Amphibolites and Metagabbros from the Proterozoic Telemark Suite of Setesdalsheiene, South-central Norway

T. PRESTVIK & F.M. VOKES

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Proterozoic supracrustal rocks of the Telemark Suite, including large thickness of basic metavolcanites, occur as a large-scale isolated outlier within the older gneiss-migmatite-granite complex on the mountain plateau of Setesdalsheiene. Numerous and often large bodies of metagabbro occur mainly as concordant lenses, but may locally show intrusive relations to the supracrustals. Late Precambrian post-orogenic granites cross-cut all the other rock types.

Reviews are given of the lithostratigraphy and structure of the Telemark Supracrustals as a background for a more detailed study of the petrology of the basic meta-igneous rocks. Petrographical investigations of these rocks show that the amphibolites (metabasalts) are almost completely recrystallized, while the metagabbros have usually retained the outlines of primary hypidiomorphic plagioclase crystals. Mineral compositions and assemblages indicate that the area suffered metamorphism of uppermost low-grade conditions. Chemically the rocks are metabasalts of transitional tholeiitic/alkaline character. The geological environment and the chemical data indicate that the amphibolites and metagabbros originally were formed in a within-plate (continental) environment. These findings are compared with present-day tectonic regimes and with published plate tectonic models for southern Norway. It is suggested that the amphibolites represent rift volcanism in a subsiding basin not very far from a continental margin. The supracrustal rocks were deformed, metamorphosed and intruded by gabbro magmas during later adjacent orogenesis which was related to subduction and calc-alkaline volcanism.

Tore Prestvik & Frank M. Vokes, Geologisk Institutt, N-7034 Trondheim-NTH, Norway

Introduction

Supracrustal rocks considered to belong to the Precambrian Telemark Suite (Dons 1960, 1963; Sigmond 1978) occur as large outlier, in the form of a synclinorium, in the area of Setesdalsheiene, south-central Norway (Plate 1). The location and extent of the outlier is shown on the recently published 1:250 000 geological map-sheet Sauda (Sigmond 1975, 1978); it measures some 15 km by 10 km.

Geological investigations were carried out in parts of the area during the years 1965 to 1968 by F.M. Vokes and T. Vrålstad, centred on small copper-molybdenum and copper deposits lying in the area between Skyvatn and Langvatn (Plate 1). An account of the mineral exploration and deposit assessment methods employed in the Langvatn area has been given by Vokes et al. (1975).

During the course of the investigations, detailed mapping of the rocks in the area Skyvatn–Holmavatn–Mjåvatn was carried out at a scale of 1:12,500, in order to provide a geological framework for the investigation of the mineral deposits. The present report gives the results of the above geological field work and of subsequent studies carried out at Geologisk Institutt, NTH, Trondheim.

General geology

The area under consideration lies between Mjåvatn in the east and Sandvatn and Holmavatn in the west (Plate 1). It covers roughly 135 km² and represents the southwesterly two-thirds of the synclinorium mentioned in the introduction. The area is largely occupied by Precambrian supracrustal rocks probably correlatable with the Bandak Group of the central area of the Telemark Suite (Dons 1960, Sigmond 1978). The highest mountains of the area (Plate 1) are capped by parautochthonous to allochthonous Palaeozoic rocks comprising basal grits, phyllites, schists and gneisses (Sigmond 1978). These rocks will not be discussed in this paper.

The Telemark Suite rocks include metabasalts, with quartz-mica and calcareous schists, arenites, conglomerates and other clastic sedimentary rocks; and possibly also some units of originally acid volcanic rocks. Large masses of metagabbro occur, usually in the form of apparently concordant intrusions into the supracrustal units. The rocks underlying the Telemark Suite rocks, the Gneiss-Migmatite-Granite Complex of Sigmond (1978), were not investigated in the present study.

In the extreme north of the area mapped, along the shores of Holmavatn, there is a non-foliated granite showing irregular, intrusive contacts against the Telemark supracrustals and their intruding metagabbros. These outcrops appear to represent the southeastern margin of a very large granitic batholith which extends northwestwards towards the Folgefonna area, a distance of some 60 km. This granite is of Precambrian age, but is younger than the deformation and metamorphism of the Telemark supracrustals of the region. The possibility that this granite might be present at depth under the Langvatn area has relevance to discussions on the genesis of the Mo-Cu deposits there. Its likely presence is tentatively suggested in the vertical section, Fig. 1.

Telemark suite rocks

LITHOSTRATIGRAPHY

The present study has established a lithostratigraphy for the Precambrian supracrustal rocks of the Langvatn area, based on field observations and the structural interpretation shown in Fig. 1. The writers have adopted the formational names proposed by Sigmond (1978) for these rocks. A brief summary is given below, starting with the uppermost unit exposed.

5. *Svartepodd metasandstone.* Calcareous sandstones, generally shistose in the northeast; possibly tuffites. Amphibolite layers (metabasalts) in the southwest.
4. *Båstogvatn conglomerate.* Conglomerate with clasts of metabasalt. Much detrital epidote. An impersistent unit.
3. *Skurefjell metabasalts.* Metavolcanites. A unit of homogeneous, fine-grained and porphyritic ('speckled amphibolite') metabasalts.
2. *Skyvatn conglomerate.* Conglomerate with predominantly sedimentary clasts.
1. *Veggine formation.* Three members distinguished:

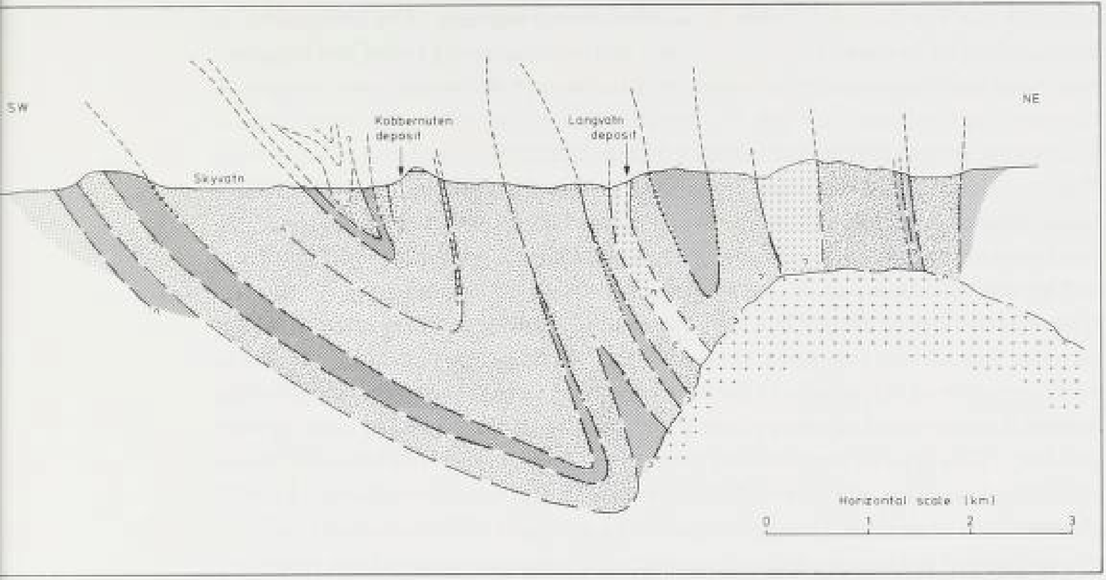


Fig. 1. Interpreted vertical section through the Kobbernuten and Langvatn deposits. Vertical relief not to scale. Legend as for map, Plate 1.

