Geology of the Røssjøkollan—Dokkvatn Area, Oppland

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Nickelsen, R. P. 1974: Geology of the Røssjøkollan–Dokkvatn area, Oppland. *Norges geol. Unders. 314*, 53–99.

The Røssjøkollan–Dokkvatn area at the eastern edge of Valdres Sparagmite exposures is comprised of a number of allochthonous litho-tectonic units in which Precambrian Jotun basement, and Late Precambrian or Eocambrian Valdres Group, tillite, and equivalents of the Vangsås Formation occur in conformable sequence beneath Cambro–Ordovician slates and arenites. The Late Precambrian age of the Valdres Group has been corroborated on the basis of sedimentary relationships to the known Eocambrian Vangsås Formation. The various allochthonous litho-tectonic units exhibit differences in sequence and facies which suggest that they are derived from slightly different sedimentary areas within the same root zone.

Of the four phases of deformation recognized, the first two were most important in affecting the configuration or distribution of large units of rock. Litho-tectonic units of the Valdres nappes emplaced during D_1 were penetratively deformed and elongated in the NW–SE direction (300° $\pm$ 20°) during D_2. The slaty cleavage, elongation lineations and regional low grade metamorphism are all products of D_2. Later deformation is recorded in several slip cleavages and in steeply-dipping, Post-Caledonide, faults.

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Introduction

Recent geologic studies at Mellane (Nickelsen 1967; Loeschke 1967a) Grønsennknipa (Loeschke & Nickelsen 1968, Hossack 1972) and near Bygdin (Loeschke 1967b, Hossack 1968) have demonstrated: the allochthonous nature of the Valdres (Sparagmite) Group in the Valdres Nappes (Kulling 1961), the unconformable sedimentary contacts between some Jotun basement rocks and the Valdres Group, the late Precambrian–Eocambrian age of the Valdres Group, the Cambro–Ordovician age of the Melsenn Group, and the complex deformational history of the Valdres Group. This work has been concentrated in the southwest (Grønsennknipa) and central (Mellane, Bygdin) parts of the large area of Valdres Group sparagmite which lies southeast of the Jotunheim Mountains (Fig. 1). In the light of these new findings it seemed particularly appropriate to restudy the easternmost exposures of the Valdres Group in the Røssjøkollan–Dokkvatn area, an area which had influenced but at the same time seemed to contradict the conventional interpretation of Valdres Group age and contact relationships. The Røssjøkollan–Dokkvatn area had been visited and partially described by Bjørlykke (1894, 1905) and Goldschmidt (1916a and b) and partially mapped by Strand (1938). It was known to contain a gabbroic basement massif, embedded in Valdres Group

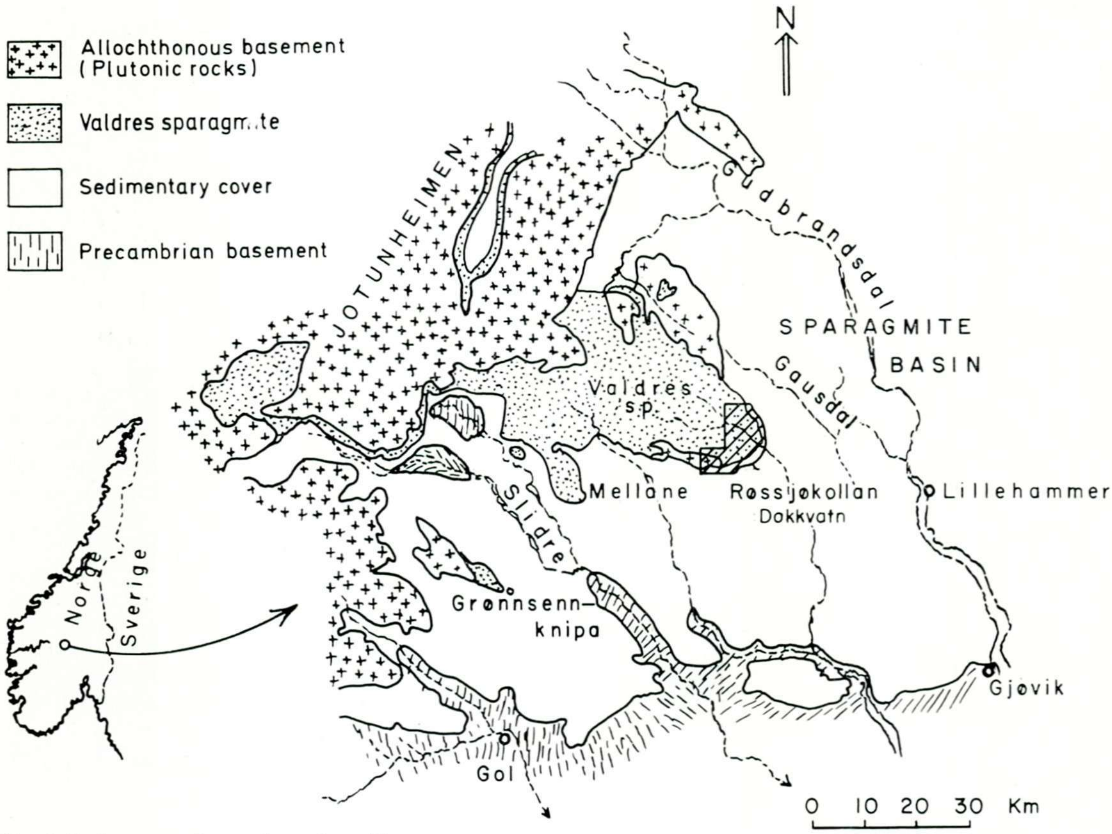


Fig. 1. Index map of central southern Norway.

sparagmite and thrust over Mellsenn slates and quartzites, which had served as one of the prime examples of the Lower Jotun Nappe (Strand 1960, pp. 190–193). In addition, Bjørlykke (1905, p. 453) had described a conformable overturned sequence along the Dokka including sparagmite and Paleozoic rocks which seemed to corroborate our findings on the age of the Valdres Group. Finally, the area was close enough to the classical Late Precambrian–Eocambrian sparagmites to facilitate correlating Valdres subunits with them. Thus the present study of the Valdres Group and associated rocks in the Røssjøkollan–Dokkvatn area was initiated to corroborate newly established ages, to extend our regional knowledge of the phases of deformation, tectonic units and stratigraphic correlations and to discover if previous interpretations of the geology fit our newly evolving concepts.

