitable for industrial applications. A thorough survey should enable the quarrymen to know at all times which horizon they are working, and thus the quality of the schists that they are working. Apart from these curently active operations, the author intends to investigate new areas of potential skifer reserves, some being previously worked quarries - although on a very small scale.

Evaluation of these reserves will lead to the subject of rationalisation of the quarrying and processing methods currently employed, involving comparisons with British operations in an attempt to introduce new practices.

The Caledonides of southwest Norway were built upon the Precambrian Baltoscandinavian Shield (basement), of which only the western part (Western Gneiss Region) was significantly involved in Caledonian deformation. An Upper Proterozoic to lower Paleozoic sedimentary cover (phyllite and quart-schist) to this basement acted as the principle decolement during Caledonian collosion, above which the large Jotun and Ryfylke nappe complexes and other units of the Middle Allochthon were emplaced. The Bergsdalen Nappes are sheets of detached Precambrian basement (Proterozoic quartzite, quartzite schist, mica-schist, metadacite, metarhyolite, granite, monzonite, gabbro etc) that were tectonically incorporated with the mostly phyllitic Upper Proterozoic to lower Paleozoic Metasediments. The Bergsdalen Nappes form two major tectonic units, the Lower Bergsdalen Nappe (LBN) and the Upper Bergsdalen Nappe (UBN), which are separated by an almost continuous zone of phyllite. The lensoid allochthonous sedimentary and crystalline Precambrian rocks are also internal discontinuities of tectonic character which have been interpretated as thrusts, but these appear to be associated with relatively small displacements. The Bergsdalen Nappes are bounded to the southeast by the extensional Hardangerfjord Shear Zone, to the southwest by the partly ophiolite and island arc-related rocks of the Hardangerfjord Group and the Bergen Arc System, and to the north by the Western Gneiss Region. To the northeast the Nappes taper out in the phyllites beneath the Jotun Nappe. The Upper and Lower Bergsdalen Nappes are composed of very similar lithologies, and also seem to have a common Precambrian history, detailed petrographic descriptions of the various lithologies are in part covered in this report, but are also given in Kvale (1946),Gray (1978) and Ragnhildstveit (1987). It is noted from these that the most obvious lithological difference between the UBN and the LBN is that there are more quartz-mica schists and less quartzite in the UBN, and it is the quartz-mica schists of the Kvitnos Group of the middle thrust sheet of the UBN that the study area is located. The Ordovician-Silurian thrusting caused intense deformation and mylonitization, particularly within and near the decollement zone, and resulted in Southeast directed nappe diaplacements of several hundred kilometers. The strains and displacements involved in the thrusting are great, but in general, the thin-skinned deformation pattern in the study area is relatively simple. For our purpose the thrusting event will be refered

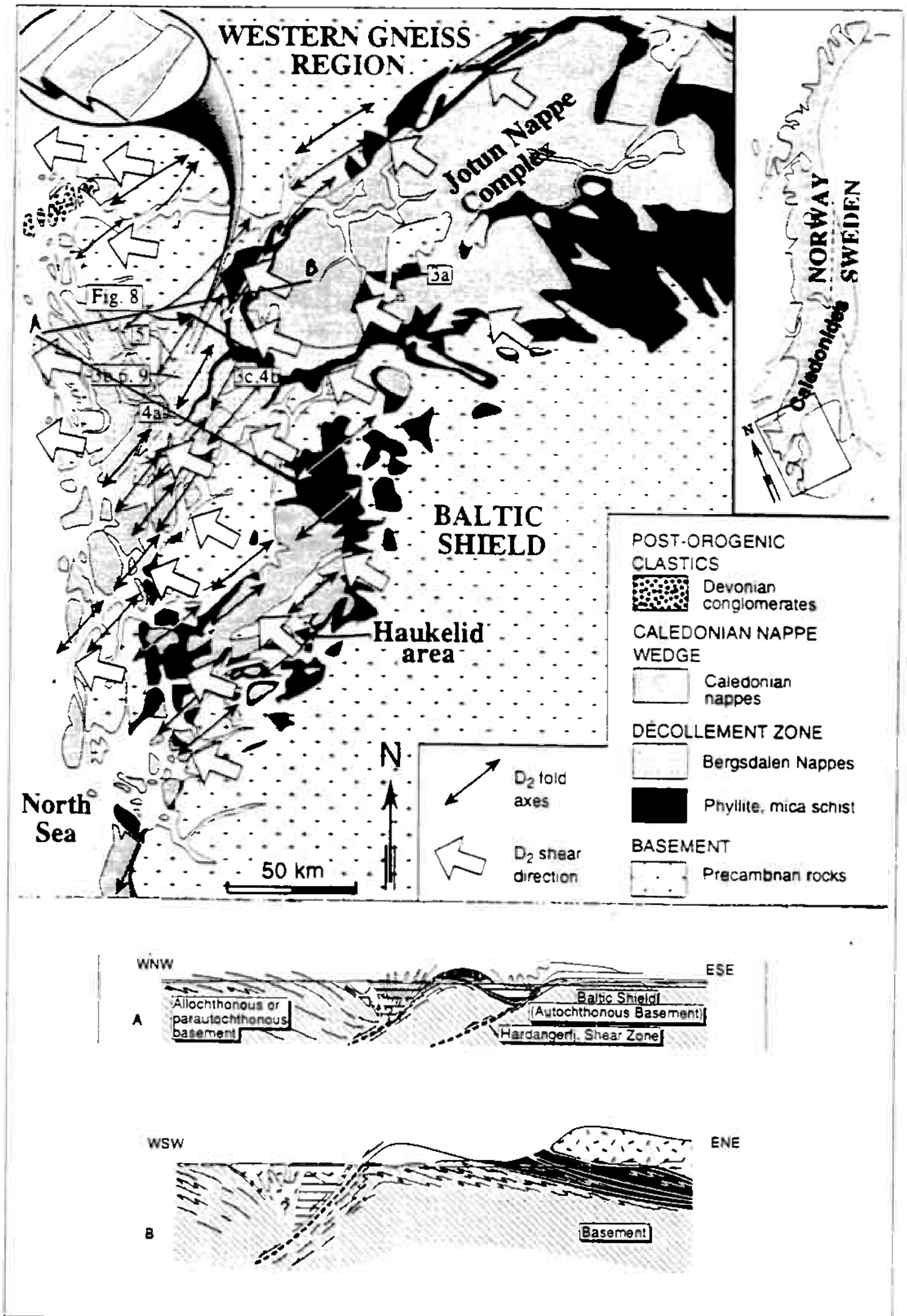


Fig 2. Geological setting of the Bergsdalen Nappes in southwestern Norway, showing the sense of shear for the D_1 and D_2 tectonic events. LBN = Lower Bergsdalen Nappe. LN = Lindas Nappe. MaBa = Major Bergen Arc. UGC = Ulriken Gneiss Complex. UBN = Upper Bergsdalen Nappe. WGR = Western Gneiss Region. Taken from Fossen, H., 1993. *Nor. Geol. Unders. Bull 424, 23-49*, with additions from author.

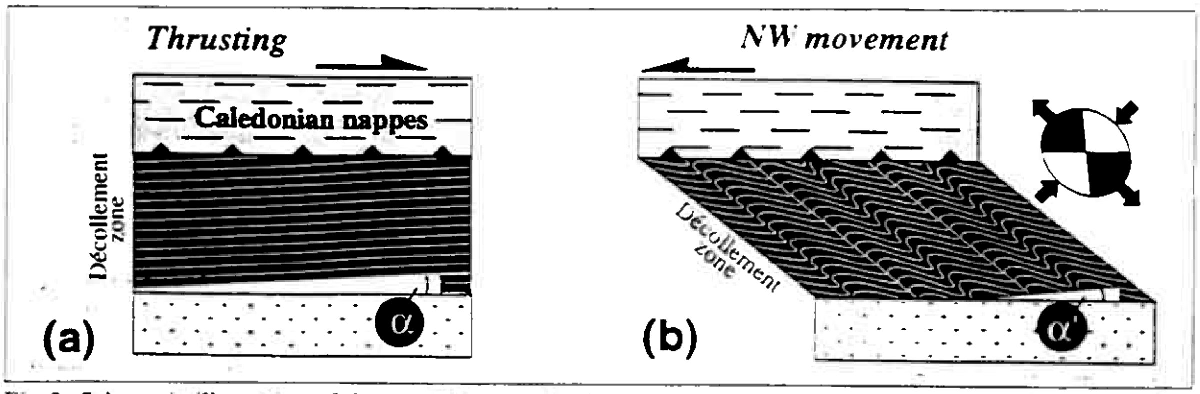


Fig 3. Schematic illustration of the tectonic events in the study area. The shear zone shows an internal layering initially inclined to the boundaries as shown in (a) is likely to result in the development of symmetric folds with a vergence corresponding to the sense of shear. (b) Schematic illustration of a vertical NW - SE section through the decollement zone during (a) thrusting (D_1) and (b) back movement (D_2). The planar fabric and lithological layering in the decollement zone. The orientation of the incremental strain ellipse is shown in (b).

to as D_1, although the deformation structures seen locally may suggest a polyphasal deformational history. Such a history can be attributed to a Devonian deformational phase (D_2), a top to the5 north-west back movement of the Caledonian nappes and stretching of the basementThe D_2 phase is recognized amongst the duplex system of our study area of the UBN, and elsewhere by clear cut W to NW verging structures that overprint southeast verging structures related to thrusting. Both events involved extensive synkinematic recrystallization under middle to uppermost greenschist facies conditions, and their heterogeneous nature has resulted in areas of low D_2 and high D_1 strains amongst the quarried skifer horizons, and of course vice versa.Both events produced lineations, hence the present lineation pattern is a combination of lineations formed during D_1 and D_2, with the D_1 fabric being the strongest. Thus D_1 lineations are best observed in areas of weak or no D_2 reworking, the economic zones within the study area, but they can be seen in any part of the mylonitic and phyllitic zones of the Bergsdalen Nappes and can be traced in many places into the overlying Jotun Nappe Complex.

Quartz-Schist Horizons - Kvitnos Group, Middle Thrust Sheet of the UBN.

Quart-mica Schist - Skifer horizons

Texture - Medium to coarse grained with a poorly developed schistosity usually developed, causing the rock to cleave into slabs.

Structure - usually foliated a result of the original isoclinal folding that is so important in the formation of the quartz-schists.

Mineralogy - Quartz is a major component together with feldspar. Micas, both muscovite and biotite usually occur and tend to concentrate into particular layers.

Field Relations - Grades with increasing quartz into quartzite, and by a decrease in quartz into schist and pyllite. Represents a metamorphosed grit and sandstone which originally contained a high proportion of feldspar and mica. Occurs with other metamorphosed rocks such as quartzite and schists-mylonites.

Mylonite - Mylonitized quartz-mica-schists

Colour - Usually grey to dark green

Texture - Fine to medium grained with a well developed schistocity

Structure - Small scale corrugations may occur, sometimes as alternate mica-rich and mica-poor layers that follow the axial planar cleavage.

Field Relations - Mylonites can represent a medium to moderate grade of metamorphism and tend to be associated here with phyllites and quartz-mica-schists as they grade continuously from the two.

Colour - Usually grey to dark grey

Texture - Fine to medium grained with a well developed schistocity.

Structure - Small scale corrugations may occur: sometimes see alternate mica rich and mica poor layers that follow the axial planar cleavage.

The Phyllites - Parauthonous rocks of assumed Cambrian and partly Precambrian rocks

Interpretated as an overthrust Precambrian Lower Tectonic Unit of the Upper Bergsdalen Nappe. Intercalated with the Bergsdalen Nappes are dark hard phyllites and mica schists which have experienced internse deformation and have lost all primary structures, they form envelopes around the thin lensoid quartz mica schists and quartzites of the UBN and are considered to be, at least partly, Lower Paleozoic in age, and to be part of the continuous belt of strongly sheared phyllitic rocks that underlie all Caledonian nappes in south-western Norway. These rocks vary from dark-grayish phyllites with multiple cleavage to dark mica schists, both with milky white quartz veins and lenses. In places more calcareous or quartzitic layers are found within the phyllites, and may reflect a primary lithological stratification. Phyllies/mica schists also act as a lubricating medium in internal imbrication decollement ramping up thrusts in the quartz-mica schists of the study area.

Texture - Fine to medium grained with a well developed schistocity by the parallel alignment of flaky minerals enabling the rock to be split into weak fissile layers.

Colour - Dark gray to black, quartz pods/lenses are milky white

Structure - Minor folds and corrugations are often present

Mineralogy - Chlorite and/or muscovite are essential constituents, and give to their phyllites their dark gray-greenish colour

Field Relations - Phyllites are produced from pellitic rocks under conditions of low-grade metamorphism, usually grading into mica schists-mylonites.

Voss Cementvarefabrikk L/L was established in 1956 and is now an operation with a workforce of 30. The company consists of three operations, Gudvangen Stein AS - an anorthosite mining operation, Voss Skifferbrud AS - a schist quarrying operation, and a glacial gravel and sand quarry. There are 12 independent quarry workers based at three operations in the Voss area, Mon, Velehagen and Norheim-Kyte, these have contracts with Voss Cementvarefabrikk to supply the finished product as required. Voss Skifferbrud is based at the Norheim-Kyte quarry, and has two workers - working only with the skiffer, with plans to increase this to four, and twenty in the cooperative. This expansion depends upon the potential of finding new reserves, new end uses, and ultimately new domestic and foreign markets. Present foreign markets include long-term contracts to Switzerland for irregular roofing and precut tiles to Japan.