c) Mixed clastic sedimentary rock – metabasalt unit. Lithologies are either interbedded, or metabasalts occur as semiconcordant sills in sediments. Current-bedded sediments are abundant. Metagabbro layers in the south-east.

b) Homogeneous metabasaltic volcanites.

a) Mixed clastic sedimentary rock – metabasalt unit. Lithologies are either interbedded, or metabasalts occur as semiconcordant sills in sediments.

Metagabbros of varying field appearance and structural relations occur within all units.

The present account will deal mainly with aspects of the metabasalts of the Skurefjell and Veggine formations, and of the intrusive metagabbros of the area.

STRUCTURE

The supracrustal rocks of the Langvatn area, as well as the intrusive metagabbros, are strongly folded along NW-SE trending axes. The intensity of the folding increases in a north-easterly direction across the area. A line running NW-SE through Storheddervatn and Øydeskyvatn divides the area into two structurally distinct parts. Southwest of this line, the folding is less intense and the supracrustals are disposed in a single syncline with a slightly overturned NE limb (the Båstogvatn syncline). The rocks are little deformed and sedimentary structures, such as cross-bedding and graded bedding, are abundant in the clastic units.

Northeast of the Storheddervatn–Øydeskyvatn line the folding becomes isoclinal and an axial plane schistosity is prominent in the supracrustal rocks, especially in the belt immediately northeast of Langvatn. The differences in structural styles between the southwestern and northeastern parts of the Langvatn area have made correlation between the sedimentary units somewhat uncertain.

TELEMARK SUITE LITHOLOGY – FIELD OBSERVATIONS

The metavolcanite units (units 1b, and 3) can reach considerable thicknesses of homogeneous lithology (Plate 1). The Skurefjell metabasalts (unit 3 above), for example, are at least 100 m thick in the southwestern part of the area mapped.

The *metabasalts* are dark green massive to schistose amphibolites. Two main types can be distinguished. The rather more abundant of these is massive and has an even, fine to very fine grain size and occurs in units from a few decimetres to a few metres thick. Especially in the southwestern part of the area, this amphibolite variant is massive and in many places it is difficult to distinguish any layering with certainty. This type of amphibolite commonly shows a vesicular structure where possible amygdales are now filled with calcite, epidote and quartz. Another characteristic feature of this rock type is the presence of lens-shaped bodies of coarse-grained epidote, quartz ($\pm$ calcite) with maximum sizes of the order 1–2 metres. These lie parallel to the formational contacts of massive and schistose amphibolites. No obvious pillow structures were observed, although the above-described epidote-rich lenses may possibly represent altered pillows.

The second, less abundant, amphibolite type has a speckled or flecked appearance due to an abundance of lens-shaped spots, 2–5 mm in length, that are aligned parallel with the planar structure of the rock. These spots, consisting mainly of dark green amphibole, occur in a fine-grained, light green groundmass. The two types of amphibolite occur in intimate association. The units of speckled amphibolite are generally in the form of impersistent lenses from 10 to 100 m in lengt. The two types were not differentiated during the mapping of the area on 1:12,500 scale.

Metagabbros. These rocks vary in character from apparently fresh, massive, coarse-grained, equigranular metagabbros to foliated coarse- to medium-grained types.

The contact relationships shown by the metagabbros are somewhat variable. The majority take the form of large sill-like bodies and lenses intruded into the metavolcanic and sedimentary rocks more or less parallell to their original layering or bedding. In the northeastern part of the area, however, where the folding is tight to isoclinal, and where axial plane schistosity is developed in the supracrustal rocks, the possibility exists that some of metagabbros may have been emplaced parallel to this schistosity and may cross-cut the layering of the rocks at depth. If so, there are two episodes of gabbro emplacement.

A particularly large mass of metagabbro present in the area southeast of Storhedderfjell shows cross-cutting relationships and a chilled margin against the surrounding supracrustal rocks of the Svartepoddvatn metasandstone formation. These relations are best seen in the area between Skyvatn and Storheddervatn (Plate 1), where the intrusion of the gabbro produced a considerable disturbance of its country rocks. The layering in the supracrustals is partly overturned, while a large raft of amphibolites and fine-grained metasediments lies structurally above, and is partly enclosed by, the gabbro. This is interpreted as part of the core of the Båstogvatn syncline which was lifted up from the underlying rocks due to the forcible intrusion of the gabbro. The layering in the supracrustals has been torn apart, and fingers and xenoliths of these rocks can be found along the margins of the metagabbro body. Similar effects can be seen west of Mjåvatn in the extreme southeast of the mapped area, where large lenticular bodies of metagabbro occur parallel to the layering of the supracrustal rocks and finger out into these in both directions along the strike. Such relationships indicate that much of the gabbro intrusion occurred either simultaneously with the folding of the supracrustal rocks or subsequently to this.

Petrology of the basic rocks

About ninety thin-sections and polished sections of volcanic rocks and metagabbros have been examined. Plagioclase (18) and amphibole (18) compositions were determined using the automatic ARL microprobe at the Institutt for Røntgenteknikk, University of Trondheim-NTH. Furthermore, selected samples of volcanic rocks (17) and metagabbros (8) were analysed for major and selected trace elements.