The Røssjøkollan–Dokkvatn area was mapped during approximately 25 days of 1968 and 1969 with the assistance of T. Hubka, A. Canepa, and A. Kehew. Photographic enlargements at scales of 1:12,500 and 1:25,000 of the Synnfjell (sheet 1717 II) and Svatsum (sheet 1717 I) quadrangles of series M 711 served as base maps for geologic mapping. Air photos at a scale of ca. 1:40,000 flown in 1955 by the AMS were used in mapping and served locally, after enlargement, as base maps. Compass measurements were recorded clockwise

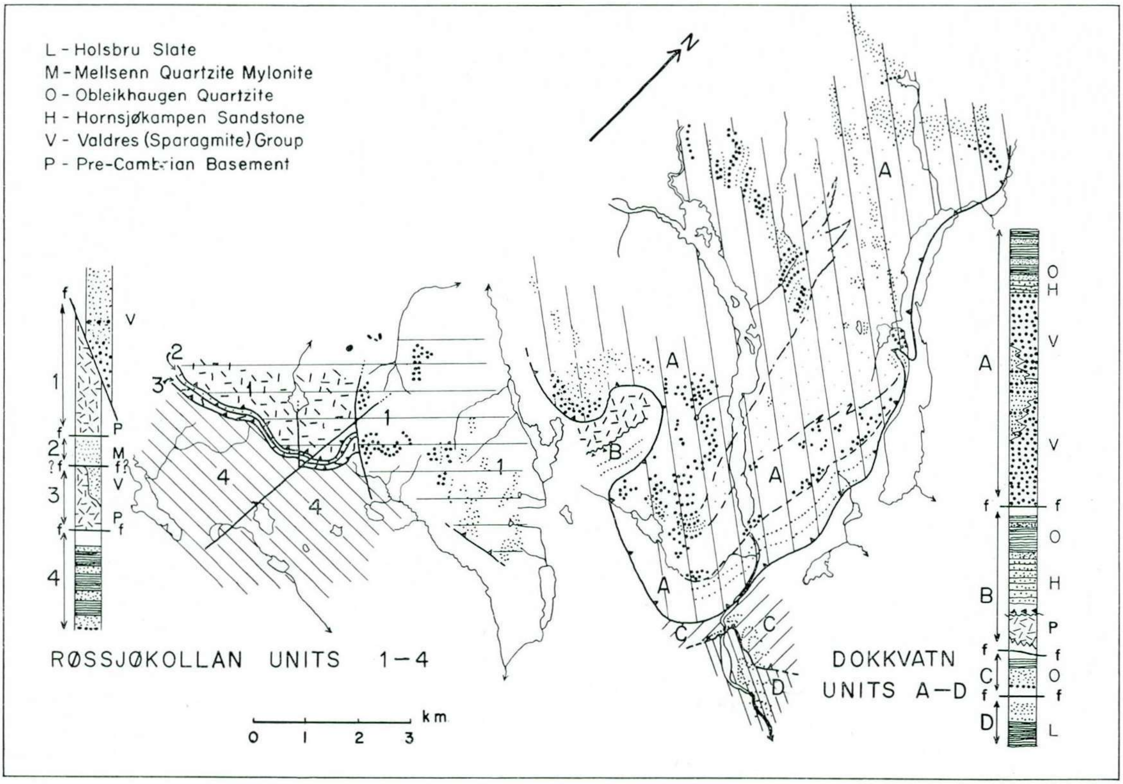


Fig. 2. Litho-tectonic units, Røssjøkollan–Dokkvatn area.

in 360° and stereonet data are plotted on the lower hemisphere of a Schmidt net. Rock color descriptions utilize terms appearing in the Rock Color Chart prepared by the Rock Color Chart Committee of the U.S. National Research Council in 1948.

Lithological succession

Allochthonous, Precambrian Jotun basement, late Precambrian Valdres sparagmite, Eocambrian tillite or Vangsås arenites and slates, and lower Paleozoic phyllites and arenites are exposed in the Røssjøkollan–Dokkvatn area. Although relatively few stratigraphic units are involved, they occur in different stratigraphic relationships and as different facies in two groups of four thrust-bounded litho-tectonic units (Fig. 2, Table 4, col. 4). Units 1–4 of the Røssjøkollan litho-tectonic group occur in the Røssjøkollan–Snuen–Sæbu–Røssjøen area in the western half of the region. They are separated by a broad, northwest-trending, drift-covered valley (occupied by the Snæra River, Snærevatn, and Uppsjøen) from Units A–D of the Dokkvatn litho-tectonic group exposed along the Dokka and around Hornsjøen. Dokkvatn litho-tectonic units cannot be traced into Røssjøkollan litho-tectonic units but tentative lithologic and structural correlations are suggested.

Parts of the Eocambrian and lower Paleozoic section in the Dokkvatn litho-tectonic units can be correlated with the well-known stratigraphy of the Hedmark Group and overlying Paleozoic rocks in the classical Sparagmite area of southern Norway (Skjeseth 1963, Bjørlykke et al. 1967). As these correlative units occur in conformable stratigraphic sequence above the Ormtjernskampen Conglomerate of the Valdres Group, the stratigraphic relations to the type sparagmites can be demonstrated here more precisely than they have been elsewhere (Nickelsen 1967, Loeschke 1967a).

The stratigraphy of Røssjøkollan litho-tectonic units cannot be directly matched with the sections in the classical Sparagmite region although they are approximately of the same age.

PRECAMBRIAN BASEMENT ROCKS

Precambrian basement rocks which apparently served as one of the sources of the Ormtjernskampen Conglomerate of the Valdres Group and other Precambrian or Eocambrian sediments are preserved in two parts of the Dokka–Røssjøkollan area – above the major Valdres thrusts on the mountain Røssjøkollan (Røssjøkollan litho-tectonic units 1 and 3) and in the low ground north of Ormtjernseter (Dokkvatn litho-tectonic unit B). These areas of basement rock occur in apparently different, allochthonous, thrust slices, are slightly different in composition, and have different contact relationships to adjacent sedimentary rocks. The basement rocks in Røssjøkollan litho-tectonic unit 1 are in thrust contact with the Valdres and Melsenn sedimentary rocks to the south and in gravity (?) fault contact with Valdres conglomerates and sandstones to the east. The highly sheared basement in Røssjøkollan litho-tectonic unit 3 is bounded by thrusts at base and top. Within the unit basement rocks are apparently unconformably overlain by Valdres Group sparagmite. On the other hand, the basement rocks north of Ormtjernseter (Dokkvatn litho-tectonic unit B) are overlain unconformably by a section including stratigraphic equivalents of the Moelv Tillite, Ekre Shale and Vangsås Formation.