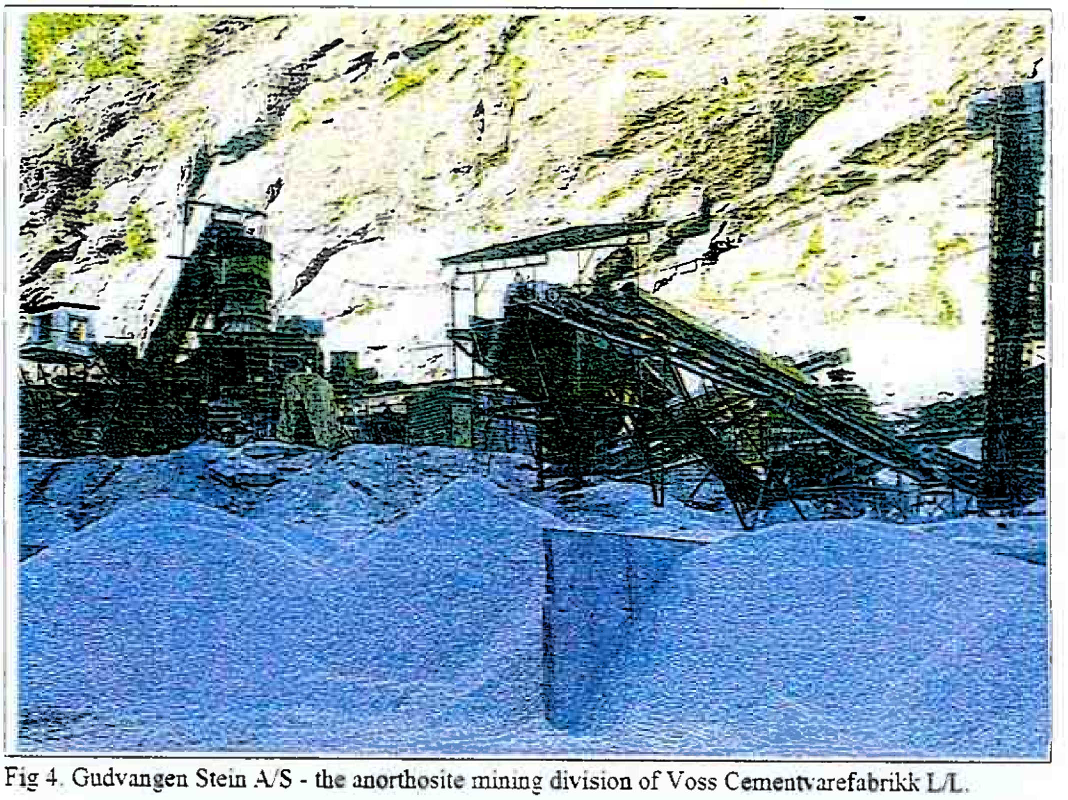


Fig 4. Gudvangen Stein A/S - the anorthosite mining division of Voss Cementvarefabrikk L/L.

Finished products include roofing tiles, irregular material for paving and sawn material for interior surfaces i.e. fireplaces and domestic worktops. Production has traditionally by hand as it is now, but with a view to expansion, alternative methods of extraction and processing are now being sought, this being the subject of the Case studies of British operations chapter.

Commercial skiffer production began in the area in the 1800's, with small quarries located throughout the Voss area. The Norheim-Kyte operation peaked in the 1920s when 250 men were employed, the quarry extending for 1250 m in a NW-SE direction, with almost horizontal strata. In 1980 almost 75 m of rock had been removed. Average annual production is approximatley 560 m^3, about 35 to 40% of the skiffer is lost during extraction, with further losses during processing. Thus approximately 780m^3 is actually extracted. At current production rates it would take one year to extract a 1m deep,50m wide block of a full 15m high skiffer horizon.

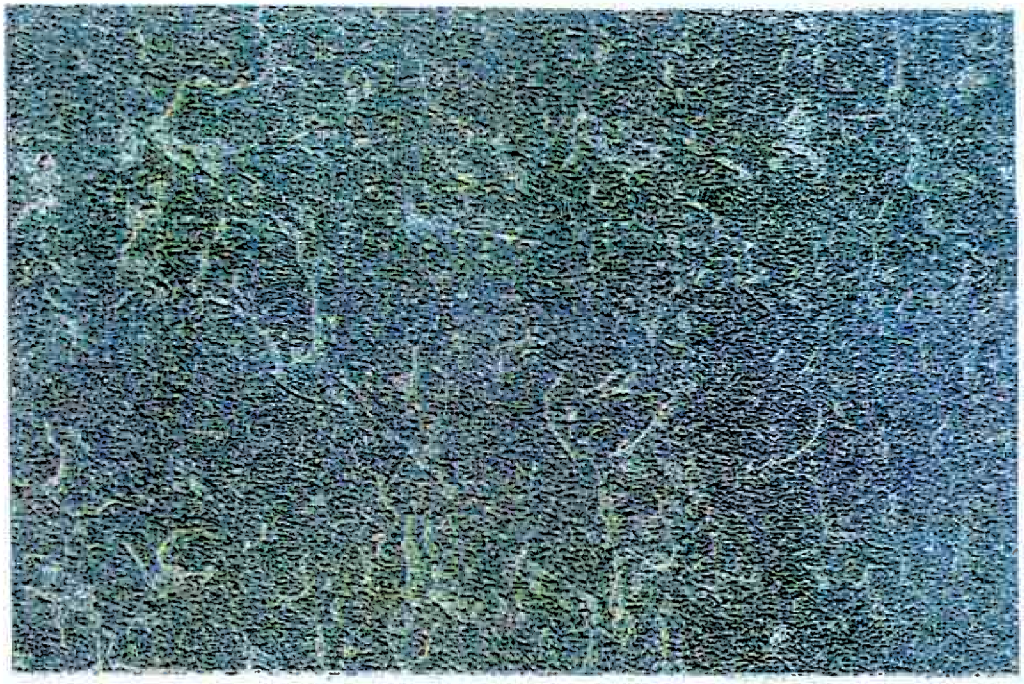


Fig 5. Voss Quartz schist - Skiffer

The Mon quarry began production about 1800, and now extends 110m in a NNW-SSE direction, with strata dipping at approximatley 32^0. The operation at Vetlehagen extends 100 m in the same direction as the Mon quarry, but has only been worked over the last few years.There are several disused workings in the immediate area that were abandoned at the onset of World War II, only a few of these being reworked in the mid 1950s due to a lack of labour and alternative employment. The Mon quarry and areas north of the Vetlehagen quarry were briefly mined for a period, with a down dip extension of no more than 5m the operations were once again abondoned.

Extraction involves blasting, with unmanageable sized blocks being broken down to 1.5 x 2m blocks that are taken to the splitting area for spitting by hand.

MATERIALDATA (MIDDELVERDIER):					
Egenvekt KN/m^3	Trykkfasth N/mm^2	Bøyestr. - fasthet N/mm^2	Slitasje-tall mm/2000 om.	Varmeutv. koeff. (0-110°C) $10^{-6}\,°C^{-1}$	Vann-absorpsjon % vekt
27.2	302.5	35.0	3.2	10.7	0.13

Table 1 Physical properties of Voss Quartz-schist

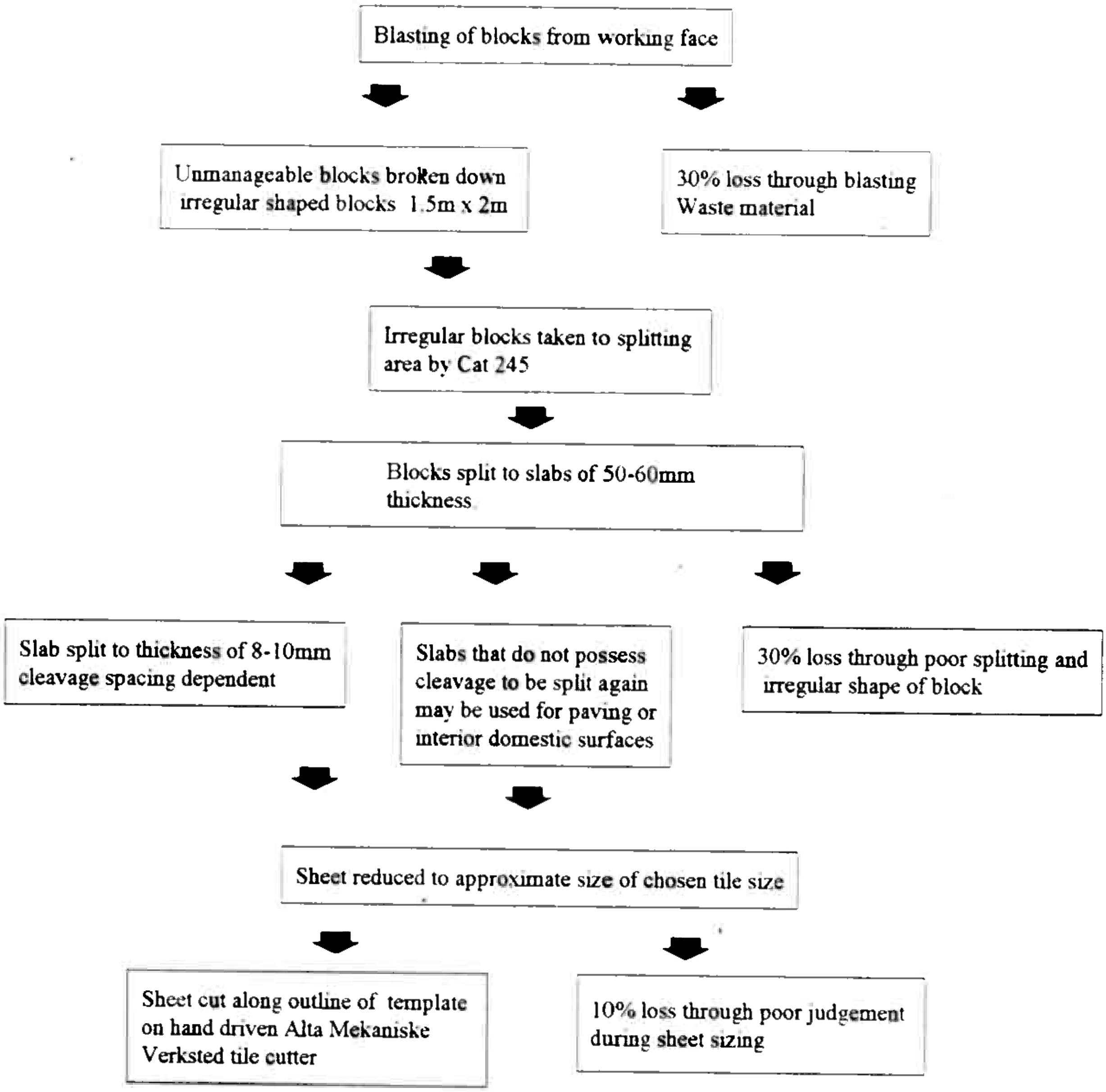


Fig 6 Flow diagram of current extraction and processing methods

Blocks are split to slabs of thickness of 50 to 60 mm, then further split to the required thickness of the tile - most are 10 mm.

Fig 7 Traditional method of producing tiles by hand

Slabs are then carefully reduced to the approximate size of the required tile, then cut using a simple hand driven cutter, which also produces the chamfered edge. Lineations seen in the surface of the slabs are small fractures caused by discontinuous layers of micaceous minerals within the skiffer. If tiles are cut with the fracture running accross the tile then this may cause leakage of rain water through the tile.

Voss skifer is a light, fine grained quartz-schist, or quartz-sericite schist as it contains the light very fine grained variety of muscovite known as sericte. Other minerlas include Kfeldspar and albite. Some other minerals can occur in small amounts, but does not contain ore minerals thus does not give a ferrous weathering product. The cleavage is thought to be the result of bedding- axial planar cleavage intersections, and the parallel alignment of mica due to D_1 thrusting tectonics. Schist quality varies in both mineralogy and mineral orientation. Cleavage must be absolutely planar, as any folding yields the schist unworkable.

A large part of the Bergsdalen quarangle has been mapped by Kvale and other geologists, and the geologic map shown in Plate xxxx includes data from the maps prepared by Kvale (1946), Gray (1978), Kvale and Ingdahl (1985), and Ingdahl et. al. (1990). Mapping carried out in 1991 has concentrated in the western half of the Bersdalen Nappes.

Bjorn Lunde of the NGU conducted surveys at Vetlehagen, Mon, and Norheim-Kyte during a rainy week in the summer of 1992, the resultant work was of no use to Voss cementvarefabrik, thus the author has great hopes for this report.

Anders Kvale executed an extensive survey of Norheim-Kyte in 1977 with the University of Bergen, as an attempt at resource evaluation.

The skiffer operations all required detailed geological surveys of occurences of quartz schists (Kvart Skiffer), some layers contain quartz veins that make the skiffer unsuitable for industrial applications, other problems include cleavage, nappe folds, joint relationships, and also layer thickness.

Detailed schist surveys must be carried out to find out whether there is any system in occurences of good and bad quality skiffer, also determining whether there are particular structural horizons within which quartz veins occur. Schistosity, nappe folding, mineralogy of horizons and the pattern of joint sets also needed to be surveyed.

The geological survey took the form of preparation of an overall tectonostratigraphic map establishing the economic horizons in the quarries, aswell as in the surrounding area as part of reserve evaluation. Sections were taken up through the thrust sequence at all localities and are represented in Figure 15. Joint orienatation surveys were conducted in detail at both the Norheim-Kyte and Mon-Vetlehagen quarries, and are represented as stereographic projections. It is hoped that estimations of block sizes may be made from the joint data in order to assign particular industrial uses for each horizon.

Distinct lineations were noticed from cleavage surfaces in Quartz-Schist Horizons but are not thought to affect skiffer quality, and are the result of the Caledonian thrusting event. Isoclinal folding is thought to represent a crutial element of skiffer formation, yet does not affect skiffer quality.

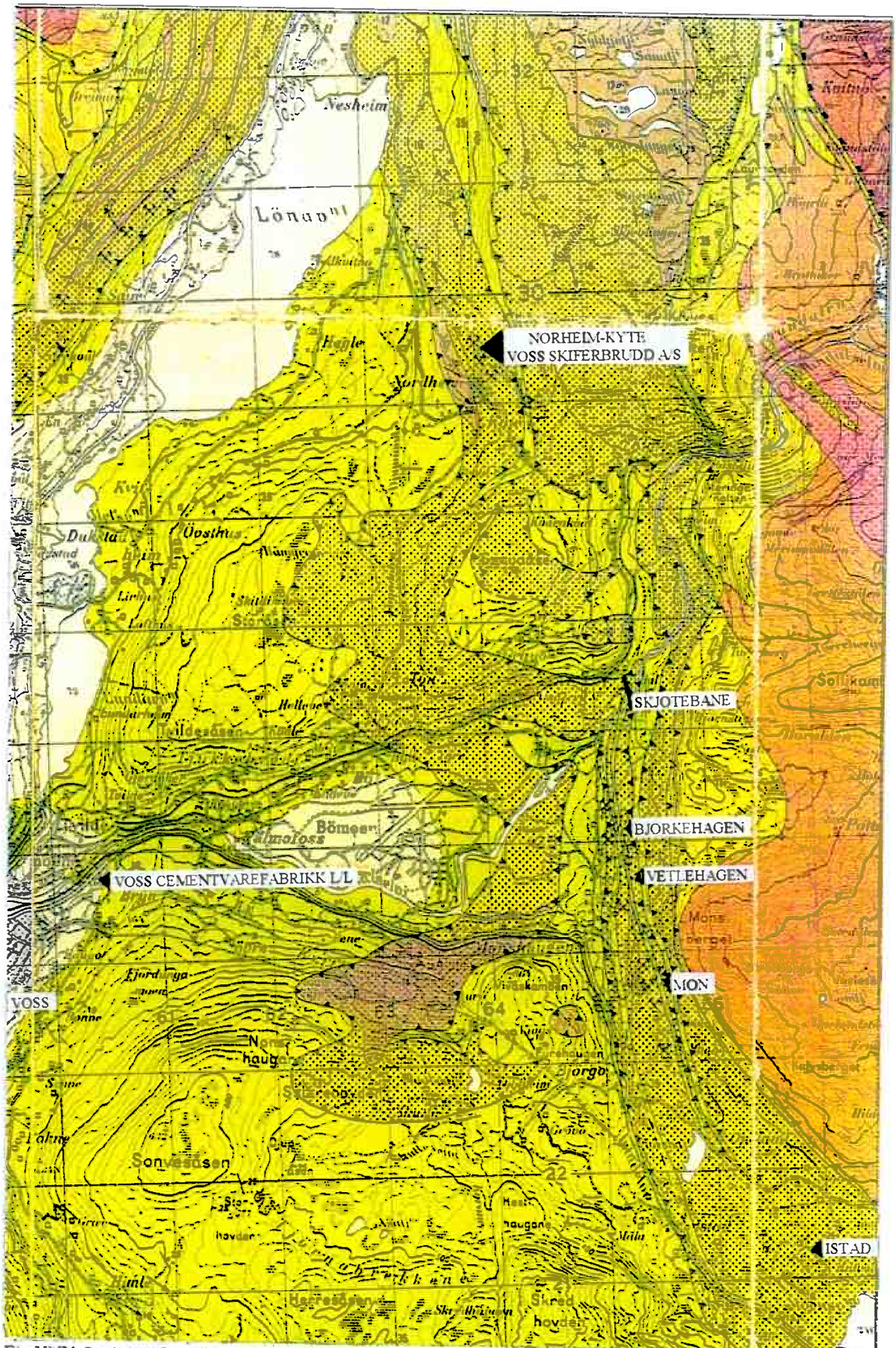


Fig XXX Geology of the Voss area. NGU report 1316 III Voss, Kvale. A., Ingdahl. S.E., 1985. Scale 1:50,000.