PETROGRAPHY

Volcanic rocks (amphibolites). Primary textures are usually obliterated. Only in one sample has a porphyrite-like texture been observed, and possible amygdales were found in rocks from only a few outcrops. The present metamorphic mineral assemblages are characterized by a texture where amphibole porphyroblasts occur in a 'matrix' of more fine-grained, granoblastic and commonly untwinned plagioclase. In the speckled amphibolites the amphibole crystals are quite large (up to 5 mm) or consist of many smaller grains clustered together, thus giving the characteristic speckled appearance. The main minerals are plagioclase, amphibole, chlorite and epidote with subordinate biotite, rutile, calcite, sericite and opaque minerals. Apatite has not been observed. Albite, quartz, chlorite, epidote and calcite are the principal minerals in secondary veins and in amygdales. The plagioclase is a basic oligoclase (An 22–26.5), except in one sample (LV 176) where andesine (An 35) was found. The amphibole is usually homogeneous and transitional between actinolite and pargasite/ferropargasite in composition (Fig. 2). However, in a few cases a zoned amphibole with a core of actinolite is found. The common amphibole seems to be in a equilibrium relations with green chlorite. The opaques comprise ilmenite with hœmatite lamellae, pyrite, and subordinate chalcopyrite.

Systematic variations in petrographic characteristics have not been recorded within or between the two main volcanic units. The textural differences between the massive and speckled varieties of amphibolite are not easily understood. A tentative explanation is that they may reflect different conditions for mineral growth during metamorphic recrystallization.

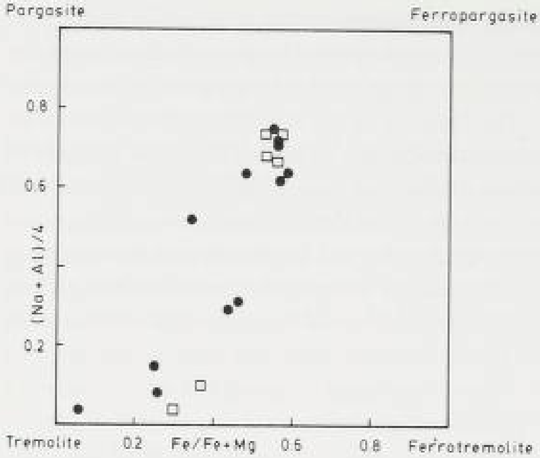


Fig. 2. Distribution of Langvatn amphiboles in the composition range: tremolite-ferrotremolite-pargasite-ferropargasite. □ = from metagabbros, ● = from amphibolites.

Metagabbro. This rock type is medium- to coarse-grained. Primary textural features such as hypidiomorphic plagioclase crystals are commonly preserved; however, incipient recrystallization of plagioclase is prominent in some samples. In these cases the minerals usually form equidimensional grains with typical granoblastic texture similar to that found in the amphibolites. The plagioclase is now a basic oligoclase (An 23.5 – An 30) and is always saussuritized. The number of small epidote grains is greatest in the central parts of the plagioclase crystals indicating original normal zoning. The amphibole is sometimes poikiloblastic with abundant quartz inclusions. In one sample an amphibole crystal probably is a pseudomorph after pyroxene. Some of the amphiboles are zoned with a core of pale actinolite and a pleochroic yellow-green to blue-green rim of hornblende. The common, homogeneous amphibole is of the latter type. In many samples there is abundant apatite in grains up to 2 mm in size. Other minerals are green chlorite, olive-brown biotite, epidote, sericite and opaques. When chlorite occurs, it seems to be in equilibrium relations with amphibole. The principal opaque mineral is ilmenite, which characteristically has exolved hœmatite lamellae. Magnetite and sulphides (pyrite, chalcopyrite and pyrrhotite) are subordinate phases in most samples. The biotite is commonly associated with ilmenite and its brownish colour is probably due to a relatively high Ti/Fe ratio. Epidote and sericite are breakdown products of plagioclase. Accessory minerals are quartz, calcite and sphene.

METAMORPHIC GRADE

Some of the minerals present in the metamorphic basic rocks from Langvatn may be used to infer the metamorphic grade. According to Winkler (1974) the transition from actinolite to hornblende and the coexistence of oligoclase (An $>$17) and hornblende is typical in the upper part of low-grade metamorphism. The appearance of oligoclase (An 17) is estimated to take place 20°–40°C lower than the transition between low-grade and medium-grade metamorphism. The slightly higher An-content of the Langvatn plagioclases thus indicates a somewhat higher metamorphic grade. However, Winkler (1974, p. 165) further states that

Table 1. Major element and CIPW-norm compositions of amphibolites and metagabbros from Langvatn