On Røssjøkollan the basement rocks of litho-tectonic unit 1 are brown-weathering, grayish-green, medium- to coarse-grained, massive, plutonic rock of approximately gabbroic composition. All parts of the mass have been fractured, sheared, and retrograded and the rock commonly breaks along acutely intersecting surfaces coated with chlorite. Mineralogic composition of a specimen from the south summit of Røssjøkollan, based upon 500 points counted is:

Plagioclose (albite, An0–5) + sericite	55.4%
Amphibole (hornblende)	29.4%
Chlorite (penninite)	7.0%
Quartz	4.0%
Accessories (apatite, rutile, calcite)	3.0%
Pyroxene (augite)	1.2%

Dominant constituents of the original plutonic rock were plagioclase and hornblende with some centers of augite preserved. During metamorphism, original plagioclase was retrograded to albite (An0–5) and sericite, chlorite, and calcite were also formed. Quartz occurs in veins and patches and does not appear to have been an original igneous constituent. Four sheared and fractured outcrops of granitic rock occur in a poorly exposed area 1½ km north of Røssjøkollan and are assumed to be part of Røssjøkollan litho-tectonic unit 1. Relations of this granitic rock to the dominant more basic crystalline rocks of litho-tectonic unit 1 and to the Valdres Group are obscure.

In the thin slice of litho-tectonic unit 3 south of Røssjøkollan, basement rocks are strongly foliated, greenish-black to dark greenish-gray, metagabbro. The mineralogic composition of one specimen is given in the following Table.

Plagioclase + sericite	63.1%
Amphibole (hornblende)	28.7%
Chlorite	3.5%
Calcite	3.5%
Epidote	.9%
Accessories – apatite, sphene, zircon	.3%
	100.0%

It is quite similar to the gabbro from Røssjøkollan litho-tectonic unit 1.

In conclusion, the dominant basement rock on Røssjøkollan shows evidence of origin as a plutonic rock of gabbroic to perhaps dioritic composition. It now contains a green schist metamorphic mineral assemblage which seems to have been formed during tectonic transport of these basement blocks to their present allochthonous location.

The Precambrian crystalline mass in the low ground north of Ormtjernseter (Dokkvatn litho-tectonic unit B) is a white to gray-black, coarse-grained, well-foliated, plutonic rock of intermediate composition. Bands of concentration of light and dark minerals are interpreted as Precambrian, and of primary origin since they are truncated by the nonconformity separating these basement rocks from the overlying Eocambrian sandstones, slates and tillites (see Fig. 3). Mineralogic composition of two specimens collected no more than 20 feet below the unconformity is:

	Spec. 53	*Spec. 54*
Plagioclase + sericite	41.5%	49.2%
Amphibole (hornblende)	26.0%	39.2%
Microcline	7.4%	7.0% (some anti-perthite present)
Quartz	12.8%	3.6%
Chlorite–biotite aggregates	7.9%	1.0%
Epidote	4.	0.
Zircon	Tr	
Apatite	Tr	

(Composition based upon 500 point count)

Fig. 3. Nonconformity; foliated Precambrian basement overlain by Eocambrian Sandstones from the basal member of the Snæresvatn Formation. (Photo).

Primary igneous constituents were plagioclase, hornblende, microcline, quartz, and biotite (Fig. 4). Relict crystals are anhedral and relict igneous texture is subophitic with large grains of hornblende partially enclosing the irregular crystals of plagioclase. During metamorphism original plagioclase was retrograded to albite but plagioclase composition is variable and relict grains with anorthite content as high as An 20 are preserved in Specimen 54. This rock is the low grade–metamorphic equivalent of a Precambrian quartz-bearing syenodiorite or mangerite. Retrograde metamorphism presumably occurred during tectonic transport and subsequent folding that also affected the Paleozoic and Eocambrian sedimentary rocks of the region.

PRECAMBRIAN, EOCAMBRIAN AND PALEOZOIC SEDIMENTARY ROCKS

Valdres Group – Precambrian and Eocambrian

The traditional Valdres Sparagmite is referred to as a Group because within its region of occurrence it contains a number of mappable units that qualify as Formations. Examples of Valdres Sparagmite formations are the Ormtjernskampen Conglomerate of this paper and the Rabalsmellen, Rognslifjell, and Rundemellen-type Sparagmites of Mellane (Loeschke 1967).

Thick allochthonous sections of Valdres Group sparagmite occur in the uppermost (1 and A) Røssjøkollan and Dokkvatn litho-tectonic units (Fig. 2). In each litho-tectonic unit the Valdres Group is comprised of both the Ormtjernskampen Conglomerate and the more typical feldspar-rich sandstone which is found generally throughout areas of Valdres exposure in the region.

The Valdres Group on Snuen, the mountain comprising the eastern half of Røssjøkollan litho-tectonic unit 1, strikes northwest and dips steeply except

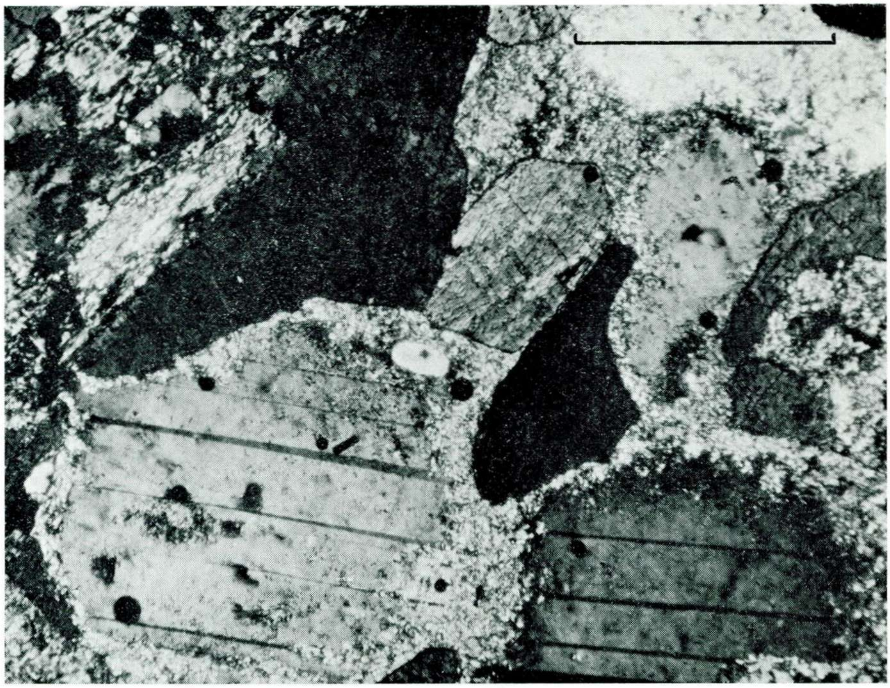


Fig. 4. Retrograded quartz-bearing syenodiorite basement, Dokkvatn unit B. bar = ½ mm. (Photo).