TEGFORKLARING/Legend

SEDIMENTER AV KVAT .ER ALDER
Quaternary Sediments

1 — MORENE, GRUS, SAND, LEIRE
Moraine, gravel, sand, clay

JOTUNDEKKEKOMPLEKSET, PREKAMBRISKE BERGARTER, FRAMSKJØVET UNDER DEN KALEDONSKE FJELLKJEDEDANNELSE
Jotun Nappe Complex, Precambrian rocks, overthrust during the Caledonian orogeny

UNDRE JOTUNDEKKE
Lower Jotun Nappe

5 — BÅNDET GNEIS, ØYEGNEIS, FINKORNET GNEIS, DELVIS MYLONITTISERT OG FORSKIFRET
Banded Gneiss, augen gneiss, fine-grained gneiss, partly mylonitic and schistose

VOSSADEKKEKOMPLEKSET, PREKAMBRISKE BERGARTER, FRAMSKJØVET UNDER DEN KALEDONSKE FJELLKJEDEDANNELSE (TIDLIGERE KALT ØVRE BERGSDALSDEKKE)
Voss Nappe Complex, Precambrian rocks, overthrust during the Caledonian orogeny (former name: Upper Bergsdalen Nappe)

SKORAFJELLDEKKET (TIDLIGERE KALT ØVRE FLAK AV ØVRE BERGSDALSDEKKE)
Skorafjellet Nappe (former name: Upper Thrust Sheet of The Upper Bergsdalen Nappe)
DYPBERGARTER
Plutonic rocks

6 — KVARTSIDIORITT
Quartz diorite

RAUNDALSKOMPLEKSET
Raundal Complex

7 — GRANITT
Granite

8 — GRANITTISK OG DIORITTISK GNEIS
Granitic and dioritic gneiss

KVITENOSGRUPEN
Kvitnos Group

10 — AMPHIBOLITT
Amphibolite

11 — KVARTSKIFER (METASANDSTEIN)/KONGLOMERATT
Quartz schist (metasandstone)/conglomerate

SLETTAFJELLDEKKET (TIDLIGERE KALT MIDTRE FLAK AV ØVRE BERGSDALSDEKKE)
Slettafjellet Nappe (equivalent to Upper Bergsdalen Nappe, Middle Thrust Sheet

STØRKNINGSBERGARTER
Igneous rocks

14 — GABBRO, FOLIERT
Gabbro, foliated

KVITNOSGRUPEN
Kvitnos Group

16 — KVARTSSKIFER (METASANDSTEIN) KONGLOMERATT
Quartz-schist (metasandstone) conglomerate

17 — AMPHIBOLITT
Amphibolite

NÆ STEDEGNE BERGARTER AV ANTATT KAMBRISK OG STEDVIS PREKAMBRISK ALDER
Parautothonous rocks of assumed Cambrian and partly Precambrian age

35 — FYLITT STEDVIS OGSÅ GLIMMERSKIFER
Phyllite, locally mica-schist

The Mon quarry currently works a 23m horiizon of quartz-schist dipping at 33 to the North-East, with lateral extent of 50m. The horizon lies sandwiched between two phyllite layers the upper represents an internal imbrication decollement thrust, both are extremely deformed, hosting milky white quartz veins and lenses.

The worked sequence represents a massive horizon, showing no quartz veining and no noticable structural features. The economic quartz-schist horizon ends ubruptly in a 20cm thick quartz vein, above which lie layers of quartz-schist that are heavily impregnated with quartz veins. Abandoned workings 200m to the south of the present quarry present potential interest, bu are separated by a zone of post - thrusting reworking.

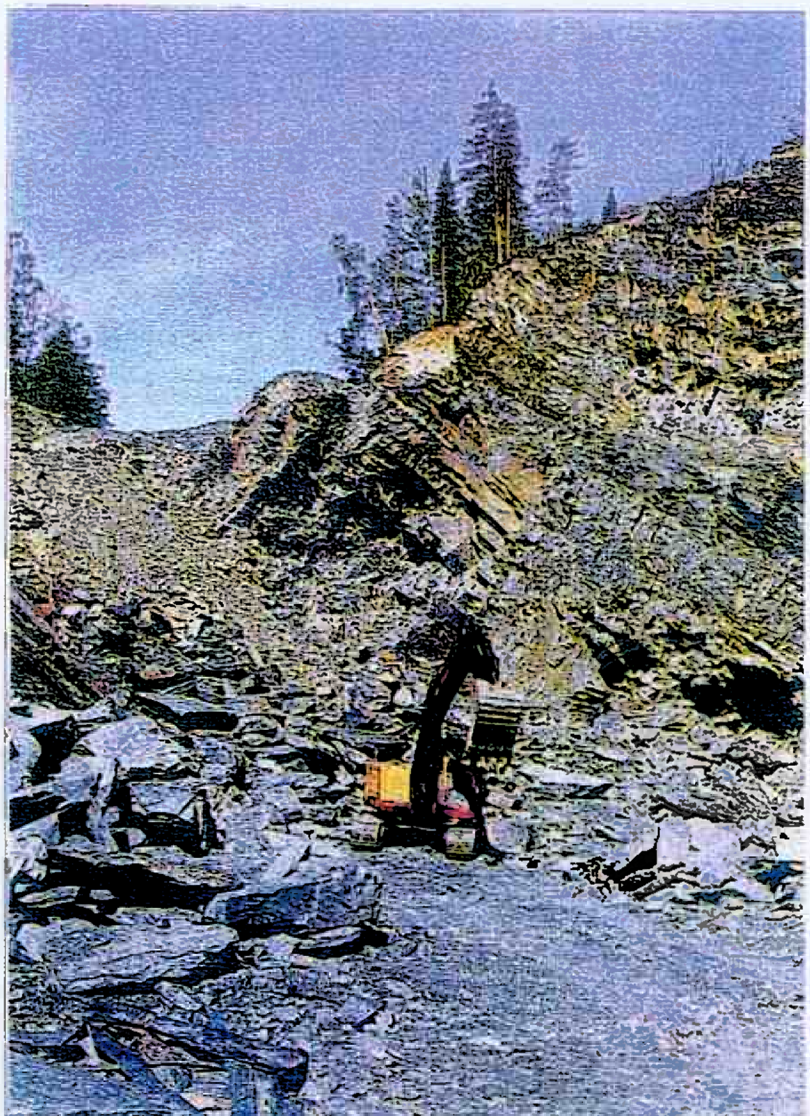
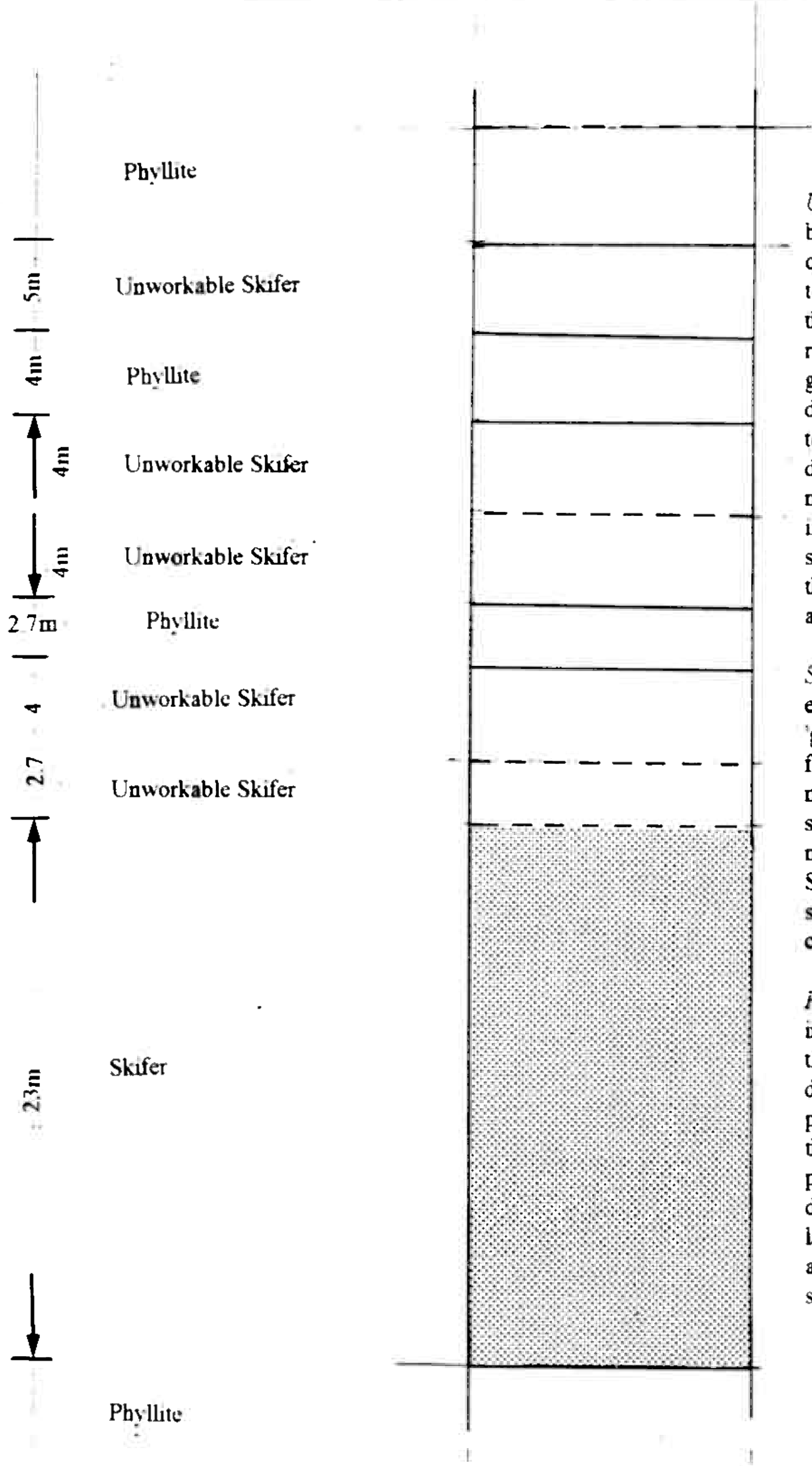


Fig 10. Mon Quarry (looking north)

The tectonostratigraphy is explained in more detail in Fig. 11.

The skifer is currently extracted via access roads that approach the face along strike, as quarrying directly down dip would be problematic. The quarry is now reaching its currently approaching its full potential in its present form, Mon is the only operation where underground methods have and could again be used. The arguement for underground methods is supported by the high stripping



Unworkable Skifer - high concentration of boudinaged concordant and discordant quartz veins, varying in thickness from 1cm to 10cm. Strata has been heavily fractured, this may be due to a higher competance, but results in worthless material. Joint sets are generally non-pervassive, yet frequent. The deformed nature of these horizons is thought to result to their proximity to the decollement shear zones, causing local metasomatism, i.e. rocks tend to become increasingly silica rich with nearness to a shear zone, thus loosing the micas that form the cleavage that is paramount for industrial applications.

Skifer - homogeneous, vein-free strata, with excellent cleavage. Occassionally show 'ghost structures' of small (10cm vavelength) fold hinges highlighted by quartz mineralization in their limbs. These structures support the arguement of a thrust nappe isoclinal fold eveloutionary model. Such structures are mostly 'sheared out' by subsequent thrusting, and do not affect the cleavage of the rocks.

Phyllites - seen as lubrication mediums for internal ramping up decollement thrusts. It is thought that some phyllites/mica schists develop as a result of the metasomatic proceseses of solution transfer during thrusting, and are not just slices of the basal phyllite common to the area. The decollement phyllites show very fine planar laminations with shear band fabrics verging again to the south-east, yet 'ramping up' in a southerly direction.

Fig 11 MON QUARRY - Main working face Location - see Base Map in Appendix ratio faced by any proposed open-pit design (Table 2).

Table 2. *Reserve estimation of preliminary pit-design*

Material		*Tonnage Factor*	*Tonnes*
Recovered skifer		2.7	6 112 96.07
Overburden		2.7	33 08 345.215
Waste skifer		2.7	2 61984
Waste		2.7	35 703 29.215
Stripping Ratio	=	**5.8 : 1**	

The estimated stripping ratio is high, and would increase further as quarrying continued down dip. Estimates are based on excavation of the Mon pit for 38m down dip with a batter angle of 53 degrees (Ref Fig 16 Map of reserve estimation).

Vetlehagen Quarry is located south of the Horjolo River, the current operation is working a thickness of 7 m, of lateral extent 30m, dipping 30 to 33/340 NE. Previous operations in the immediate vicinity were located to the north, with more extensive reserves, and represents significant reserves with little overburden.

The skiffer here is characterized by a continuous laminar mylonitic fabric, that becomes progressively deformed to the south, the result of the Devonian back-thrustig movement. Evidance for this movement were seen as stretching lineations, illustrated by Fig 2.8 orientatred to 290 to 295 verging NW.

Table 3. Reserve estimation for a preliminary open-pit design

Material	*Tonnage Factor*	*Tonnes*	
		Zone 1	*Zone 2*
Recoverable skifer	2.7	49,896	39,690
Overburden	2.7	484,110	173,745
Waste skifer	2.7	21,384	17,010
Waste	2.7	505,494	190,755
Stripping ratio	=	**10 : 1**	**5 : 1**

The data above was calculated on the assumption the design extends down-dip for approximately 35m, as at Mon, stripping ratio increases with increasing down-dip excavation. Zone 1 (Fig 13 Map of Vetlehagen and Bjorkehagen Reserves) including the present Vetlehagen Quarries south of the Horjolo River are likely to become uneconomical with further extraction, and are now thought to be of less recovery potential than Zone 2. Zone 2 comprises areas of low-relief north of the Horjolo River, and could be considered to be a potential area for development. The economics of all of the surveyed areas is discussed on page 42.