	AMPHIBOLITE																	METAGABBRO							
		UNIT 1b										UNIT 3					UNIT 5								
	LV1	LV2	LV40	LV140	LV143	LV193	LV11	LV12	LV20	LV44	LV46	LV98	LV109	LV113	LV116	LV122	LV86	LV15	LV51	LV75	LV80	LV89	LV108	LV110	LV161
SiO_2	45,18	43,63	46,27	44,59	43,75	46,39	47,14	45,79	45,44	46,68	43,67	49,79	44,79	45,24	44,29	48,12	44,94	46,04	44,64	44,92	45,85	44,40	42,90	45,37	42,87
TiO_2	2,95	1,26	2,33	3,70	2,33	1,95	2,90	1,39	2,87	1,15	3,03	2,25	1,60	1,11	1,39	1,40	3,02	1,20	2,95	1,83	2,95	2,76	3,90	2,56	3,93
Al_2O_3	15,76	15,35	15,33	15,09	16,99	16,79	16,02	16,64	15,91	9,78	16,25	15,68	16,71	17,80	17,32	16,31	15,44	17,13	18,30	18,47	16,66	15,62	16,00	17,28	15,73
Fe_2O_3	5,44	4,54	4,31	3,76	3,18	4,81	2,30	7,08	4,16	5,01	4,72	5,03	2,51	3,38	5,13	4,51	9,59	3,36	2,98	1,80	2,02	2,48	2,78	2,35	2,64
FeO	9,60	7,71	9,03	10,91	10,43	8,61	10,62	5,13	10,67	5,21	9,86	7,72	10,74	7,93	7,15	7,80	6,22	7,48	9,64	9,73	10,30	11,07	13,97	10,66	12,69
MnO	0,23	0,23	0,17	0,19	0,26	0,23	0,17	0,13	0,25	0,23	0,23	0,19	0,23	0,21	0,22	0,18	0,22	0,19	0,17	0,17	0,16	0,16	0,24	0,15	0,16
MgO	6,10	9,20	7,86	6,30	7,39	7,35	5,95	7,51	6,28	12,13	8,28	5,20	9,53	8,83	8,37	7,11	6,64	7,73	6,58	8,08	6,74	8,10	5,86	7,63	6,79
CaO	9,24	10,44	9,67	7,33	8,79	9,69	8,53	10,25	9,15	15,69	7,24	8,89	8,58	9,89	8,43	9,57	6,85	9,74	8,50	8,29	7,52	8,23	8,45	8,68	7,61
Na_2O	2,77	4,35	4,20	2,53	3,07	2,25	2,50	3,09	2,79	2,09	3,35	3,36	2,84	2,91	2,80	2,98	2,68	2,84	2,28	3,10	2,98	3,28	2,51	2,43	2,59
K_2O	0,60	0,29	0,18	0,22	0,42	0,11	0,85	0,64	0,55	0,09	1,00	0,34	0,33	0,32	–	0,67	0,35	0,97	0,67	0,75	0,42	0,81	0,93	0,80	0,47
P_2O_5	0,20	0,12	0,29	0,59	0,17	0,13	0,48	0,13	0,20	0,05	0,22	0,17	0,12	0,06	0,12	0,19	0,41	0,08	0,29	0,18	0,47	0,61	0,45	0,41	0,33
H_2O^+	1,93	1,74	1,36	3,22	2,82	1,59	0,94	1,27	1,78	1,18	2,53	1,13	2,85	2,32	3,47	1,22	2,03	1,67	2,44	2,26	2,45	2,06	1,69	1,75	2,55
H_2O^-	0,04	0,08	0,10	0,10	0,02	0,01	0,14	0,13	0,04	0,07	0,07	0,03	0,08	0,02	0,09	0,08	0,08	0,10	0,10	0,10	0,12	0,08	0,03	0,07	0,08
CO_2	0,07	–	–	0,32	0,04	0,16	0,04	0,20	0,01	0,12	–	0,01	0,04	0,05	0,32	0,12	0,12	0,04	0,04	0,05	0,20	–	0,02	0,40	0,14
Total	100,11	98,94	101,10	98,86	99,66	100,07	98,57	99,38	100,10	99,48	100,43	99,97	100,95	100,07	98,81	100,26	98,58	98,57	99,58	99,73	98,84	99,66	99,73	100,54	98,56
Q	–	–	–	3,3	–	–	2,0	–	–	–	–	1,9	–	–	–	–	–	–	–	–	–	–	–	–	–
Or	3,5	1,7	1,1	1,3	2,5	0,7	5,0	3,8	3,3	0,5	5,9	2,0	2,0	1,9	–	4,0	2,1	5,7	4,0	4,4	2,5	4,8	5,5	4,7	2,8
Ab	23,4	11,7	25,7	21,4	24,0	19,0	21,2	21,9	23,6	9,4	23,8	28,4	23,7	21,0	23,7	25,2	22,7	21,4	19,3	24,5	25,2	26,2	21,2	20,6	21,9
An	28,8	21,5	22,5	29,2	31,3	35,4	30,0	29,7	29,3	17,0	26,4	26,7	31,9	34,6	34,7	29,2	29,1	31,4	37,7	34,3	30,8	25,5	29,7	33,9	29,9
Ne	–	13,6	5,3	–	1,1	–	–	2,3	–	4,5	2,4	–	0,2	2,0	–	–	–	1,4	–	0,9	–	0,8	–	–	–
Cpx	12,5	24,0	19,2	1,0	8,8	8,9	9,2	15,6	12,1	47,9	6,5	13,3	7,9	11,2	3,5	13,3	1,2	13,3	1,8	4,3	1,7	9,2	7,6	3,2	3,8
Opx	8,5	–	–	22,7	–	21,4	19,2	–	9,0	–	–	16,2	–	–	9,3	8,1	27,4	–	18,8	–	22,6	–	7,8	16,0	16,8
Ol	8,5	17,8	15,2	–	18,6	3,7	–	16,8	8,8	12,3	20,0	–	24,6	20,9	16,3	11,4	–	17,2	2,6	20,2	–	18,3	10,2	7,9	4,5
Mt	6,5	4,0	5,6	7,5	5,6	5,0	6,4	4,2	6,3	3,8	6,6	5,4	4,5	3,8	4,2	4,2	6,6	3,9	6,5	4,8	6,5	6,2	4,8	5,9	7,9
Il	5,6	2,4	4,4	7,0	4,4	3,7	5,5	2,6	5,5	2,2	5,8	4,3	3,0	2,1	2,6	2,7	5,7	2,3	5,6	3,5	5,6	5,2	7,4	4,9	7,5
Ap	0,5	0,3	0,7	1,4	0,4	0,3	1,1	0,3	0,5	0,1	0,5	0,4	0,3	0,1	0,3	0,5	1,0	0,2	0,7	0,4	1,1	1,4	1,1	1,0	0,8
Cc	0,2	–	–	0,7	0,1	0,4	0,1	0,5	–	0,3	–	–	0,1	0,1	0,7	0,3	0,3	0,1	0,1	0,1	0,5	–	–	0,9	0,3
H_2O^+	1,9	1,7	1,4	3,2	2,8	1,6	0,9	1,3	1,8	1,2	2,5	1,1	2,8	2,3	1,2	1,2	2,0	1,7	2,4	2,3	2,4	2,1	1,7	1,8	2,6

Analysts: P.R. Graff, NGU (LV1, LV20, LV46, LV51, LV75, LV98, LV108, LV113, LV143, LV193)
I. Rømme & I. Vokes, NTH (LV2, LV11, LV12, LV15, LV40, LV44, LV80, LV86, LV89, LV109, LV110, LV116, LV122, LV140, LV161).

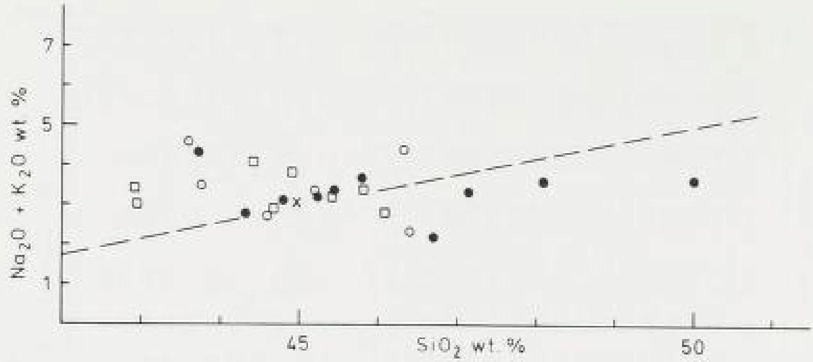


Fig. 3. Alkalis versus silica plot of Langvatn rocks. Dividing line after Irvine & Baragar (1971). □ = metagabbros, ● = amphibolites of units 1b & 3, x = amphibolite of unit 5.

«the presence of chlorite in the paragenesis is diagnostic of low grade». The parageneses of the Langvatn rocks thus formed under upper low-grade metamorphism very close to the transition to medium-grade.