where locally folded into Z-shaped folds plunging northwest. Cross-bedding at several exposures on the southeast end of Snuen (see Plate 1) indicates stratigraphic up to the east and as a result, the Z-folds face downward to the east. The Ormtjernskampen Conglomerate is restricted to the southwestern part of the Valdres Group exposure near the gravity (?) fault contact with the basement rocks on Røssjøkollan and is thus lower in the section and older than the arkosic arenites and wackes that comprise the northeastern half of Snuen. On Snuen the Ormtjernskampen Conglomerate and overlying sandstone are conservatively estimated to be 1500 meters thick. The northwest trending, steeply dipping, fault separating the Røssjøkollan gabbro from the Ormtjernskampen Conglomerate is late, possibly Permian, cutting through the Valdres thrusts and displacing them less than 100 meters down on the northeast. It is likely that the Ormtjernskampen Conglomerate here was originally deposited unconformably upon the Røssjøkollan gabbro massif but no sedimentary contact can be found. This is disappointing because additional exposures are needed to confirm the unconformable relations between allochthonous Precambrian crystalline rocks and Precambrian Valdres sedimentary rocks documented at only one exposure on Grønsennknipa (Holtedahl 1959, Nickelsen 1967, p. 117, Loeschke & Nickelsen 1968, p. 353, Hossack 1972).

Røssjøkollan litho-tectonic unit 3 contains both gabbroic basement and sandy to pebbly Valdres Group sparagmite elsewhere in the region (e.g. 8 km to the west near Djuptjernskampen), but within the Røssjøkollan map area

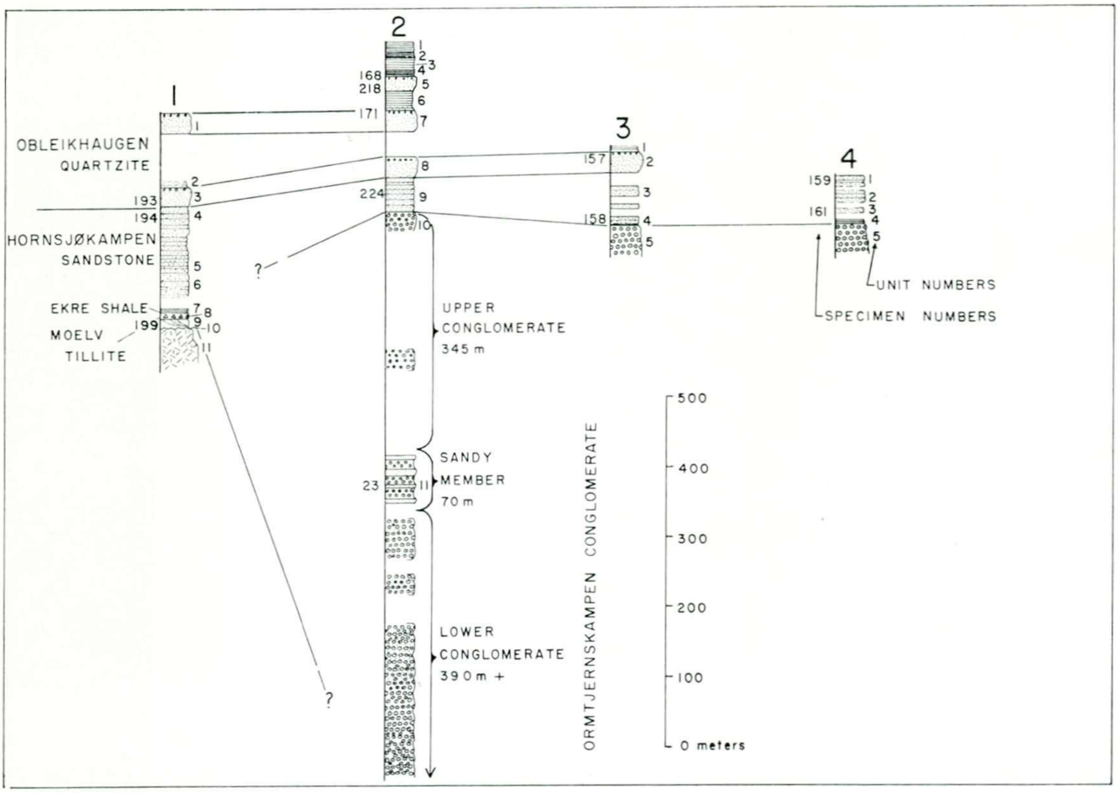


Fig. 5. Stratigraphic sections and correlations, Dokkvatn units A and B.
1. Stratigraphic sequence along structure section 3, Dokkvatn unit B.
2. Stratigraphic sequence along structure secion 4, Dokkvatn unit A.
3. Stratigraphic sequence at Obleikhaugen, Dokkvatn unit A.
4. Stratigraphic sequence at Hornsjøkampen, Dokkvatn unit A.

basement and sparagmite are not differentiated in the field, and no section of sparagmite can be measured.