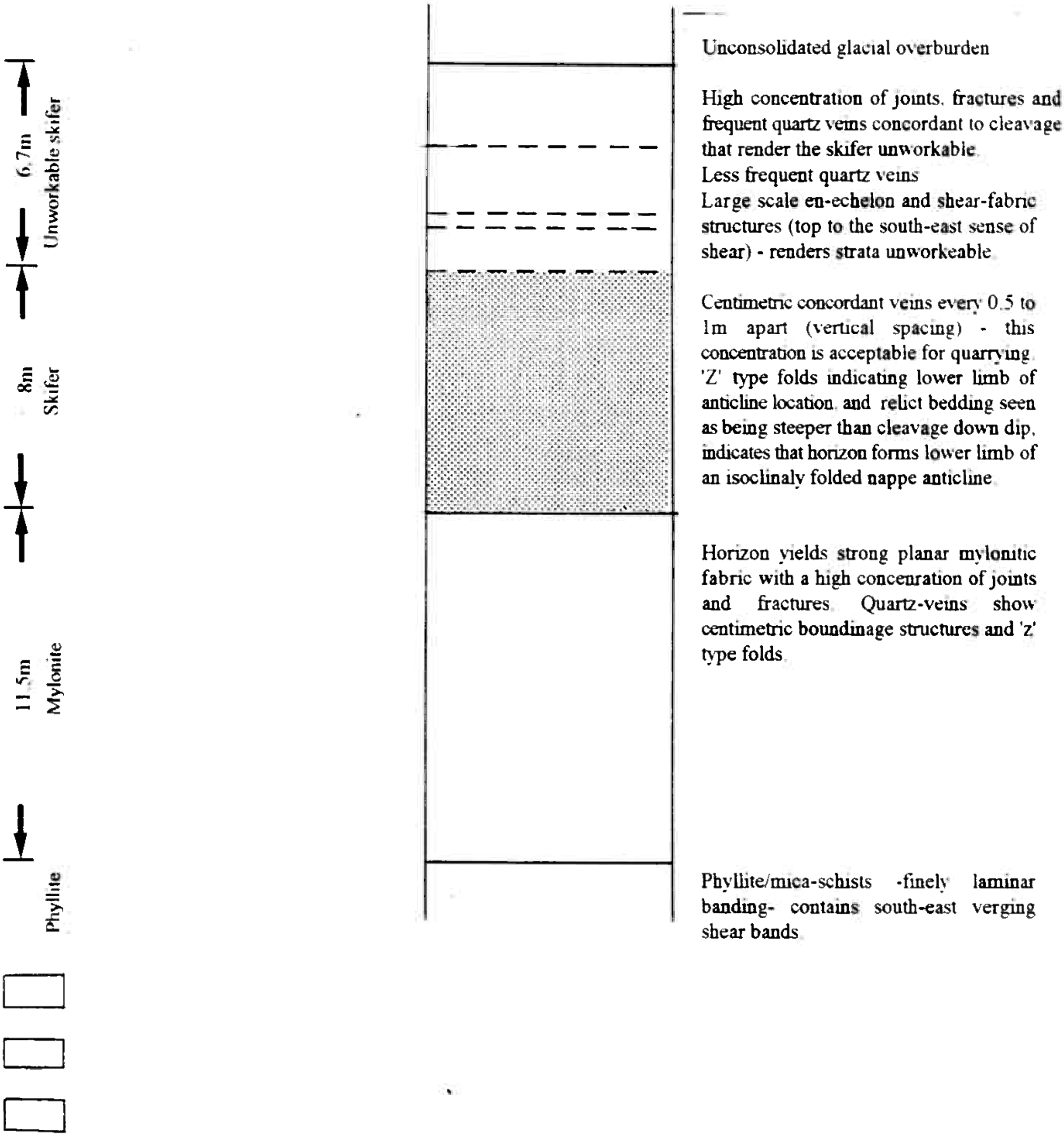


Fig 12 VETLEHAGEN Profile 5 Loc-see Fig 13

This study comprises surveys of the areas between the Mon and Vetlehagen quarries, and areas to the North, South, and East of the quarries to identify potential skiffer reserves for future quarry expansion. Previously worked small-scale workings were seen in some of these areas, and reflect potential reserves for extraction.

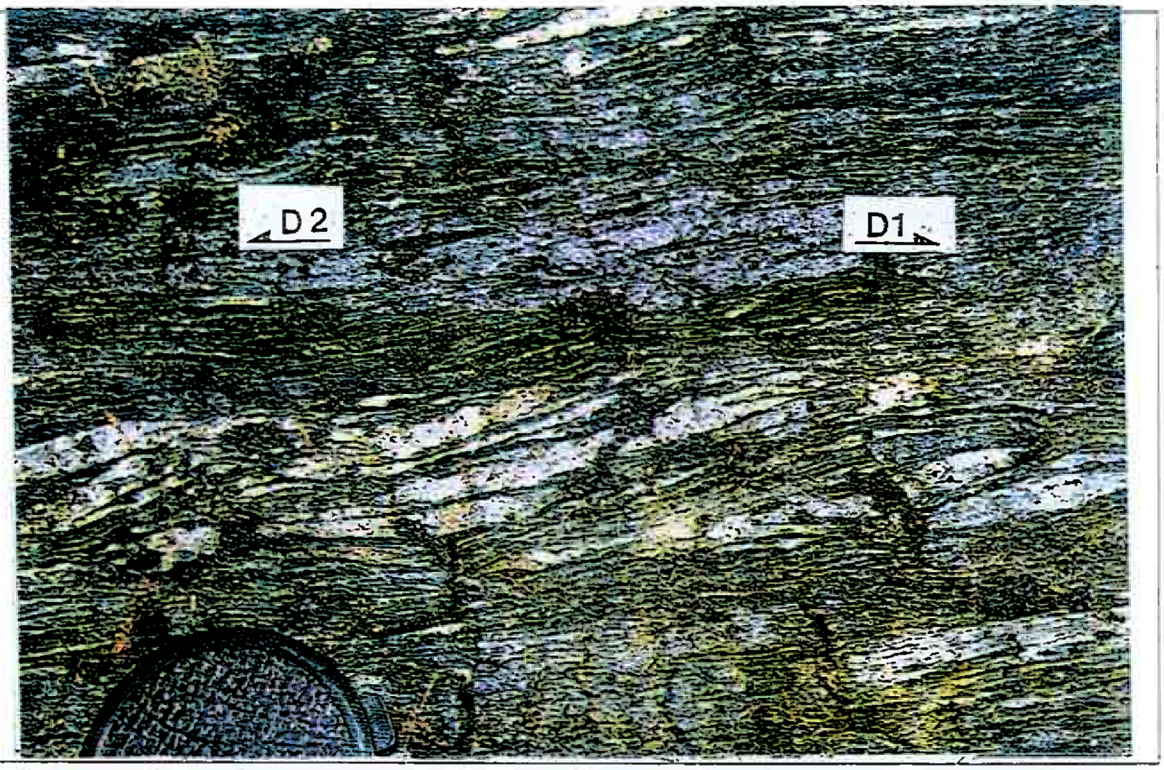


Fig 14. Structures in mylonite close to phyllite horizon (Locality XXX). Sigmoidal shaped competant lens in the weak (dark) mylonite indicate illustrate the D_1 southeast verging sense of shear. Later asymmetric small-scale folding and and SE dipping crenulation cleavage is developed in weak, mica-rich layers, reflecting the Devonian D_2 back-thrusting event.

The areas between the Mon and Vetlehagen Quarries has been largely unworked and were unknown as to the potential of skiffer reserves there. The quarries lie within the same tectonstratigraphic level, albeit at different levels. The area between them comprise rocks of a quartz-schist nature, yet showing a mylonitic fabric throughout with high concentrations of quartz lenses and veins mostly concordant to the expected cleavage in the area Quartz vein folding is seen of wavelength approximatley 1m, with hinge line orientation E-W, but little deforms the overall mylonitic fabric of the rock There are several possible explanations for this zone of uneconomic schistose/mylonitized rocks, the first is that during the SE verging Caledonian D_1 thrusting event there were variations in the amount of strain produced, the economic skiffer horizons being zones of higher overall strain. The second explanation involves reworking of the horizon by the NW verging Devonian D_2 back-thrusting event, involving remobilization of silica producing the large concentrations of vein and lensoid quartz and hinge-line rotation. The author favours the Devonian D_2 back-thrusting event based on small-scale structures seen in the mylonite-phyllite contacts within the study area. Mylonitic structures close to the phyllite horizons, support this view, where sigmoidal shaped milky white competant quartz lenses within the mylonite illustrate the D_1 southeast sense of shear. Later asymmetric smaller-scale folding and SE dipping crenulation cleavage is developed in weak, mica rich layers, reflecting the Devonian D_2 back-thrusting movement (Fig 14). Surveys of the horizons directly above the Mon workings and disused workings north of there show internal imbrication structuresthat were lubricated by incompetant pyllite layers that constitute horizons of thicknesses of several metres that taper out northwards, these being contained between larger roof and basal thrusts . Refer to Fig 8. for extent of ramping up decollement structures. Sections were made up-stratigraphy in four areas and are represented in Fig 15. in a comparitive form. Surveys of the Vetlehagen-South quarry show that the skiffer here has a poor cleavage and strong centimetric mylonitic fabric with a low concentration of quartz veins and lenses. Areas surveyed to the north of the Horjolo river reflect new areas for extraction (Localities 47-53). The horizon of quartz-schist at Loc.47 consists of a massive, homogeneous unit with a low-concentration of quartz veins and lenses.These are concordant to cleavage and continuous along strike, occuring at intervals of several metres and are not thick enough to cause any large scale disruption to the surrounding economic skiffer, thus acceptable for extraction. Joints in the exposure are at regular intervals of 0.5 to 2.5m orientated $349/85^0$ WSW, almost perpendicular to the working face, thus facillitating extraction.

Table 4. Reserve estimation based on a preliminary open-pit design at Bjorkehagen

Material		*Tonnage Factor*	*Tonnes*
Recoverable skifer		2.7	101,300
Waste		2.7	189,236
Stripping ratio	=	**1.8 : 1**	

The estimation given above is based on a hypothesised open-pit with a down-dip extension of 70m and strike length extension of 70m. An operation such as this would prove very economical, due to the lack of overburden, and general low relief in the area.

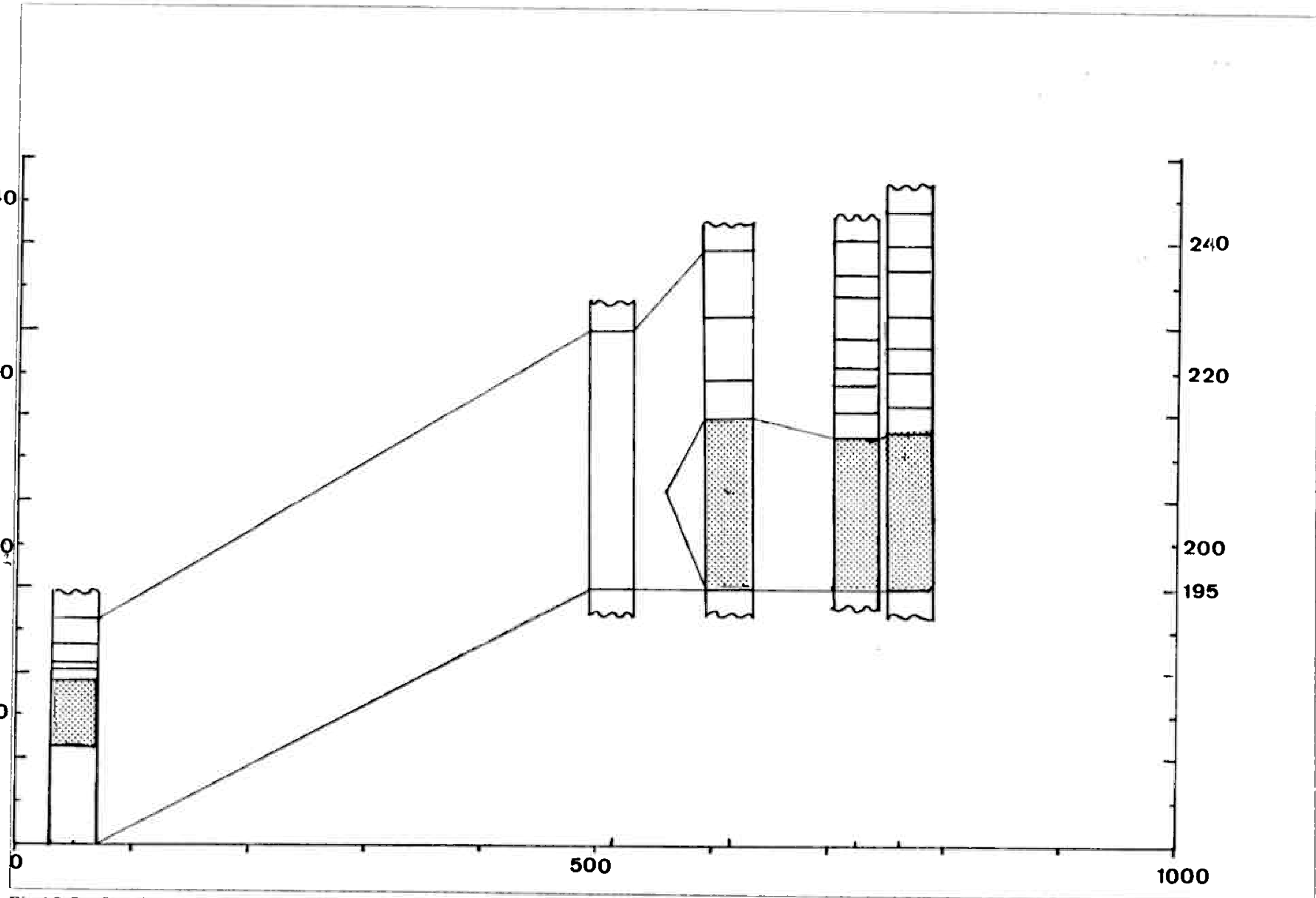


Fig 15. Profiles from Mon (1) to Vetlehagen (5) showing lateral extent of skifer reserves. See appendix Base Map for locations of profile traverses.