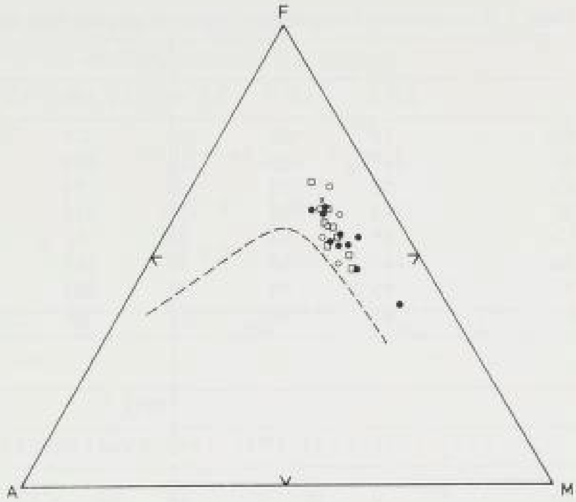
The actinolitic cores of amphiboles of the metagabbros and in a few amphibolites might indicate that the rocks were metamorphosed under other conditions previously. The significance of this feature however, is not easily understood since actinolite may exist both in low-grade (Winkler 1974) and in medium-grade metamorphism (Miyashiro et al. 1971). One possible explanation is that these zoned amphiboles represent uralitized clinopyroxenes in which equilibrium relations were not attained during the metamorphism. The low-Al actinolitic cores, then, may represent more closely the original clinopyroxene composition, whereas the outer hornblende rims may reflect the actual metamorphic conditions.

These findings correspond well with the general conclusion of Sigmond (1978) who found that supracrustal rocks of the Telemark Suite in the Sæsvatn – Valldal area have been subjected to conditions corresponding to the transition between low- and medium-grade metamorphism. The interpretation that abundant chlorite represents a later low-grade retrogradation (Sigmond 1978) is, however, not supported by the present investigation. In that case one would also have expected some adjustments of the plagioclase composition.

CHEMISTRY

Major and trace element data for the analysed rocks are presented in Tables 1 and 2. The major element chemistry (Table 1) is 'basaltic' for rocks of all units. A general feature is the quite low silica content. The rather broad variation of TiO_2 displayed by all groups of rocks is probably a result of some kind of fractionation or accumulation process. K_2O also shows considerable variation, but this may, at least partly, be a result of secondary processes. However, the rather high TiO_2 and K_2O values found in many of the rocks are typical of basalts from plateau lavas, from some oceanic islands and from anomalous oceanic ridge segments (Wood et al. 1979). In the alkalis-silica diagram (Fig. 3) the rocks straddle the division line between the alkaline and subalkaline (tholeiitic) fields. Molecular norms vary

Fig. 4. AFM diagram. Dividing line after Irvine & Baragar (1971). Symbols as in Fig. 3.



from slightly ne-normative via ol + hy-normative varieties to slightly q-normative (Table 1). Both these methods of classifying rock types are, however, sensitive to secondary processes and may thus not be conclusive as to the original chemical affinity. In the AFM diagram (Fig. 4) the samples plot within the area of alkaline and tholeiitic rocks.

Trace element data are presented in Table 2 and in variation diagrams (Fig. 5). The variation patterns of Ni, Cr, Y, P_2O_5, K_2O and TiO_2 versus Zr do not show significant separate trends for any of the groups of rocks. The metagabbros have a much higher Sr mean value than the amphibolites (Table 2), but this is probably an effect of plagioclase accumulation because the highest Sr contents are found in samples especially rich in Al_2O_3 (Tables 1 & 2). The more incompatible (and immobile) elements P_2O_5, TiO_2 and Y show semi-linear trends with Zr. This feature indicates that a certain range of fractionation is represented or that the rocks represent magmas formed as a result of various degrees of partial melting of a mantle source which was homogeneous for these elements. The irregular groupings of Ni, Cr, Sr and K_2O may perhaps represent primary features, but are more likely of secondary origin because these elements are generally thought to be rather mobile during alteration and metamorphism (Pearce 1976).

In the Zr-Ti-Y diagram (Fig. 6) most of the Langvatn rocks plot in the fields of within-plate basalt and ocean-floor basalt. The Zr-Ti-Y diagram does not always successfully discriminate between the tectonic setting of basaltic rocks (Prestvik 1982). It was found, e.g., that Upper Miocene plateau basalts in Northern Spitsbergen (Prestvik 1978), just as the Langvatn rocks, plotted in the same two fields of the Zr-Ti-Y diagram. Based on this similarity, the fact that no geological features indicate that the amphibolites (or metagabbros) of the Langvatn area represent an oceanic environment, and other geochemical/geological features referred to above, it may be concluded that the Langvatn rocks are of transitional tholeiitic/alkaline character and were formed in a within-plate (continental) environment.

Table 2. Trace-element compositions (ppm) of amphibolites and metagabbros from Langvatn

	UNIT 1b						
	LV 1	LV 2	LV 40	LV 140	LV 143	LV 193	Mean Unit 1b
Rb	28	<5	<5	<5	12	<10	–
Sr	225	199	218	303	185	198	221
Y	52	25	46	74	47	35	46.5
Zr	218	23	156	243	185	112	156
Cu	35	32	55	59	12	34	38
Zn	147	36	55	186	110	103	106
Ni	45	44	35	103	–	70	49.5
Cr	85	99	157	99	143	119	117

	UNIT 3											UNIT 5
	LV11	LV12	LV20	LV44	LV46	LV98	LV109	LV113	LV116	LV122	Mean Unit 3	LV86
Rb	5	9	19	<5	19	11	<5	17	<5	25	–	<5
Sr	336	269	210	239	123	288	241	220	223	243	239	289
Y	50	27	54	27	56	45	24	27	17	18	34.5	42
Zr	224	64	225	64	246	182	41	66	76	97	128.5	174
Cu	66	24	37	16	15	34	19	17	63	205	49.5	31
Zn	15	43	138	8	176	114	73	88	149	39	84	86
Ni	81	91	51	39	58	47	62	115	98	91	73	82
Cr	39	67	88	39	116	80	39	141	98	99	80.5	39

	META GABBRO								
	LV 15	LV 51	LV 75	LV 80	LV 89	LV 108	LV 110	LV 161	Mean Gabbro
Rb	6	25	23	<5	<5	30	9	<5	–
Sr	191	435	405	348	287	250	406	272	324
Y	31	43	30	34	38	65	39	28	38.5
Zr	65	218	132	186	205	340	151	155	181.5
Cu	35	17	21	43	31	66	39	67	40
Zn	42	135	118	82	55	143	82	137	99
Ni	61	106	150	109	71	44	94	102	92
Cr	38	149	159	124	98	18	67	67	90

Analysts: J. Sandvik, I. Rømme & I. Vokes, NTH [Rb, Sr, Y, Zr, (XRF); Cu, Zn, Ni, Cr (AAS)]
G. Faye & M. Ødegård, NGU [Ni, Cr (XRF)]

Discussion

If the Langvatn amphibolites (and younger metagabbros) are continental, in what kind of geological setting did they form? The sedimentary rocks of the area do not conclusively point to a continental milieu, but the alternation between quartzites, conglomerates and volcanic rocks together with calcareous sandstones, often cross-bedded, is a strong indication that the rocks were deposited in a shallow water, marine environment, possibly in an intracratonic basin. On the other hand, the lack of obvious pillow structures in the amphibolites may indicate that these were erupted as subaerial flows.