The Valdres Group of Dokkvatn litho-tectonic unit A is dominantly Ormtjernskampen Conglomerate in its southern exposures on Ormtjernskampen (Plate 1; Fig. 5, section 2) but comprised mostly of arkosic arenite at the north end of Hornsjøen. On Ormtjernskampen the section is overturned toward the southeast and the upper and lower Ormtjernskampen Conglomerate members and intervening sandy member are 805 meters thick (Fig. 5, section 2). The section is stratigraphically conformable with the younger Vangsås Formation lying overturned to the south of Ormtjernskampen. Halfway up the southeast spur of Ormtjernskampen, interbeds of sandstone occur between the 380-meter thick lower conglomerate member, and the 345-meter thick upper conglomerate member of the Ormtjernskampen Conglomerate. These sandy beds between the Ormtjernskampen Conglomerate members can be traced southwest to there they crop out above the road in the north shore of Ormtjern (Fig. 6). When traced northward across Dokkvatn, however, the sandstone thickens greatly as the upper and lower conglomerates thin, resulting

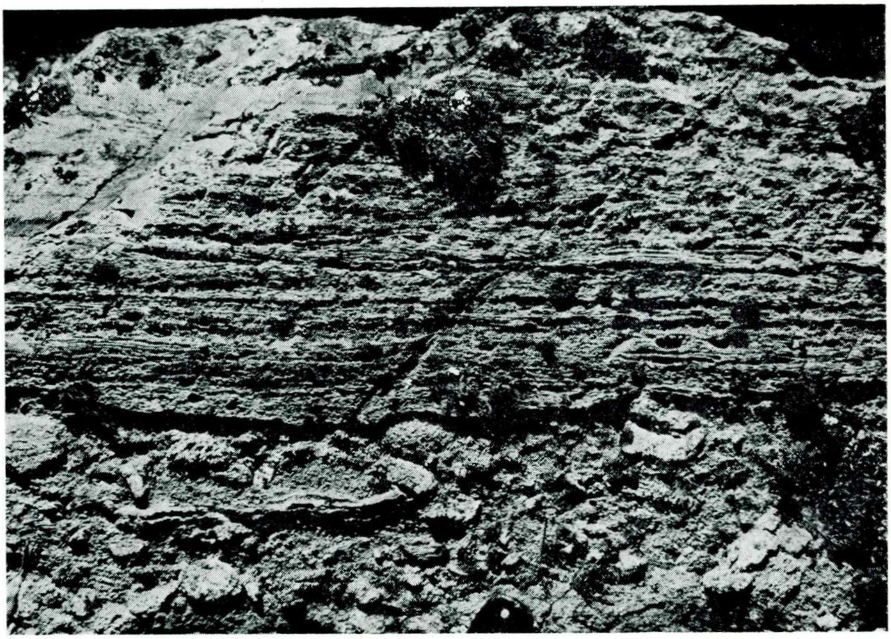


Fig. 6. Sandy member of the Ormtjernskampen Conglomerate, Ormtjernseter. (Photo).

in a predominantly sandy aspect in the northern part of the map area. The lower Ormtjernskampen Conglomerate, which is most completely exposed on the summit of Ormtjernskampen, also crops out on Dokkampen and Snæreskampen and the arkosic arenites to the north and west are interpreted to, in part, lie beneath the lower Ormtjernskampen Conglomerate and, in part, interfinger with it.

In summary, the Valdres Group of Dokkvatn litho-tectonic unit A lies conformably beneath the Vangsås Formation (Fig. 5, sections 2, 3, 4) and consists of greater than 800 meters of conglomerate and sandstone; in descending sequence the upper Ormtjernskampen Conglomerate, the Sandy Member, the Lower Ormtjernskampen Conglomerate, and lowermost, an unknown thickness of sandstone. The upper and lower Ormtjernskampen Conglomerate members thin northward by interfingering and facies change from their maximum development on Ormtjernskampen.

It should be emphasized that the above stratigraphic and structural interpretations place the Ormtjernskampen Conglomerate member at different stratigraphic positions in different litho-tectonic or geographic parts of the area. In Røssjøkollan litho-tectonic unit 1 it is basal, overlain by 1000 meters of arenite, whereas in Dokkvatn litho-tectonic unit A it occurs as a northeast thinning pair of wedges (see Fig. 2) which persist farthest to the northeast near the top of the Valdres section. The different relationships are entirely consistent with a depositional scheme of local clastic wedges derived from intra-basin highs or basinal margins.

The Ormtjernskampen Conglomerate is a pebble to boulder orthoconglom-

Fig. 7. Conglomerate member of the Ormtjernskampen Conglomerate, Valdres Group. (Photo).

erate; greenish gray to greenish black; compositionally immature, comprised dominantly of anorthosite, gabbro or quartz diorite detritus with less than 5% granite boulders and quartz pebbles (Fig. 7). Generally it is texturally mature to submature with matrix rarely exceeding 10% in coarse facies. However, north of Dokkvatn, along the Gryta, the conglomerate is finer-grained, consisting of resistant pebbles suspended in arkosic wacke (Fig. 8).

Composition of three of the most common basic boulders as determined by point count of 300 grains in each boulder of a specimen from Dokkvatn litho-tectonic unit A is given in the following Table:

	1	*2*	*3*
Pyroxene	3.7%	– %	– %
Amphibole (hornblende)		60.0%	48.8%
Plagioclase and alteration products	58.4%	23.9%	38.6%
Chlorite	19.0%	15.1%	4.7%
Sphene	13.2%	1.0%	2.8%
Epidote	4.2%	–	3.7%
Opaques	1.5%	–	1.4%
	100.0%	100.0%	100.0%

The rare granite boulders have reddish weathering rinds and are quartz monzonites as determined by point counting a boulder in a specimen from Røssjøkollan litho-tectonic unit 1.