VOSSADEKKEKOMPLEKSET, PREKAMBRISKE BERGARTER, FRAMSKJØVET UNDER DEN KALEDONSKE FJELLKJEDEDANNELSE (TIDLIGERE KALT ØVRE BERGSDALSDEKKE)
Voss Nappe Complex, Precambrian rocks, overthrust during the Caledonian orogeny (former name: Upper Bergsdalen Nappe)

SKORAFJELLDEKKET (TIDLIGERE KALT ØVRE FLAK AV ØVRE BERGSDALSDEKKE)
Skorafjellet Nappe (former name: Upper Thrust Sheet of The Upper Bergsdalen Nappe)

KVITENOSGRUPEN
Kvitnos Group
AMPHIBOLITT
Amphibolite
KVARTSKIFER (METASANDSTEIN)/KONGLOMERATT
Quartz schist (metasandstone)/conglomerate

SLETTAFJELLDEKKET (TIDLIGERE KALT MIDTRE FLAK AV ØVRE BERGSDALSDEKKE)
Slettafjellet Nappe (equivalent to Upper Bergsdalen Nappe, Middle Thrust Sheet

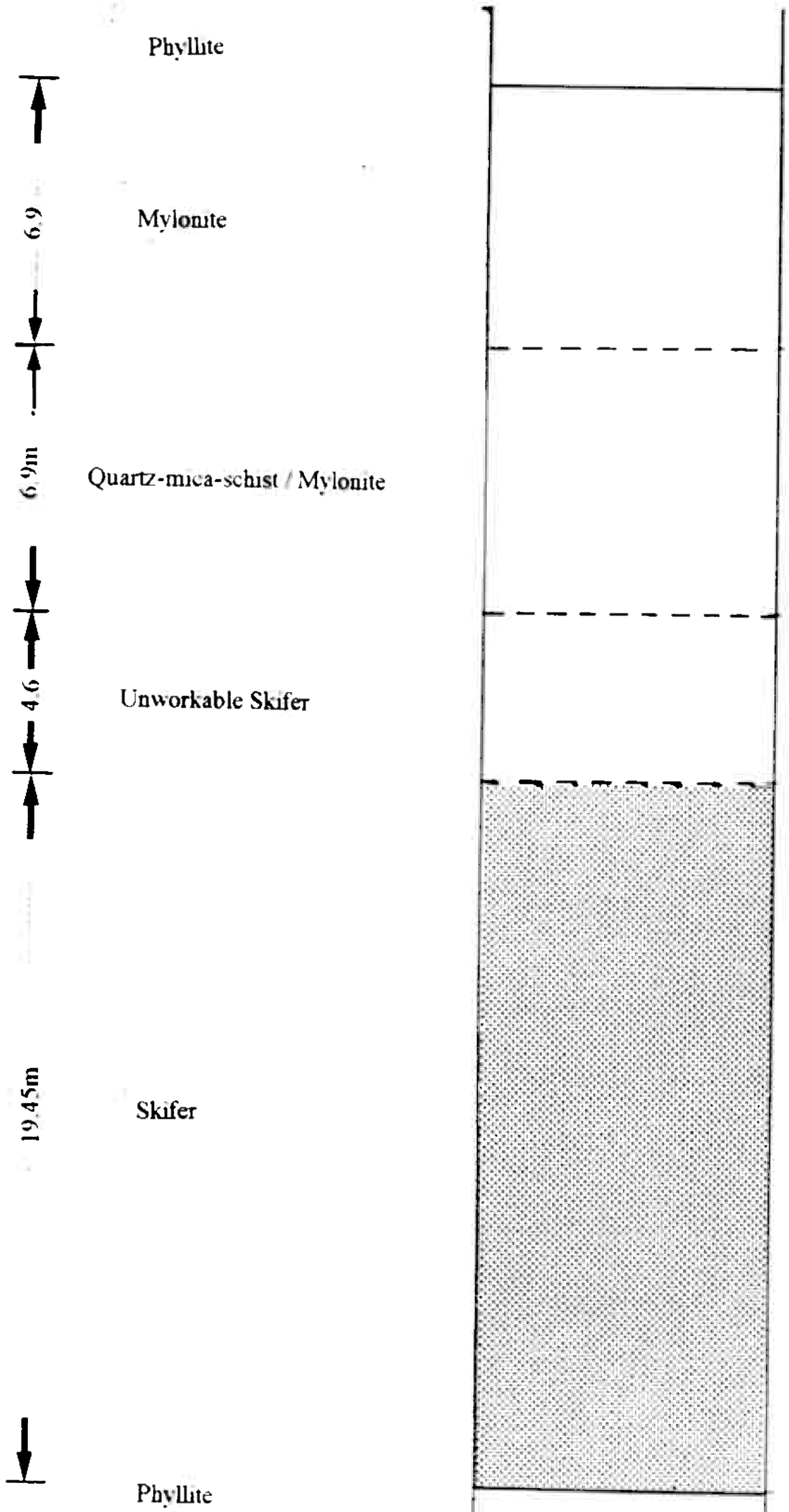
KVITNOSGRUPEN
Kvitnos Group
KVARTSSKIFER (METASANDSTEIN)/KONGLOMERATT
Quartz-schist (metasandstone)/conglomerate
MYLONITT (METASANDSTEIN OG KONGLOMERATT)
Mylonite (heavily metamorphosed sandstone and conglomerates)
NÆ STEDEGNE BERGARTER AV ANTATT KAMBRISK OG STEDVIS PREKAMBRISK ALDER
Parautothonous rocks of assumed Cambrian and partly Precambrian age
FYLITT STEDVIS OGSÅ GLIMMERSKIFER
Phyllite, locally mica-schist

GEOLOGISKE SYMBOLER
Geological symbols

BERARTSGRENSE
Lithological boundary
BERGARTSGRENSE, USIKKER
Lithological boundary, uncertain
SKYVEGRENSE FOR SKORAFJELLDEKKET
Thrust contact to the Skorafjellet Nappe
SKYVEGRENSE FOR SLETTAFJELLDEKKET
Thrust contact to the Slettafjellet Nappe
SKYVEGGRENSE FOR GRASBERGDEKKET
Thrust contact to the Grasberget Nappe
SKYVEGRENSE INNEN DEKKEFLAKENE
Internal thrust contact (imbrication) of the thrust sheets
SKYVEGRENSE FOR NÆR STEDEGNE BERGARTER
Thrust contact to parauthouous rocks
FORKASTNING
Fault
SPREKKESONE
Joint
FOLIASJON, SKIFRIGHET
Foliation, schistocity
OPPRINNELIG LAGNING
Primary Layering
FOLDEASKE
Fold axis
LINEASJON
Lineation

STEINBRUDD - Quarries
SKIFERBRUDD
Skifer Quarry
BRUDDGRENSER
Quarry boundary
SKIFER BRUDD RESERVE AREAS

Tectonostratigraphic Profile 4 - Mon - Vetlehagen Survey



Intensely sheared phyllite - showing south-east vergence

Mylonite - showing evidance of D_2 reworking

Quartz-mica-schist/Mylonite - very high concentration of concordant quartz veining, although rock has an excellent cleavage. No overall fabric is evident. There has been some test pitting in this horizon.

Unworkable Skifer - high quartz vein concentration - with boudan stretching deformation, at vertical intervals of 0.25m. Grades up into a mylonitic fabric. Some contorted veins show 'z' type folds suggesting that horizons occur in the lower limb of a nappe anticline, with the upper limb 'thrusted/sheared out' by Caledonian tectonics.

Skifer - fine grained, compositionally homogeneous - competant fabric. Rocks cleavage improves up section. Contains some large boudan quartz lenses with feeder veins that are acceptable for industrial purposes. Rock shows a degree of mylonitic banding - this feature becomes more evident along strike and develops into unworkable mylonites with high concentrations of concordant and contorted quartz. (Similar development as is seen with distance up sequence) These reserves are economic for a short distance down-dip.

Fig 17	MON - VETLEHAGEN-SURVEY Profile 4	Location - see Fig 16

The aim of the surveys at Norheim-Kyte was to assess the potential of skiffer reserves down /slope stratigraphy of the present workings. The quarries lie in the Kvitnos Group of the Middle Thrust Sheet of the UBN, bounded to the east by amphibolite and to the west by a thrust contact to the Sletafjellet Nappe Complex. The horizons are near-horizontal, dip/strike 07/260^{0}N, and plunging 10^0 to the NW.

The initial overview of the quarry results in that the potential reserves to be surveyed are concealed by a century's worth of dumped waste material - a potential resource itself. Surveys were made of the present quarry faces with several log sections being compiled, for use as a greater understanding of local geology and skiffer genesis for use in future skiffer exploration investigations.

Some estimate as to the nature of the horizons beneath the waste heaps could be made by comparing logs taken to the north and south of the waste - (Fig 19). Detailed investigations were made into the nature and orientation of joint sets and lineations observed above and below an observed internal decollement thrust, and were found to be perpendicular to the working face, thus facillitating block extraction. Shear band structures were seen in quartz-schist horizons, reflecting shearing with a top-to the south east sense of shear.

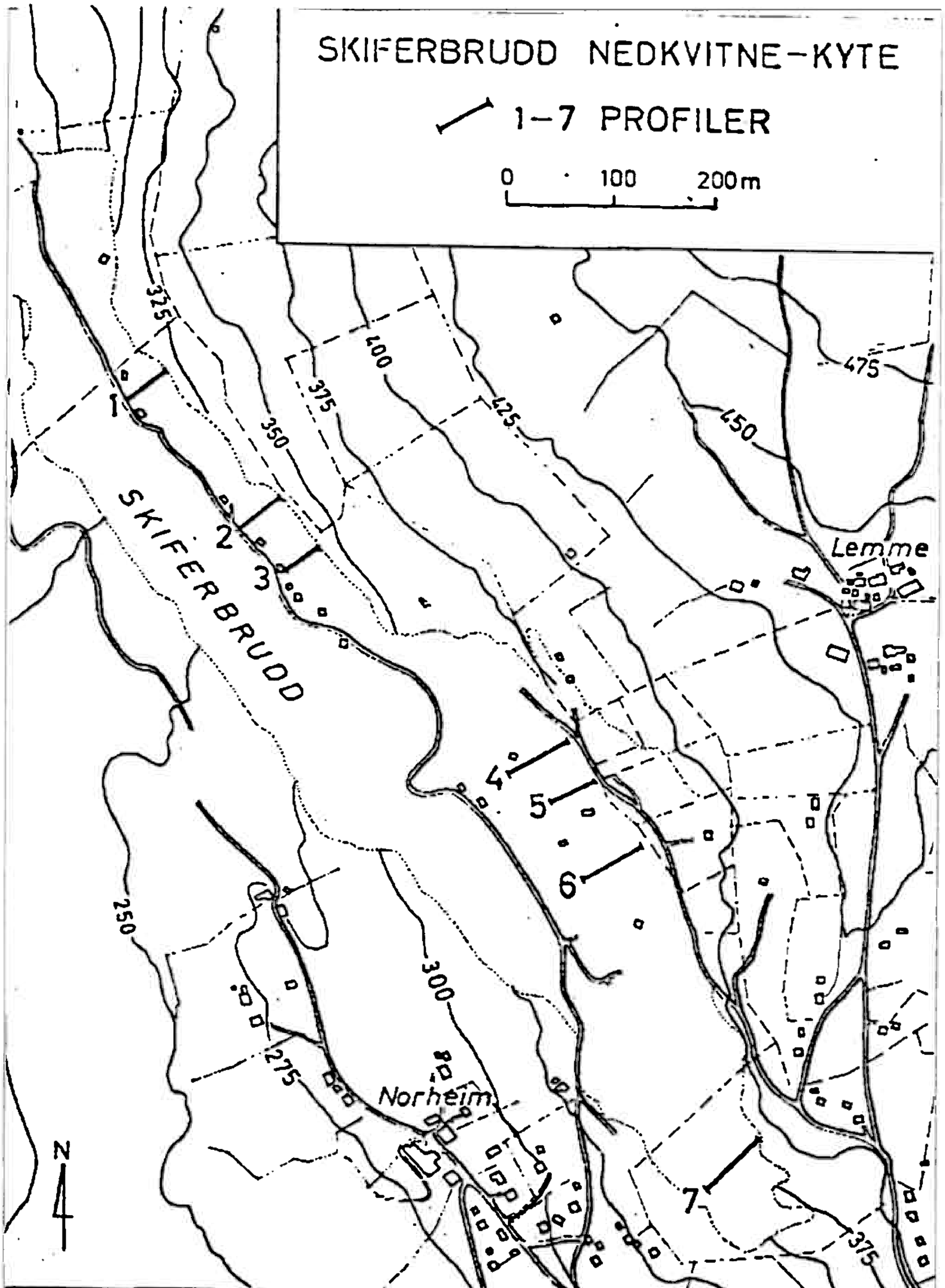


Fig 18. Norheim-Kyte Quarries, showing profile traverse locations (Taken from Kvale 1977 'Investigations of Voss Skifer' - University of Bergen, and from the author's work)

Skjotebane is a disused working north of the Raundalselvi River, consisting of a horizontal quartz-mica-schist horizon below a sharp decollement thrust contact. Skiffer is of a very high quality, similar to that at Norheim-Kyte, and has been used as polished domestic floor coverings. The phyllitic shear zone hosts shear band D_2 back-thrusting structures verging 140^0 SSE, these developed by crenulation of D_1 S-C structures. Below the contact there is a 50cm thickness of mylonite with quartz vein boudinage structures 2cm thick, and millimetric continuous veins. The Quartz-schist horizon comprises tabular blocks 3-4 cm thick, and continues down stratigraphy for 4m, the total vertical extent of these reserves are not known due to waste-rock heaps.

Fig 20. D_2 structures in phyllite by crenulation of D_1 S-C structures.

Approximately 1m below the thrust contact there is a band of concordant and discordant quartz veins (2cm) but does not affect the bulk skiffer reserve. Joints are persistant, with smooth planar faces, orientated 90/038 NE. Lineations (not in-situ) seen in economic skiffer horizons in the Mon and Vetlehagen Quarries, were observed and are thought to be a combination of the Caledonian thrusting event and the later Devonian back-thrusting event.

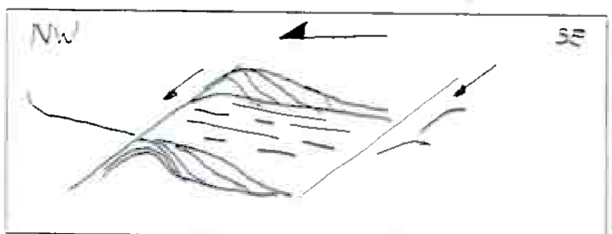


Fig 21. Development of two generations of D_2 structures in phyllite. Redrawn from field sketch. Width of sketch is 10cm.

Table 5. Reserve estimations based on a preliminary open-pit design at Skjotebane.