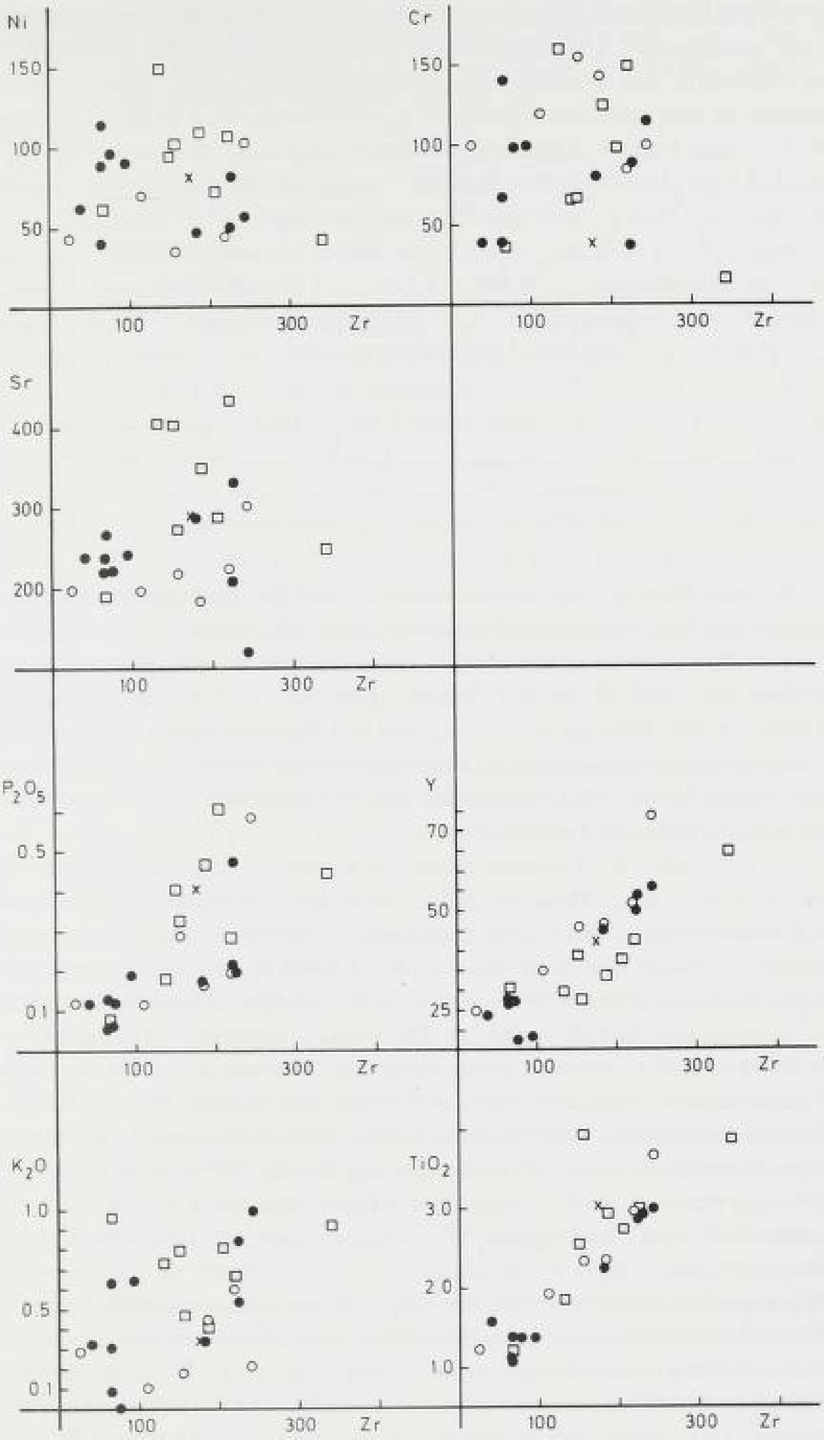


Fig. 5. Minor and trace elements of Langvatn rocks plotted against Zr. Symbols as in Fig. 3.

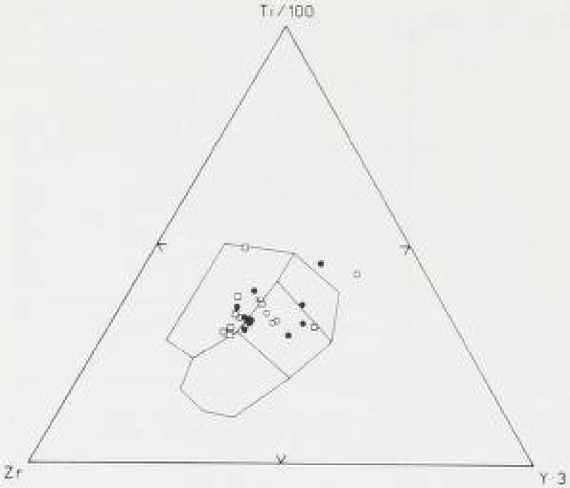


Fig. 6. Discrimination diagram using Ti, Zr and Y. (After Pearce & Cann 1973.)

In southern Norway, supracrustal rocks of about the same type as those in the Langvatn area occur in central Telemark (Dons 1960) and on the Folgefonna peninsula (Kvale 1945) as well as in some areas within the Sauda (1:250,000) map-sheet (Sigmond 1975). In Telemark, three groups have been distinguished, and basic volcanic rocks occur in the Rjukan and Bandak Groups. Quartzites and quartzite conglomerates occur in all the groups but are predominant in the Seljord Group. Singh (1968, 1969) concluded that the quartzites were deposited in a shallow sea to intertidal flat environment.