Table 1. Composition of clastic sedimentary rocks

	Quartzites								Holseter Sandstone				Hornsjøkampen Sandstone					Tillite	Valdres (Sparagmite) Group										
	32	214	157	218	193	171	156	168	38	37	40	41	194	161	224	159	158	199	166	25	25	176	163	23	183	51	115	109	110
Quartz (grains, cement; crush quartz in cataclastic rocks)	94.7	81.4	87.0	87.2	90.0	82.5	82.6	70.1	57.2	79.1	79.7	74.3	62.4	64.6	54.3	57.5	49.4	33.5	54.3	36.3	41.3	34.9	24.7	13.0	11.4	10.5	40.0	38.1	34.8
Feldspar (total)		2.1	9.4	9.1	9.6	7.0		2.9		.3	1.1				19.4	24.6		16.3				49.3	54.3	15.6	4.5	11.5			
Kspar							10.3						5.9	11.8			26.4		28.0	18.4	40.0						5.0	37.9	18.0
Plagioclase							1.2						12.5	9.0			11.8		5.3	14.2	12.3						9.1	16.0	16.3
Amphibole																								3.8	9.3	6.0			
Rock fragments								10.9	1.2	2.1	1.9							4.1	2.2			1.4	6.6	6.9	66.7	70.0			
Matrix (sericite, chlorite, fine-gr. quartz & feldspar	5.3	13.7	3.6	3.7	.4	10.5	5.9	15.6	39.6	15.0	15.0	25.7	17.6	14.2	26.0	17.9	9.3	44.9	9.2	26.8	2.1	13.9	14.4	55.6	0?	0?	12.4	6.8	28.3
Calcite		2.8															.4	1.1											
Opaques, sphene, apatite								.5	2.0	3.5	2.3		1.6	.4	.3				1.0	3.2	3.6	.5		5.1	8.1	2.0	9.9	1.1	.8
Metamorphic epidote																	2.7			1.1	.7						23.6		1.9
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.0
	Dokkvatn Formation quartz arenite Thrust above Holseter	Obleikhaugen quartz wacke Dokka bru	Obleikhaugen quartz arenite Fig. 5, Section 3	Dokkvatn Formation quartz wacke Fig. 5, Section 2	Obleikhaugen quartz arenite Fig. 5, Section 1	Obleikhaugen quartz arenite Fig. 5, Section 2	Mellsenn feldspathic arenite Solskiva	Dokkvatn Formation subfeldspathic lithic wacke Fig. 5, Section 2	Holseter quartz wacke Holseter	Holseter quartz wacke Holseter	Holseter quartz wacke Holseter	Holseter quartz wacke Holseter	Hornsjøkampen feldspathic wacke Fig. 5, Section 1	Hornsjøkampen feldspathic wacke Fig. 5, Section 4	Hornsjøkampen arkosic wacke Fig. 5, Section 2	Hornsjøkampen arkosic wacke Fig. 5, Section 4	Hornsjøkampen arkosic arenite Fig. 5, Section 3	Snæreskampen tillite Fig. 5, Section 1	Valdres arkosic arenite Hornsjøen, north end	Valdres arkosic wacke Snæreskampen	Valdres arkosic wacke Snæreskampen	Valdres arkosic wacke Hornsjøen, west side	Valdres arkosic wacke Hornsjøen, north end	Valdres arkosic wacke mudstone Dokka section	Valdres lithic arenite Dokkvatn, north end	Valdres lithic arenite Snæreskampen	Valdres feldspathic wacke East of Rossjøkollan	Valdres arkosic arenite Snuen	Valdres arkosic wacke Snuen

Fig. 8. Ormtjernskampen Conglomerate matrix-rich facies on the Gryta. (Photo).

Quartz	25.4%
Microcline & Perthite	31.9%
Albite	24.9%
Amphibole (hornblende)	11.4%
Ilmenite	1.4%
Accessories (epidote, chlorite, sphene, zircon)	4.8%
	99.8%

Although these granitic boulders are not abundant they are ubiquitous, occurring in every outcrop of conglomerate.

Finer grained interbeds in the conglomerate are matrix-rich, medium sandstones or sandy mudstones which are grayish red purple, compositionally immature and angular. Specimen 32 in Table 1 is an example of one such fine-grained interbed (Fig. 9).

Following deposition the conglomerate was thrust to its present location, penetratively deformed and metamorphosed to the green schist facies of metamorphism. Penetrative deformation is manifested in flattening in the prominent slaty cleavage plane and elongation in the northwesterly direction.

Composition of Valdres sandstones from various localities in the Røssjøkollan–Dokkvatn area are given in Table 1 and plotted on the classification diagram of Fig. 10. The specimen numbers appearing in Table 1 and Fig. 10 are also plotted on the stratigraphic sections of Fig. 5. Using the classification diagrams and terminology of Williams et al. (1958, Figs. 96, 97), Valdres sandstones are predominantly arkosic arenites or wackes with some inter

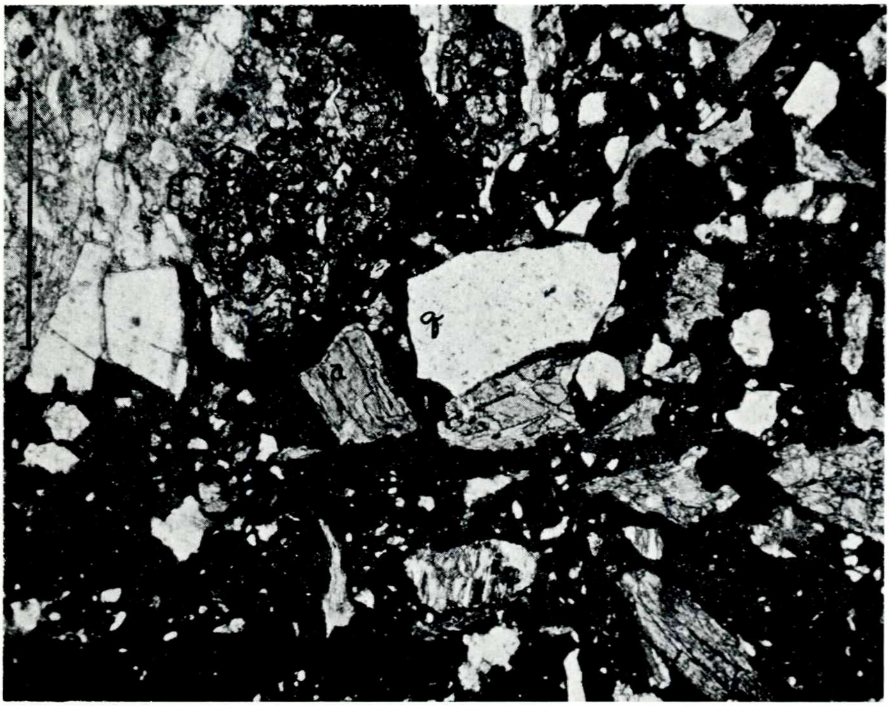
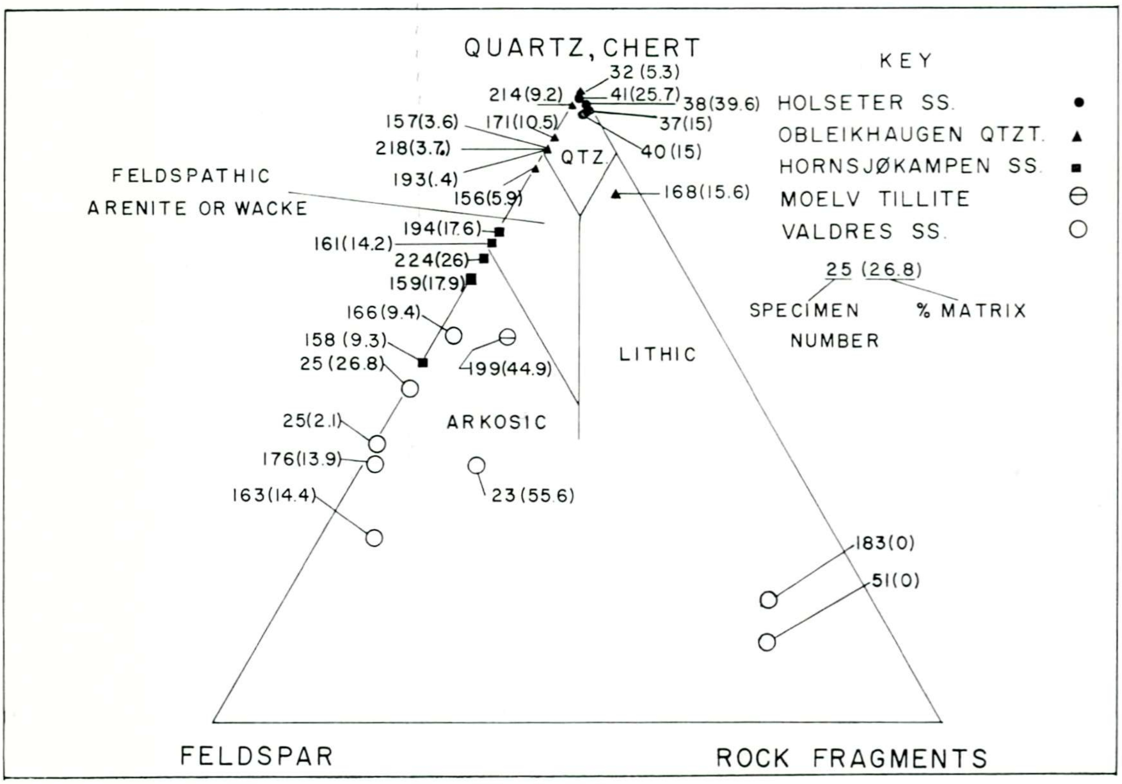