The following estimations are based on observed reserves, as the true vertical extent of the skifer horizon was not seen

Material	*Tonnage Factor*	*Tonnes*
Recoverable skifer	2.7	17,010
Overburden	2.7	67,068
Waste skifer	2.7	7,290
Waste	-	74,358
Stripping ratio	=	**4.3 : 1**

33

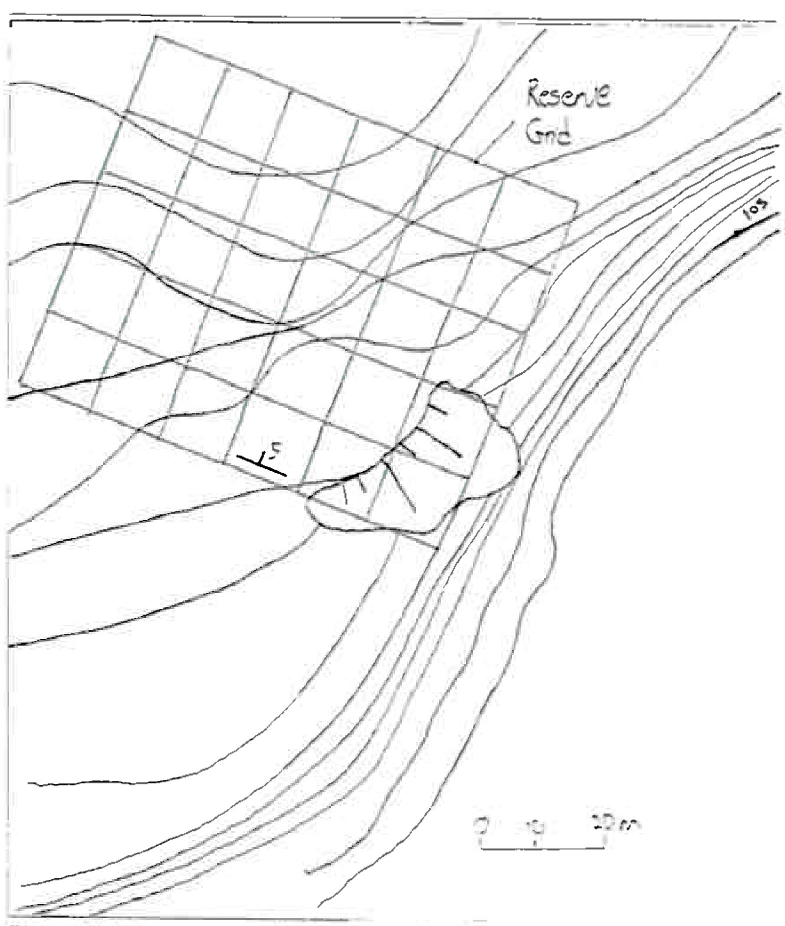


Fig 22. Skjotebane quarry showing potential reserves on transparent overlay

Istad Quarry has been disused since the 1950s, and has since flooded from the surrounding marshes. Interest has been shown by a small co-operative of workers in reworking of the quartz-schist due to an upturn in the market for skiffer. There are also large waste heaps of skiffer, and plans have been made to use this for road bases and foundations.

Fig 23. Water-filled disused quarry workings.

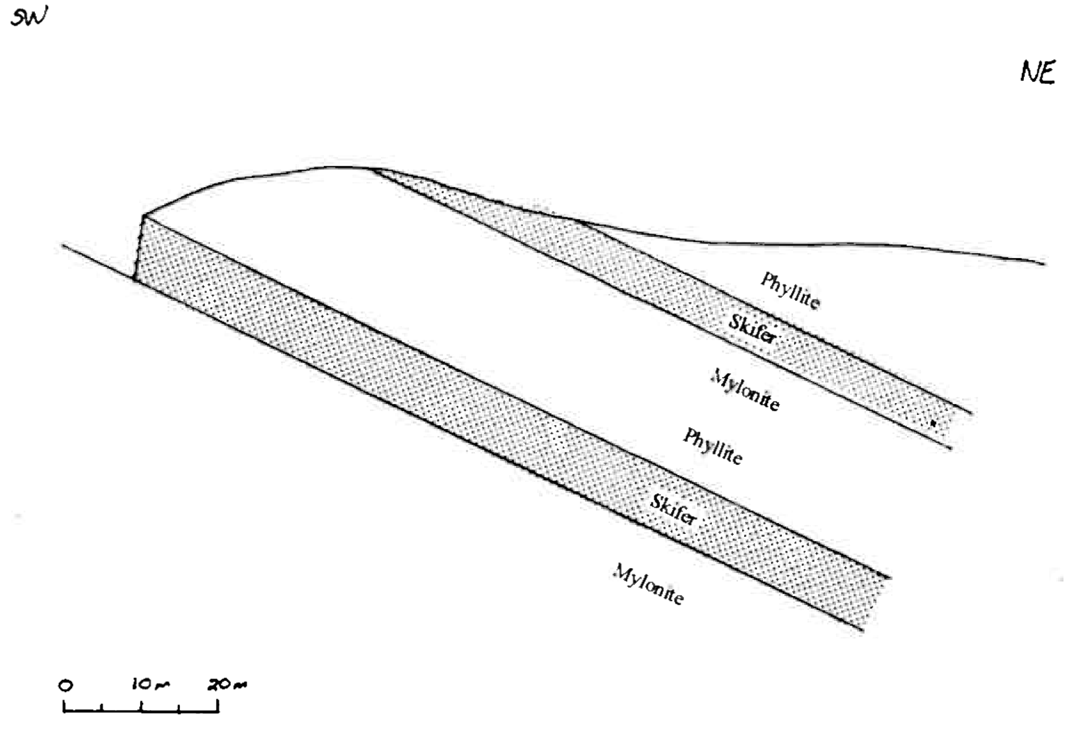
The quarry lies within the same tectonostratigraphical horizon as the other Mon quarries, in the middle thrust sheet of the UBN. The workings constitute two 100m long pits separated by a zone of intensively sheared phyllite, yielding extremely contorted quartz veins and lenses. The horizons of economically viable quartz-mica schist lie directly below the phyllitic decollement zones, and becomes progressively more mylonitized down stratigraphy, the upper quartz-mica schist band forming no thrust contact with the sheared separating decollement zone, suggesting that the horizons were not subject to simple shear but simple extensional shear (Fig 27).

The reserves calculated overleaf were based on a preliminary geological mapping survey, and should there be further interest in development, a more thorough evaluation must be implemented. The reserves do however suggest that Istad would be the most economic open-pit operation from all of the areas surveyed, as overburden is at the bare minimum.

Table 6 Reserve estimation for a preliminary open-pit design

Material		*Tonnage Factor*	*Tonnes*
Recoverable skifer		2.7	106,029
Overburden		2.7	276,804
Waste skifer		2.7	45,441
Waste		2.7	322,245
Stripping Ratio	=	**3 : 1**	

Fig 24. Simplified profile through the Istad survey area.



The Bergsdalen Nappe lithologies reflect a more competant lithology when compared to the Caledonian Nappe Complex as a whole. The quartzites and quartz-mica schists of the Upper Bergsdalen Nappes contain the quarried skiffer horizons and host southeast verging close folds with sub-horizontal axes with gently dipping W - dipping axial planar cleavage. These folds are partly deformed/'sheared out' by overbearing D_1 thrust related structures, and are interpretated as having been formed at a late stage during thrusting. A number of minor shear zones within the UBN show displacements consistent with SE directed thrusting, and form part of the complex imbricate schuppen duplex structure seen in the study area.

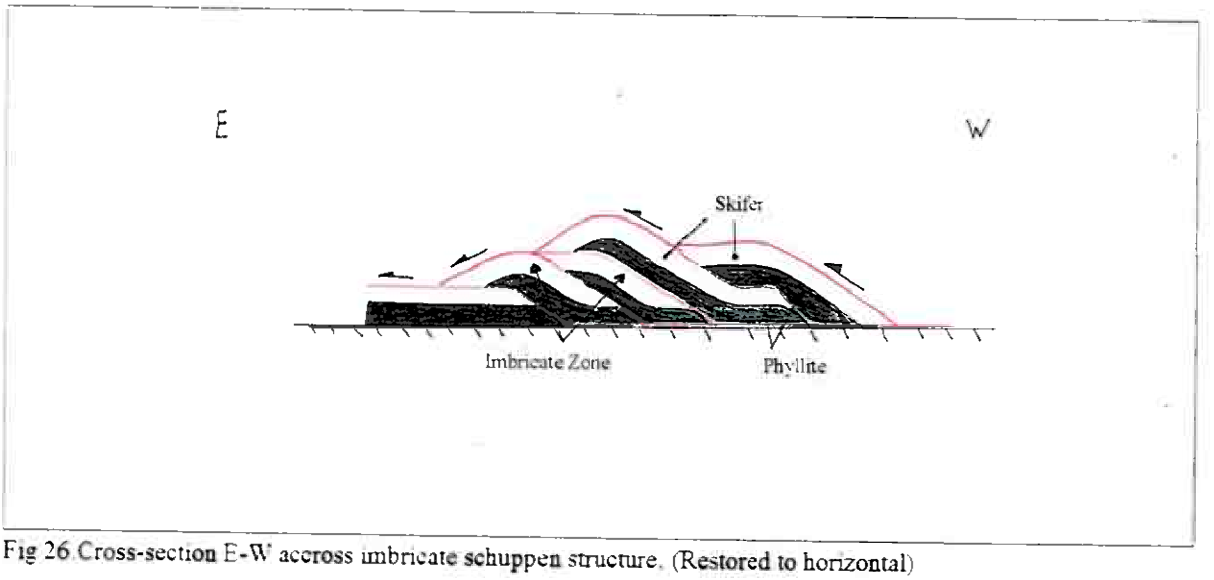


Fig 26 Cross-section E-W accross imbricate schuppen structure. (Restored to horizontal)

The author was unable to find sufficient evidance in support of parts of the work of Inghdal (1991) who mapped the area with Anders Kvale in 1985, who's observations do not reflect the geology fully and have made broad assumptions on the nature of the contacts in the study area (Fig 9). The duplex structure has been tilted, since formation to give dips of 30-35, the reconstruction above has been restored to the horizontal, and represents a section through the Mon Quarry face and upper stratigraphic levels. A major conclusion of this study is the development of a genetic model for the development and subsequent exploration of economic skiffer horizons relative to phyllitic internal imbrication structures, such as those clearly seen at the Norheim, Skjotebane and Istad Quarries, developing an almost mylonitic fabric directly beneath the dislocation, and parallel axial planar cleavage below. Economic quartz-mica-schist horizons formed by the Caledonian thrusting is a combination of simple shear thrusting and horizontal pure shear

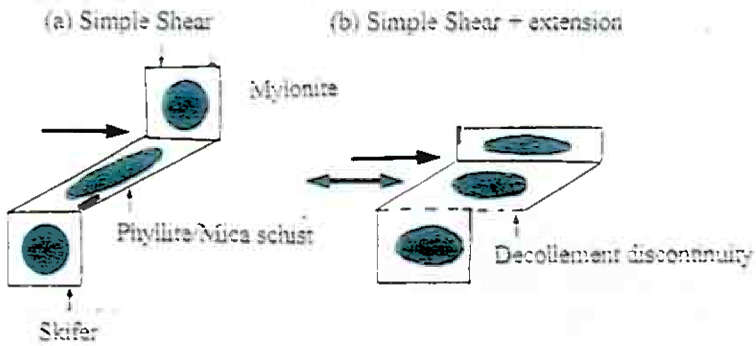


Fig 27. The effects of variation in shear accross section, illustrating (a) simple shear (b) simple shear and extension, where the economic quartz-mica-schist are relitively unstrained compared to the incompatible shear zone strains, due to D_1 Caledonide thrust movements

The horizons of economically viable quartz-mica schist lie directly below the phyllitic decollement zones, and becomes progressively more mylonitized down stratigraphy, the upper quartz-mica schist band forming no thrust contact with the sheared separating decollement zone, suggesting that the horizons were not subject to simple shear but simple extensional shear (Fig 25)

Structural Development

D1 structures - related to the Caledonian D_1 thrusting event indicate a top to the southeast shear deformation. A foliation best observed in thin-section (Fig XXX) thought to be the result of pressure-solution cleavage, and is most evidant in high strain zones, undisturbed by later D_2 deformation, and resembles a strongly linear fabric. Lineations showing distinct parallelism with insignificant difference are commonly observed in the quartz-schists of the UBN (Fig XXX). This intersection lineation is best developed where the penetrative S_1 foliation is deformed by

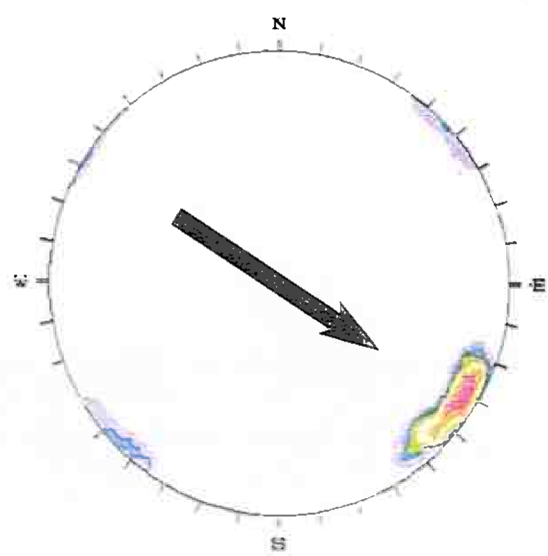


Fig 28. Stereographic projection of D_1 thrusting intersection lineation seen in Quartz-Schists of the UBN.

somewhat later D_1 folds, these themselves being destroyed by later related thrusting. This structural overprinting is interpreted as being from the progressive D_1 thrusing events which . The extent of D_1 structures is less obvious in the phyllites and mica schists that form the decolement zones between the more competant quartz-schist horizons as they have been more strongly affected by the later D_2 deformation. Although it is easily noticed that these decolement zones do possess a distinctive cleavage that can be attributed to the D_1 thrusing event.

M1 Metamorphism -lowermost amphibolite facies in heavily sheared facies, and in the dynamically recrystallized quartzites the temperatures require upper -temperatures.

D2 structures

The regional set of penetrative, linear and planar fabrics that were formed during the D_1 were consistently deformed by a tectonic event which we have been calling D_2 which involved a roughly oppsoite sense of shear. The most characteristic D_2 structures are asymmetric folds - although only seen on a small scale in mylonitic-phyllitic lithologues in the study area, and S-C structures seen as mica-fish in thin section.

D2 folds

Regionally D_2 structures are charcaterized by the development of asymmetric folds with a verging

Fig 29 Layer-parallel slip in decollement Phyllites above thrust contact with competant Quartz-schists at Skjotebane Quarry.

NW sense of shear. In the study area such features are only seen as crenulation cleavages on millimetric to centimetric scales in micaceous lithologies. Most of these small-scale fold appear to be directly related to neighbouring shear band structures, forming groups of reverse and normal slip crenulations.These are common where there is a contact between competant and incompetant lithologies, in a zone between thicker and more homogenous competant layers (Fig 29). Larger scale folds were not observed in the study area.

Shear bands, S-C structures and other mylonitic D2 structures -

These are seen in phyllites and quartz-mica-schists, as small shear zones that deform, and even more common between the quartz-mica-schist horizons i e the Mon main quarry face.