Moine & Ploquin (1972) made a geochemical study of the rocks of the Telemark supracrustal rock suite. Their conclusions were that the volcanics of the Rjukan Group indicate a thick sialic crust in the area at the time of deposition and that the basaltic rocks of this group show a partial trend of iron enrichment and are probably tholeiitic in origin. The rocks of the Rjukan Group were thought to have been contaminated by sialic material. The volcanic rocks of the Bandak Group were found to have a chemical development similar to that of the Rjukan Group, and these authors suggested that the Rjukan and Bandak Groups could be equivalents. More recent work, however, indicates that there are evident differences between the volcanic rocks of the Rjukan and Bandak Groups (Sigmond, oral communication) and that metabasalt/sandstone sequences west of the main Telemark Suite area, the Langvatn lithologies included, are best correlated with the Bandak Group (Sigmond 1978).

Lithologies similar to those in the Langvatn area occur some 30 km to the south-southwest in the Nesflaten–Grjotdokki area where they pre-date a thick succession of meta-andesitic and related rocks (Sigmond 1978). Furthermore, Naterstad et al. (1973) reported supracrustal rocks from Valldalen, 30–40 km northwest of Langvatn, and interpreted them as equivalents to the Telemark supracrustals. The lithologies described by these authors resemble those from Langvatn, and they include both metavolcanites, conglomerates and intrusive gabbros. In fact, Sigmond (1978) correlates the rocks from the Langvatn and Valldalen areas directly. However, no chemical data have been reported for the Valldalen rocks. The Langvatn, Nesflaten–Grjotdokki and Valldalen areas (Sigmond 1978) all have abundant basic volcanics correlatable with the continental Bandak Group; but only in the Nesflaten–Grjotdokki area are these rocks (the Blåbergås Group) overlain by typical orogenic meta-andesites, the Heddevatn Group (Sigmond 1978). However, the time relations between the large-scale continental volcanism and the formation of the calc-alkaline meta-andesites are not quite clear. According to Sigmond (1978) the meta-andesites are clearly younger than the basic volcanic rocks, but no unconformity or change in metamorphic grade is found between the Blåbergås and Heddevatn Groups. This indicates a more or less continuous deposition.

The vast outpouring of mainly basic volcanic rocks in a continental environment (Langvatn) was most probably related to a tensional or rifting episode (Baker et al. 1978). On the other hand, orogenic volcanism (Heddevatn Group) is probably connected with a compressive stress regime along a continental margin. A principle question is: do such different stress patterns occur more or less simultaneously in a restricted area, or could the tectonic relations be of another kind than indicated here? If the answer to the first question is *no*, it implies that the stage of tension or rifting preceded the compressive regime produsing the orogenic volcanism. Even thouth no unconformable relations are found between the Blåbergås and Heddevatn Groups, Sigmond (1978) mentions that the two groups represent well-defined and separate sedimentological and volcanological environments. This observation in itself indicates that a break between the deposition of the two groups is not unlikely. On the other hand, the answer may be *yes*, because there are well-known examples of more or less simultaneous continental and orogenic volcanism. The Patagonian plateau of South America, e.g., formed in a kind of continental back-arc environment behind the already active orogenic Andes Range (Baker et al. 1981). In the U.S.A. the Columbia River Basalts formed in a complicated structural situation (Hooper & Camp 1981) very close to the simultaneously active orogenic Cascade Range (Prestvik & Goles, in prep).

Even though most traces of original tectonic features in the Langvatn and surrounding areas are now obliterated, the features and similarities referred to above seem to support the view that this area of southern Norway developed rather close to an active continental margin where also orogenic volcanism took place.

Several models for the plate tectonic evolution of the Proterozoic of southern Norway have been proposed. Torske (1977) proposed an arcuate zonation with an *Interior Province* comprising the Telemark Suite, a *Central Belt* with gneisses and granitoid plutons and subordinate calc-alkaline volcanics, and a *Marginal Zone* where the volcanism was inferred to be of theoleiitic type. Falkum & Petersen (1980) suggested that the Telemark Suite rocks formed in epicratonic basins reflecting tensional stresses slightly before subduction and orogenic magmatism started along the continental margin. Furthermore, Berthelsen (1980) presented a model (which concentrated on the more easternmost segments of the Sveconorwegides), where he mentioned that the deposition of the Telemark supracrustals preceeded orogenesis related to eastward subduction west of the Rogaland–Agder area.

It is not the aim of this report to discuss the large-scale tectonic picture of the Late Proterozoic in southern Norway. It may be stated, however, that the conclusions reached above concerning the formation and environment of the rocks of the Langvatn area are in relatively good agreement with (at least, not in serious conflict with) all the plate-tectonic models referred to above. The Langvatn supracrustals were probably folded and metamorphosed during the period of orogenesis that was much stronger closer to the continental margin. The intrusive gabbros were probably emplaced during and partly after the main phase of this type of activity.

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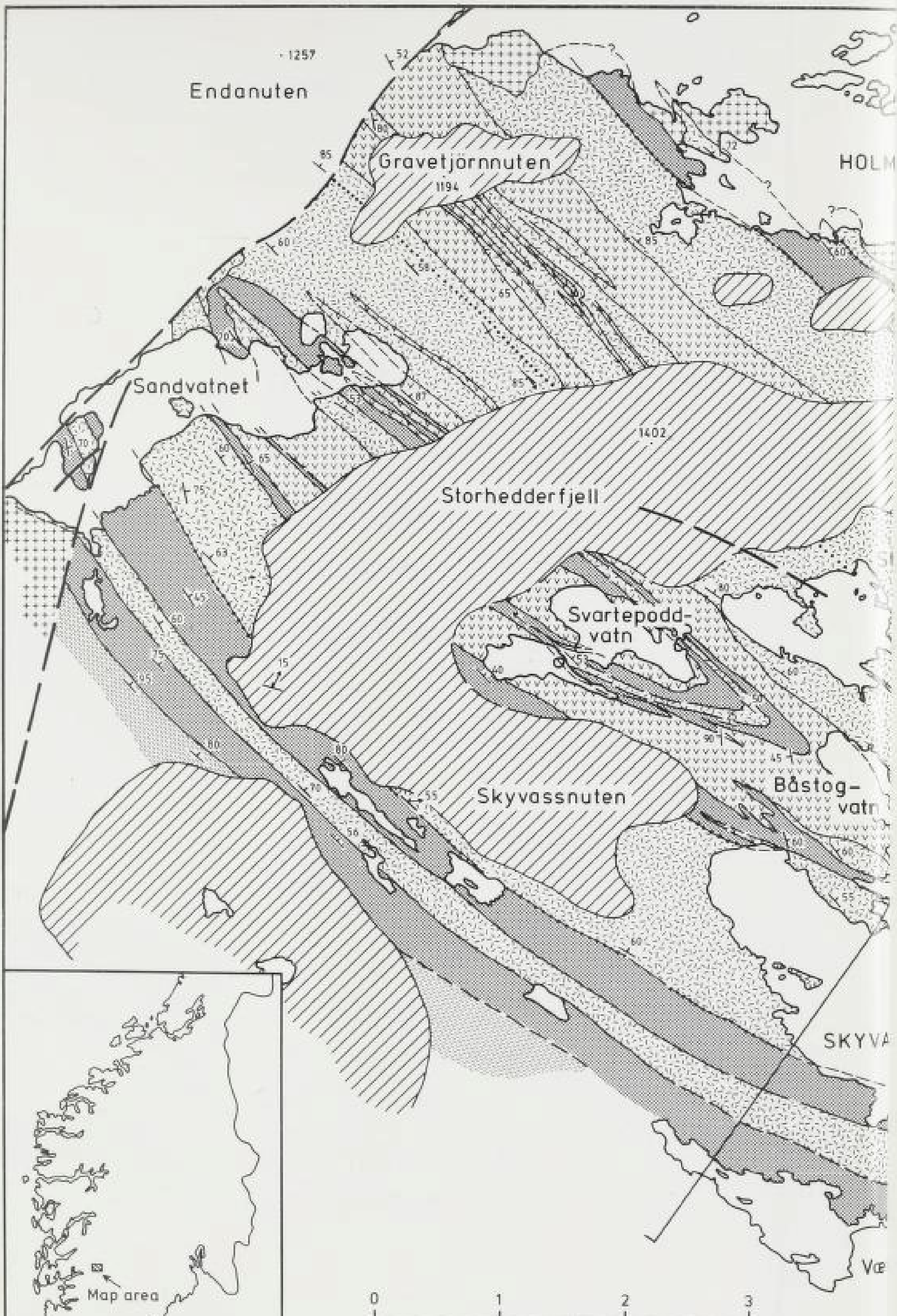