Fig. 9. Argillaceous, fine-grained sandstone in Ormtjernskampen Conglomerate. q = quartz, a = amphibole. bar = ½ mm. (Photo).

Fig. 10.



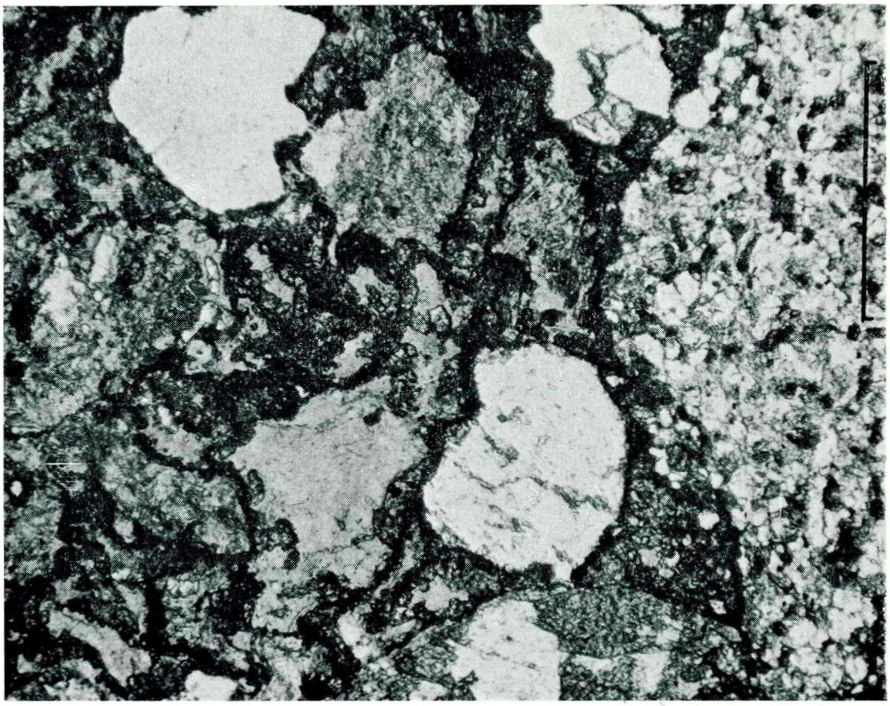


Fig. 11. Valdres Group lithic arenite from Snæreskampen (Spec. 51). Basic mineral grains and rock fragments rimmed by epidote porphyroblasts. bar = ½ mm. (Photo).

bedded lithic arenites. Grain size varies from pebbly to medium-grained sand and there are very few silty or clayey interbeds. Color of fresh exposures reflects the grain composition and matrix content quite well. Thus, arkosic arenites are commonly grayish red purple, in places flecked with dark greenish gray. Where metamorphic epidote is common as in Specimen 115 the color is moderate greenish yellow. Lithic arenites such as Specimens 51 (Fig. 11) and 183 with an abundance of amphibole, chloritized basic rock fragments, or sericite-rich rock fragments are dark to medium greenish gray. Where matrix is abundant, as in Specimen 110, the predominant color is light olive gray. However, in sandy mudstones like Specimen 23 which are interbedded with the Ormtjernskampen Conglomerate the abundant matrix imparts a grayish red purple color. All Valdres sandstones are cemented by quartz. In places, there is considerable local variability in sandstone composition and texture. An excellent example is three specimens (25, 25, 51) collected from three different beds on the summit and upper southwest slope of Snæreskampen (Table 1, Plate 1). Here, in addition to the overlying beds of compositionally immature conglomerate which are found downslope to the southwest, there are beds of lithic arenite (Specimen 51), arkosic arenite (Specimen 25) (Fig. 12) and arkosic wacke (Specimen 25) (Fig. 13).

Fig. 10. Sandstone classification diagram.