M2 metamorphism - the temperatures and pressures must ahve been lower than of the initial Cakedonide thrusting event, as so much of the initial structure remains, even after reworking by the later back-thrusting.

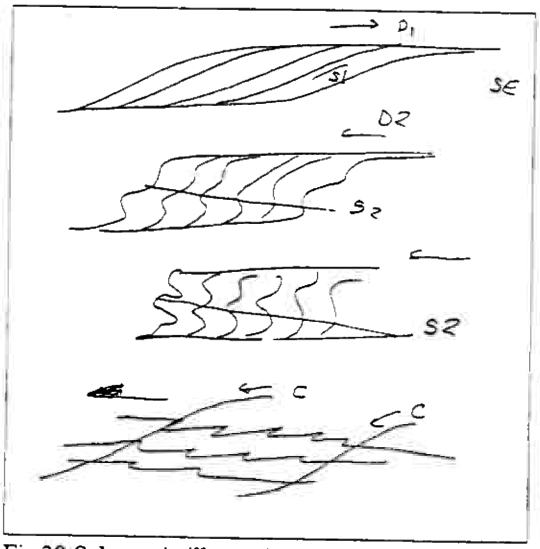


Fig 30 Schematic illustration of the development of D_2 structures in phyllite by crenulation of D_1 S-C structures. Based on field sketches - Skjotebane.

Later folding - explain difference in dips between the Norheim-Kyte areas that are near horizontal and the Mon - Vetlehagen areas that have been significantly tilted.

Microscopic observations

Fig 31 shows the typical S1 foliation seen in the skifer - this is a direct result of metamorphic processes of pressure-solution cleavage. The absence of shear fabrics/bands on this scale suggests that stretching of quartz grains was counteracted by dynamic recrystallization during the initial thrusting event.

The skifer horizons of the UBN have been preserved from reworking, due to the presence of foliation mica fish widespread boundinage structures. Reworking is sometimes easily identified in the field by rotational or deformational forms of quartz lenses.

Fig 31 Photomicrograph of Quartz-Schist from Vetlehagen Quarry, showing the distinctive (S_1) pressure solution-cleavage defined by ribbons of quartz and feldspar enveloped by more irregular, finer grained, and completely recrystallized feldspar quartz and mica. Note the characteristic S-C 'mica-fish' mylonitic features. Sample V7 (1) Mag x 40 Ppl.

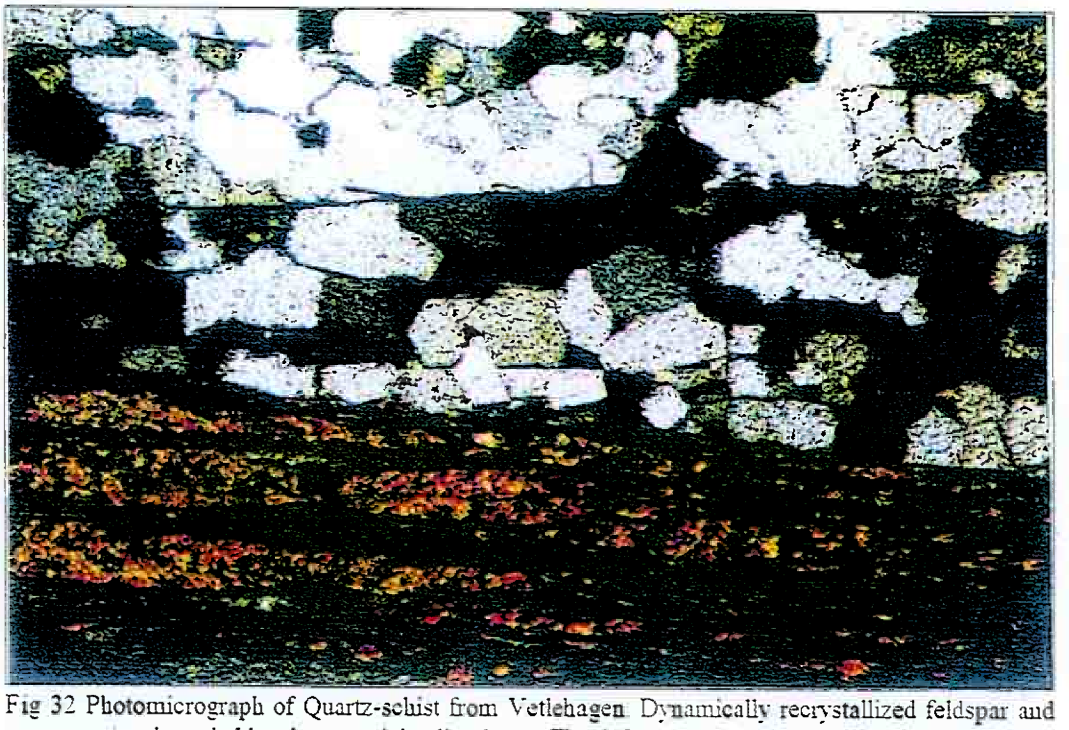


Fig 32 Photomicrograph of Quartz-schist from Vetlehagen. Dynamically recrystallized feldspar and quartz grains, bounded by sharp straight slip planes. The deformation mechanism was grain-boundary sliding or as has been suggested the mm thick nearly pure quartz are interpretated as sinks of SiO2 transferred from mica-rich layers by diffusion. Thus involving a variety of processes, solution transfer, recrystallization, grain boundary sliding, and grain-size reduction formed this characteristic S type foliation within the metasediments of the UBN. Sample V1 (1) Mag x 40 Xpl.

The reserves outlined above only reflect the preliminary work through geological mapping, although crude estimates of skiffer reserves are displayed below (Fig 34).
Suitable extractive methods can be suggested for the reserves, with opencast mining in areas of shallow overburden and low relief i.e Skjotebane, Bjorke, Istad and upper horizons at Norheim-Kyte, whereas, further feasibility studies such as a diamond drilling programme with large diameter cores to provide samples for geostatistical analysis showing the structural relations which must be conducted before shallow-depth mining could begin in the Mon and Vetlehagen Quarries.
Calculations using volumetric tonnage estimates vs overburden ratio were made to assess the viability of openpit or shallow underground operations in the area.

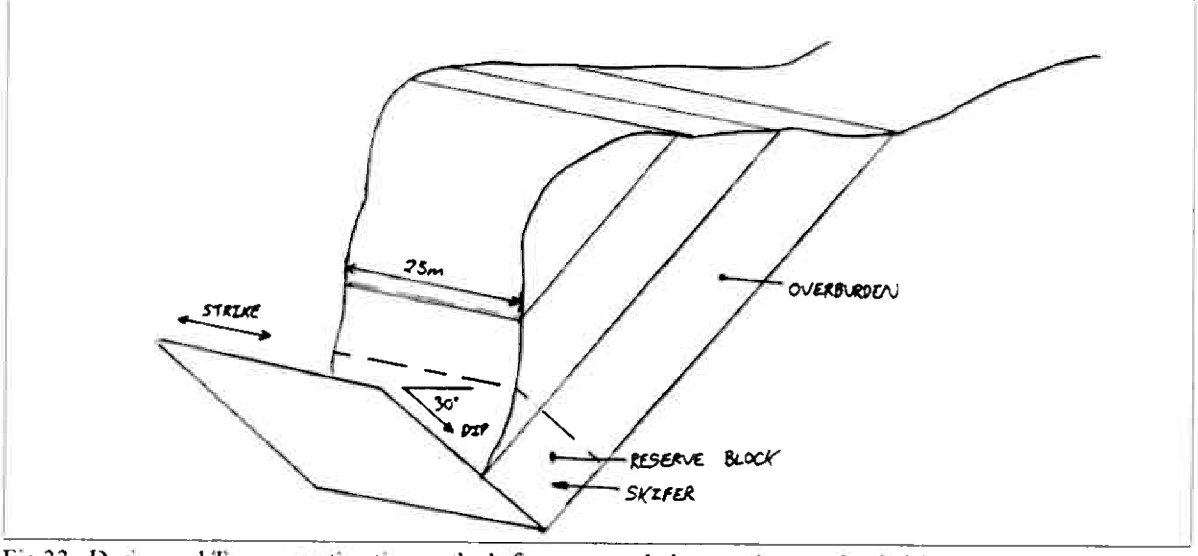


Fig 33. Design and Tonnage estimation methods for an expanded open-pit operation in Mon.

Evaluation blocks are not calculated on horizontal and vertical axis, as the method of extraction may occur on an angle, i.e at the Mon Quarry of dip 27^0, thus overburden and skiffer block volumes are calculated as they would be extracted (Fig 33).The aim of this excersise is to establish a preliminary economic assesment of operations continuing a further 50 to 70m down dip, either by opencast or underground mining methods, at a current cost of extraction of Nkr250 per cubic Metre or Nkr 93 per tonne. (£25/m^3 or £9.30/tonne), these costs are based on the work carried out at Storagrue by VossCementvarefabrikk. Tonnage estimates are given in Fig 34.
Whatever the extent of the quarry/pit boundaries a batter angle must be allowed for, this may reduce the volume of skiffer extracted. Batter angles are typically 45^0, but can vary from 35^0 in less competant overburden such as phyllites or heavily fractured quartziferous horizons to 55^0 in

quarry faces.

Fig 34 Reserve estimation information

	Down-dip *(m)*	Strike *(m)*	Tonnage *(tonnes)*	Stripping Ratio *(tonnes)*
Mon	*38*	*210*	6,112, 96	5.8 : 1
Vetlehagen 1	55	70	49,896	10 : 1
Vetlehagen 2	35	70	39,690	5 : 1
Bjorkehagen	70	70	101,351	1.8 : 1
Istad	45	210	106,029	3 : 1
Skjotebane	75	62.5	17,010	4.3 : 1
Norheim-Kyte	*No estimations made from observations*			

(Cutoff Stripping ratio based on June 1995 extraction costs per tonne of Nkr 93 or Nkr 250 m^3)

Preliminary economic assess ment of pit designs

The method of reserve estimation considers the tonnage of overburden that must be removed in order to extract a block of workable skifer of similar size, thus resulting in a Stripping Ratio. An appropriate batter angle is also taken into consideration. (Fig 33).

A given block of skifer 25m x 18.75m x 1m contains 468.75 cubic metres/ 1265.6 tonnes, of which approximately 70% is lost during extraction and processing methods. Thus to extract asuch a block 23m thick (29,108.8 tonnes) would cost Nkr 27,071,18 400.

So to extract a 23m thickness of skifer = 29,108.800 tonnes, which costs with no overburden at a rate of Nkr 93 per tonne, Nkr 27,07118.400

Stripping ratio = Tonnes of waste/tonnes of ore

or = tonnage of rock in pit - tonnage of ore(30% skifer recovery) / tonnage of ore

Mon quarry

Material	*Tonnage Factor*	*Tonnes*
Recovered skifer	2.7	6 112 96.07
Overburden	2.7	33 08 345.215
Waste skifer	2.7	2 61984
Waste	2.7	35 703 29.215
Stripping Ratio	=	**5.8 : 1**

The estimated stripping ratio is high, and would increase further as quarrying continued down dip. Estimates are based on excavation of the Mon pit for 38m down dip with a batter angle of 53 degrees. It is thought that the operation at Mon has a limited life-span using open-pit methods as they are now. Underground methods using large scale room and pillar techniques may be the only way to maintain extraction, leaving at the very least a 1m thick layer of skiffer at the roof of any mine for use as a stabilization base for roof-bolts to support the incompetant phyllitic rocks above. Further studies are required to fully assess the potential of underground mining techniques, in any case the recovery of skifer would be lower than an open-pit operation as such a substantial volume needs to be left as roof pillar supports.

Istad Quarry - area of low topographic relief and a moderate dip of 25 degrees.

Material	*Tonnage Factor*	*Tonnes*
Recoverable skifer	2.7	106,029
Overburden	2.7	276,804
Waste skifer	2.7	45,441
Waste	2.7	322,245
Stripping Ratio	=	3 : 1

The Istad Quarry represents one of the most cost-effective open-pit operations in the Voss area, the quarry is now waterfilled this being fed by swamps and marshes, but are drained by a man-made drainage canal. Istad has another feature of signifiacant economic importance, in that the overburden above the previously worked quarry contains another skifer horizon, thus further reducing the stripping ratio.

Vetlehagen Quarry - area of shallowing topographic relief to the north, thus accounting for the subdivsion of areas reflecting differing stripping ratios.

Material	*Tonnage Factor*	*Tonnes*	
		Zone 1	*Zone 2*
Recoverable skifer	2.7	49,896	39,690
Overburden	2.7	484,110	173,745
Waste skifer	2.7	21,384	17,010
Waste	2.7	505,494	190,755
Stripping ratio	=	**10 : 1**	**5 : 1**

Vetlehagen has a steady future, with operations likely to contine down-dip for a considerable distance until the quarry reaches a similar state as seen at the larger Mon quarry today.

Bjorkehagen

Material	*Tonnage Factor*	*Tonnes*
Recoverable skifer	2.7	101,351
Overburden	2.7	145,800
Waste skifer	2.7	43,436
Waste	2.7	189,236
Stripping ratio =	**1.8 : 1**	

The estimation given above is based on a hypothesised open-pit with a down-dip extension of 70m and strike length extension of 70m. An operation such as this would prove very economical, due to the lack of overburden, and general low relief in the area. Access may prove problematic due to the high cliffs directly below the old-working face.

Skjotebane

The following estimations are based on observed reserves, as the true vertical extent of the skifer horizon was not seen.

Material	*Tonnage Factor*	*Tonnes*
Recoverable skifer	2.7	17,010
Overburden	2.7	67,068
Waste skifer	2.7	7,290
Waste	-	74,358
Stripping ratio	=	**4.3 : 1**

Skjotebane requires much more detailed analysis, as vertical and lateral reserves are not fully appreciated at this time. Should reserves proove extensive, then this area should be considered carefully, as the skifer is of a quality unseen in the whole Voss area.

The methods of production in the skiffer quarries in the Voss region have changed little for over a century, extraction is by drilling and blasting producing irregular sized and shaped blocks resulting with a high percentage waste. Highly skilled craftsmen still split the blocks of skiffer by hand, but with a view to expansion, alternative methods of extraction and processing are now sought.

Comparisons of skiffer production has been made with several British slate producing operations, who have made significant efforts to modernize their extractive and processing techniques to improve production due to an upturn in interest for natural slate in roofing, flooring and cladding in recent years. These include two large operations Delabole Slate - part of the multinational RTZ company, and Penrhyn Quarries Ltd in North Wales, both quarrying slate of Devonian and Cambrian age respectively.