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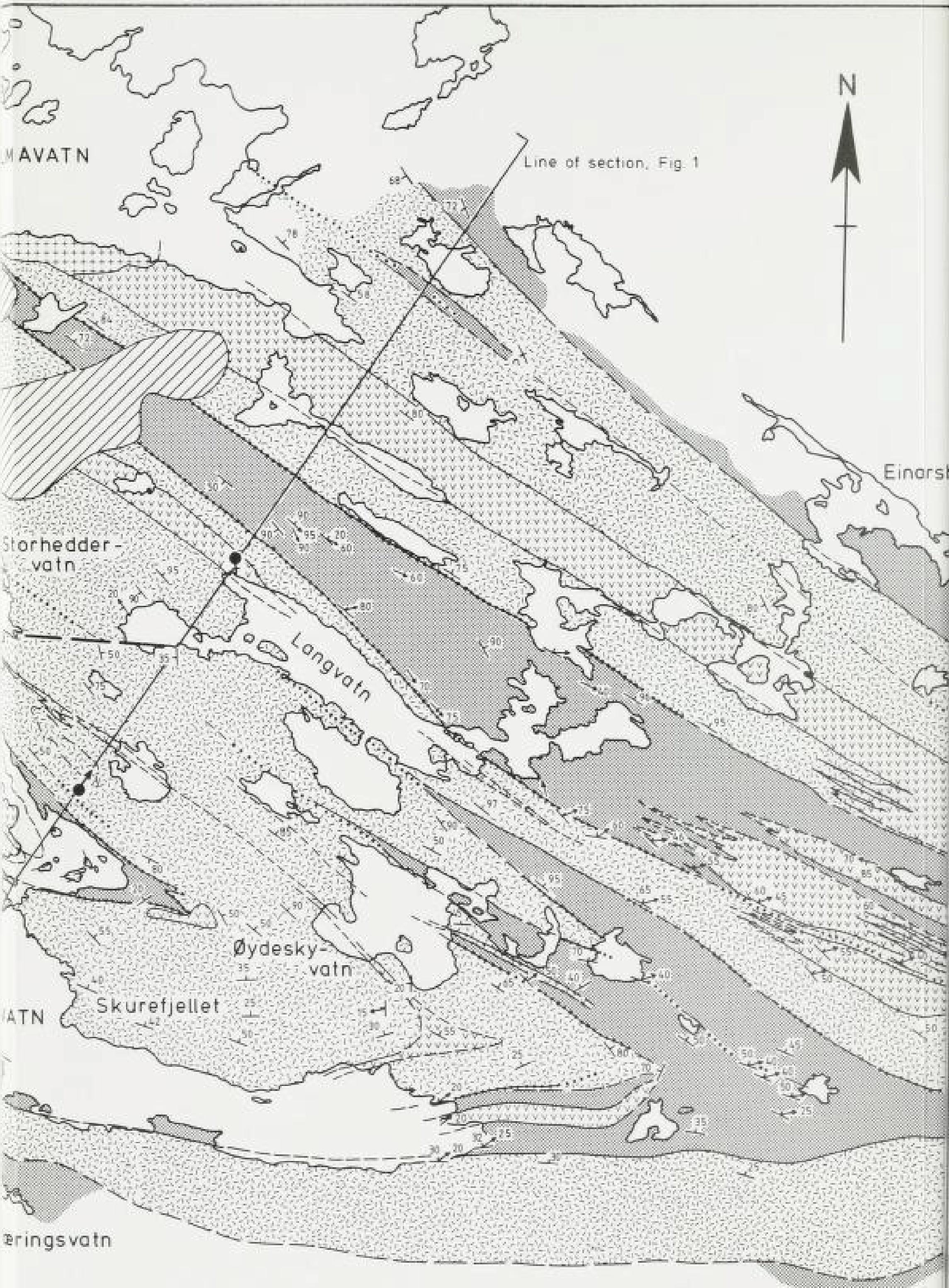
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GEOLOGICAL MAP OF A PART OF SETESDALSHEIENE, SOUTH-CENTRAL NORWAY

Mapped 1965 - 1968 : F. M. Vokes, T. Vrålstad

LEGEND

PALAEOZOIC ROCKS, autochthonous/allochthonous

- Phyllite and micaschist

PRECAMBRIAN ROCKS

Intrusive rocks

- Late or postorogenic granite
- Metagabbro
- Dolerite

Supracrustal rocks of the Telemark Suite

- Amphibolite (metabasalt)
- Mainly clastic sedimentary rocks and/or metavolcanic rocks
- Conglomerate horizons

Precambrian rocks below the Telemark Suite

- Gneiss, migmatite and various igneous rocks

- Strike and dip of planar structures vertical / inclined
- Direction and plunge of linear structures
- Fault trace
- Langvatn Cu - Mo deposit
- Kobbernuten Cu deposit

F.M.V. -82

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