Penrhyn in particular are reaping the benefits of a major modernization programme where new production equipment has enabled the company to meet the resurgence in demand for natural slate. Modernization began in 1964 when £1.5 million was invested in quarry modernization and slate roofing production, also research was begun into alternative uses for natural slate. Development also included new automatic slate-splitting machines and other specialist machinery. The patented automatic slate splitting machine is currently disused as it fails to compete with traditional methods of splitting blocks by hand. A problem that both Penrhyn and Delabole quarries have faced is the high waste production. Only 2% of the quarried material becomes finished product, the rest is discarded during preparation of the quarried blocks for splitting. Furthermore, accumulated waste from historic workings amounts to 200 Million tonnes spread over 9 square kilometres of tips, and at current working rates, is increasing at 1 Mt/year. In 1964 Penrhyn tackled this problem by investing in potential new markets for slate, particularly granulated and powdered sales, which led to a fundamental diversification. It was found that both the physical and chemical propertied of slate powder enabled it to be used as a substitute for talc, mica and other chemically inert fillers, particularly where acid resistance was required. Together with its properties and lower costs in relation to talc and mica, it found ready markets in the manufacture of modified coal tar, pipe enamel, asphaltic products, plastics and resins, mastic adhesives and insulation products. Granulated slate was also found to have uses in the manufacture of mineralised coating of asphalt roll felt, strip shingles and concrete roof tiles.

Penrhyn recently replaced their outdated rope shovels with hydraulic excavators and have greatly improved productivity being more manoeuvrable. Another step in the mechanisation of the extraction process is the installation of machines to cut the slate in blocks from the face. Penrhyn bought their first purpose built, track mounted German 1.6m circular saw and are currently assessing the machine.

Delabole Slate has also modernised its extractive process through the use of diamond wire sawing in an attempt to reduce wastage of blocks, abandoning explosives as an attempt at creating a cleaner and safer working environment. Another benefit, is that different qualities of slate in the quarry can be extracted selectively and with great precision, yielding a higher recovery rate of high-integrity material. Delabole started diamond wire-sawing with an electric powdered machine in 1987. More recently, a more powerful Pellegrini TDU 100 diesel machine has been installed (Fig XXX). It was finally decided to abondon blasting altogether, the company now relying entirely on diamond wire and hydraulic splitter extraction methods.

Delabole have been using 40m lengths of Tiger wire from Van Moppes-IDP, (FigXXX) the wire is fitted with 10mm diameter Fast-Bite beads containing De Beers SDA85+ diamond of 40-50 US mesh size in a cobalt based bond. Forty beads are provided per metre, separated by VM-IDP's rubber compound. The wire is run at 30 m/s on the Pellegrini machine. Blocks of 300-450 tonnes are isolated from the working face, then hydraulic splitters separate the mass into smaller blocks along the slate's cleavage planes. These smaller 10 tonne blocks are then taken by lorry to the processing plant. The workshops have two Anderson-Grice multi-blade frame saws, a BM monoblade which is extensively used for primary sawing, a Thibaut polishing line and Jenny Lindtype polishers, and various cross-cut saws for edging.

Despite the introduction of block-squaring by diamond sawing, Penrhyn faced the problem of how to increase output and streamline production, in an industry that relies heavily on the human element. A new almost fully automatic combined primary and secondary sawing system was put in operation which enables fully-sawn blocks to be produced, ready for hand-splitting and dressing, with the minimum of loading and offloading.

Blocks which have been extracted from the quarry face are offloaded prior to splitting into a maximum thickness of around 400 mm to suit the saw blades. Previously this was done by hand

Fig XXX The Pellegrini diesel powdered diamond wire cutting machine.

but now with a mini-excavator equipped with an hydraulic pick attatchment is used (FigXXX). This is not only quicker, but also removes what was a potentially dangerous situation of having men working in close proximity to the movement of heavy plant machinery. Before the new sawing system was introduced, the slate blocks were first cut by primary saws, usually of 1600 mm diameter. They were then off-loaded and manually split into 150 mm maximum thickness before being reloaded onto the secondary sawing bay, where a triple 600 mm diameter unit cut them into finished blocks. The new system allows blocks of up to 3 m x 3 m x 400 mm thick to be squared into standard Imperial sizes of 21.5" x 13.5" or 25.5" x 13.5" with no interim off-loading or splitting. Furthermore, once the block is aligned for the initial primary cut, very little human judgement is required to assess the optimum cutting parameters. The computer-controlled primary and secondary sawing consoles do the job almost automatically.

Blocks are loaded onto a track roller which conveys them into the primary sawing bay, which consists of a Van Voorden Helios 5, 1600 mm diameter single-blade machine and a VanVoorden Helios 6 beam. A laser beam is used to ensure that the block is located accurately and sawing commences with the twin blades set at a constant 21.5" apart and the single blade set either 21.5" or 25.5" away from the twin blades, depending on the finished slate size required.

The single blade can be removed for a second cut so that the block can be into upto 5 sections ready for secondary cutting. The secondary cutters are two Van Voorden Helios 5, and is completely automatic once the block to be sawn passes a photoelectric cell linked to the microcomputer console, calculating the total length of the block. The first cut involves twin blades

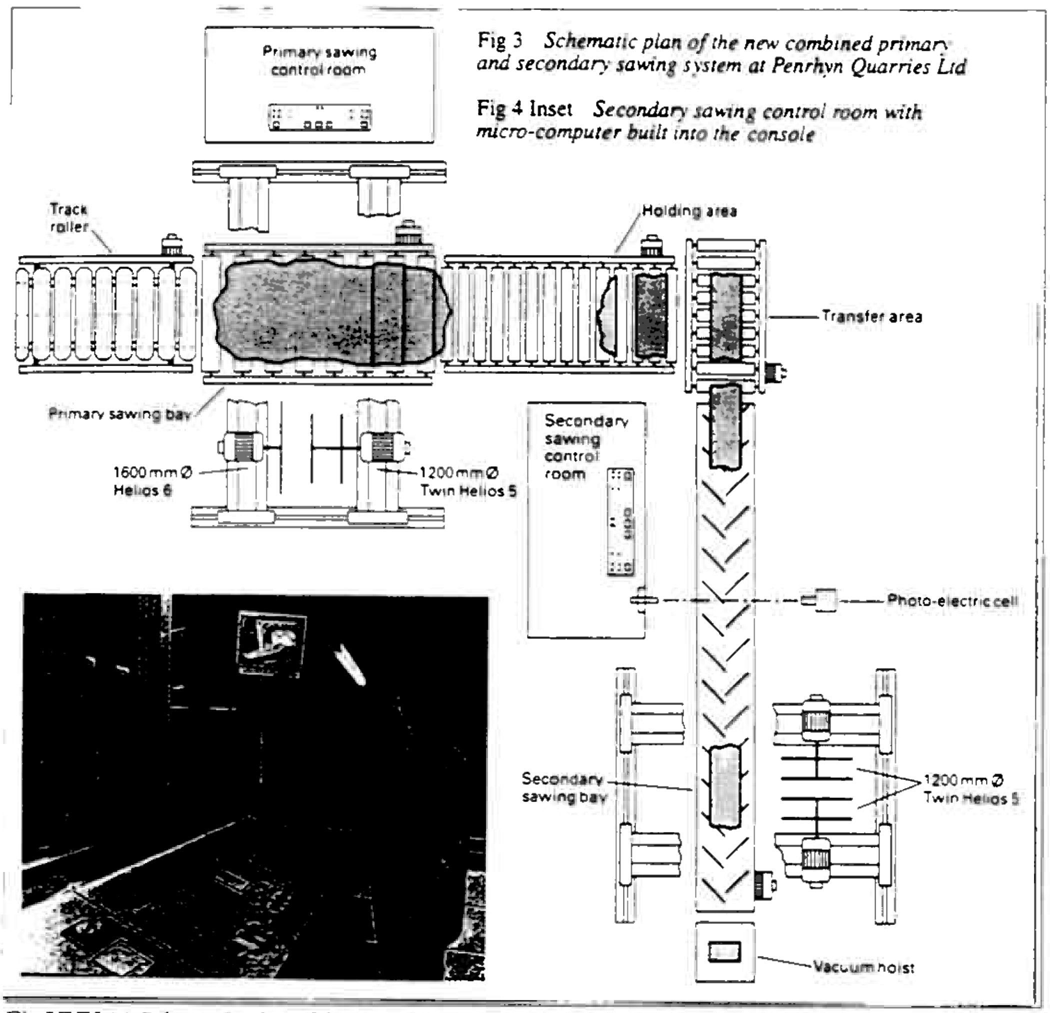
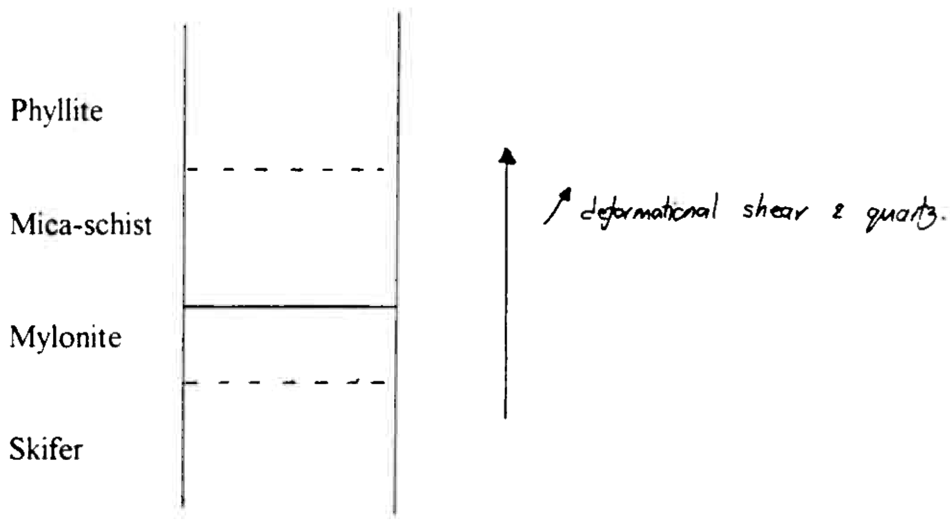


Fig XXX (a) Schematic plan of the combined primary and secondary sawig system at Penrhyn (b) Inset: Secondary sawing control room with micro-computer built into console.*Industrial Diamond Review* 3/88 pp.120 to 121.

traversing simultaneously to give three cut blocks and one piece of scrap. The computer now calculates how many more cuts are possible from the length of uncut block remaining and accordingly programs one or both twin blades to make another cut once the block has moved along the rollers. The blocks are then hoisted to the splitting and dressing area. Sixty bays are provided for splitting and dressing and there are usually 56 in operation. Each man splits the blocks by hand and then dresses to one of 26 sizes. Since the introduction of the new sawing system, Penrhyn has upped its production by about 40% to around 500 tonnes of roofing slates per week. It takes 2500 tonnes of quarried slate and 1250 tonnes of sawn slate to produce the 500 tonnes of slate roof tiles. Scrap blocks and other waste slate is crushed for a number of end uses,sub-bases and others listed above.

Field Identification of Skifer Horizons

Tectonostratigraphically, workable skifer horizons are typically found below decolement discontinuity (Figs 20 & 27), where rocks have suffered simple and extensional shear. Skifer represents competant material whereas the heavily sheared phyllite/mica schist represents a relatively incompatible unit.



Typical sequence through such an internal decolement zone.

Internal decolement zones/contacts may or may not possess an extensive phyllitic thrusting medium, thus these features may not easily be recognized in the field. In such situations, the characteristic D1 thrusting lineation seen on slip surfaces (cleavage planes), orientations of these intersection lineations vary from above and below a thrust zone, remaining constant within a particular skifer horizon. Detailed studies of the orientations of the intersections can reveal the position of decolement thrusts. Based on work at Norheim-Kyte.

In the field, skifer represents a compositionally homogeneous unit with no visible structures, except the occassional quartz-vein boudinage structures (stretched quartz-veins) and remanent fold hinges, that do not affect the quality of the skifer.

CONCLUSION

The aim of this report was to establish areas showing potential for skifer quarrying, identify geological factors that may be assigned to horizons of workable skifer, and to investigate the mining/quarrying and processing of slate/skifer in Great Britain in an attempt to suggest modernization of the currently employed methods at Voss Cementvarefabrikk. In addition to the surveys made in new areas, current operations such as Møn, Vetlehagen, and Norheim-Kyte were surveyed in order to assess their economic potential.

The new reserves identified by the author Bjorkhagen, Skjotebane, Istad, and those at or near the Mon-Vetlehagen operations have already been identified in previous chapters and it is hoped that development could arise from these preliminary surveys.

Voss Skiferbrudde A/S and the conglomerate skifer workers seem to be in somewhat of a dilema, as far as the future of skifer production in Voss is concerned, namely in the method of extraction and processing. Techniques have not changed for over a century as was the case in the British operations at Penryhn and Delabole but subsequent rationalisation involving initial expenditure of significant capitol resulted in competative large scale slate/skifer operations. The author feels that a smaller, yet similar rationalisation of operations could ensure an industrious future for the Voss skifer quarries. The Voss Skiferbrudde A/S factory at Norheim-Kyte could be used as a model for all future processing of skifer with similar factorys being constructed at Mon and Istad or at a central point recieving sawn blocks from several quarries, abondoning the traditional single man operations seen today, ready to be split in a fashion not dissimilar to that at the British Delabole operation, thus reducing the percentage recovery of skifer tiles from blocks, therefore increasing production per tonne extracted.

The importance of modenisation/rationalisation is furthermore in evidance in the subject of available skilled workers, particularly in the future, where it is unlikely that the quarries will see a young workforce replacing the current workforce. Automation as has been suggested would reduce the number of men needed in the extraction and initial splitting of skifer blocks to manageable sizes (but not drasticly!). It is noted that some workers produce skifer only as a part-time source of income.

The subject of mining or quarrying the skifer deposits as discussed earlier resulted in the conclusion that it will be more economical to quarry skiffer than mine it. This has important inplications for operations such as Mon with a relatively high stripping ratio which the author believes has a limited down-slope working life, as opposed to potential operation such as Istad, Bjorkehagen etc - areas of low stripping ratios and near horizontal strata. It must be appreciated that the fieldwork carried out in the summer of 1995 by the author centred significantly on the Mon-Vetlehagen quarries in order to establish the potential reserves between them, to (although purely academic) to discover the formational processes involved and to establish a framework for future studies by identifying the structural controls of workeable rocks - see previous chapters. Thus there is much potential for intensive additional studies at the suggested reserve areas, including the possibility of introducing diamond drilling on a large grid to establish the workability of skifer. Diamond drilling if done, must involve the production of large diameter samples for geological analysis and basic geotechnical engineering (0.15 m diameter samples). Again, the author hopes that Voss Cementvarefabrikk finds this report useful, or at the worst more useful than previous reports, and also the hope that the University of Wales, Cardiff can maintain a healthy relationship with the company for future student research.

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Useful addresses

In undertaking a project such as this in Norway, the following addresses in both the U.K. and Norway may prove useful.

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Report Copies

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Disclaimer

The author accepts no responsibility for any mining or quarrying development based on the information presented in this report. It must be emphasised that the work carried out by the author between the dates of 01.07.95 to 04.09.95 is purely a preliminary reconnaissance exploration project, and requires futher exploration surveys in support of any presented information.

Hugh P. Blethyn, Cardiff, Wales, 31.01.96

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