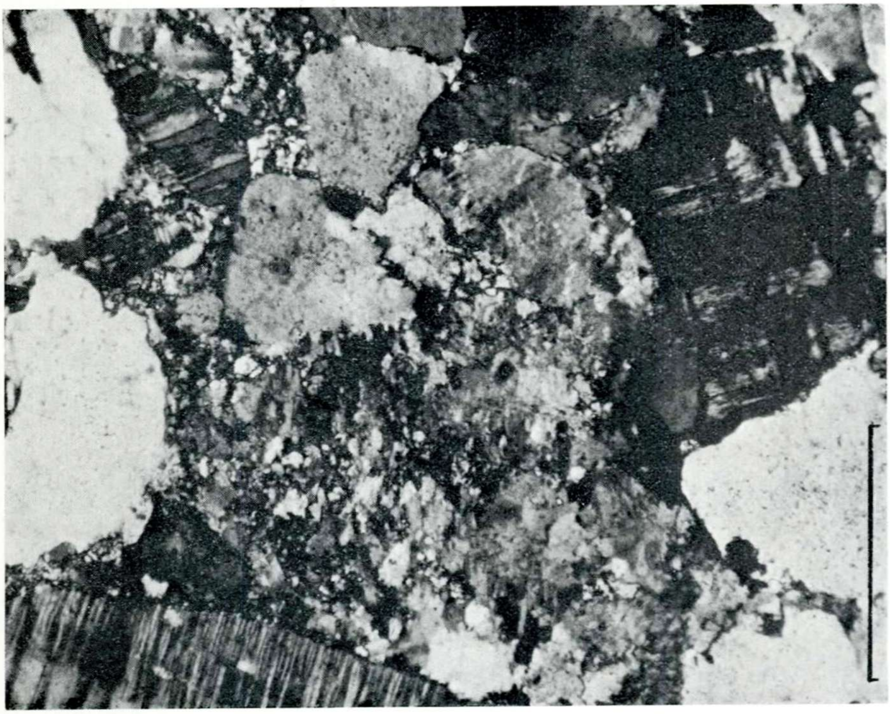


Fig. 12. Valdres Group arkosic wacke from Snæreskampen (Spec. 25). bar = ½ mm. (Photo).

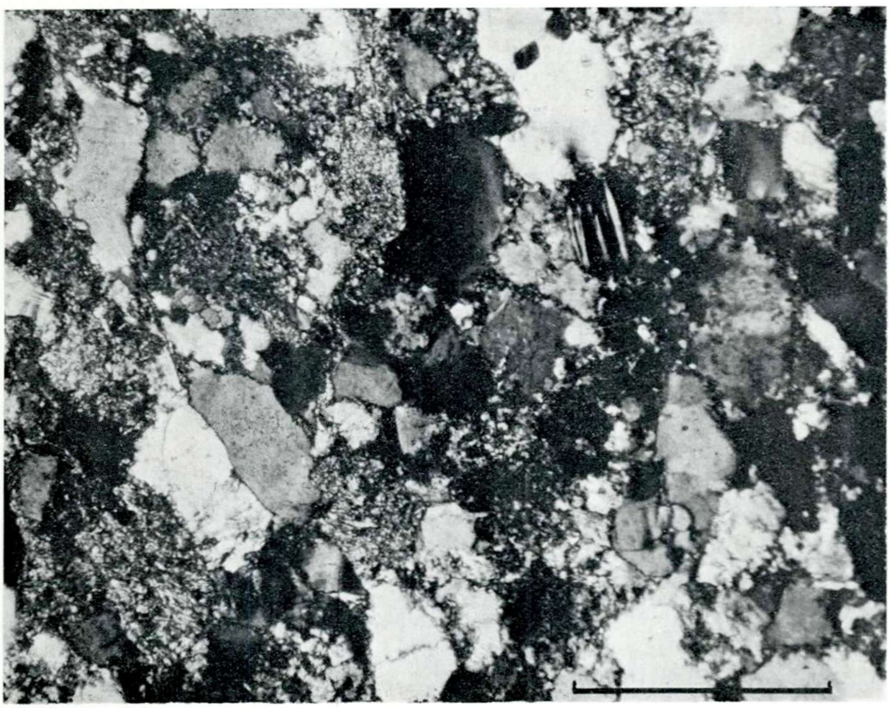


Fig. 13. Valdres Group arkosic wacke from the north of Hornsjøen (Spec. 163). bar = ½ mm. (Photo).

Fig. 14. Tillite member of Snærevatn Formation one mile west of Ormtjernseter. (Photo).

Snærevatn Formation – Eocambrian

The Snærevatn Formation is present only in Dokkvatn litho-tectonic unit B, where it consists of 12 metres of arkosic wacke, resting unconformably upon crystalline basement (Fig. 14, Fig. 5, section 1), overlain by several meters of tillite and slate. The tillite and slate are equivalents of the Moelv Tillite and Ekre Shale, respectively. Above the Snærevatn Formation is a section including equivalents of the Vangsås Formation (Fig. 5, section 1). Since both the Snærevatn Tillite of Dokkvatn litho-tectonic unit B and the Ormtjernskampen Conglomerate of Dokkvatn litho-tectonic unit A (Fig. 5, secions 2, 3, 4), underlie the Vangsås Formation it is likely that some part of the Ormtjernskampen Conglomerate is equivalent to the tillite. Unfortunately, no glacial characteristics can be recognized in any part of the Ormtjernskampen Conglomerate and exact correlation will have to await a more complete study of the regional stratigraphy of the Valdres Group.

Relations observed in this area between the tillite and other rock units are similar to those recorded throughout the range of occurrences in the Sparagmite Basin to the east as summarized by Skjeseth (1963, pp. 31–32, plate II) or by Bjørlykke (1969, p. 315). In that area Moelv Tillite rests directly on basement or a relatively thin sandstone above basement:

1. On the east side of the Sparagmite Basin in Engerdal and Rendal,
2. Around the basement windows in the northern part of the Sparagmite Basin at Snødøla, Brydal, and Øversjødal (Skjeseth 1963, p. 32).

These exposures are commonly described as autochthonous and this suggests that Dokkvatn litho-tectonic unit B is also autochthonous, despite our previous assertion that all four Dokkvatn litho-tectonic units are allochthonous. However, Englund (1969, p. 321) has recently described an inverted, thin, section in which Moelv Tillite is in contact with basement in an allochthouous outlier on Feforkampen, thus showing that till-basement contacts need not be autochthonous.

At all points within the Sparagmite Basin that are removed from the basin margin and above the décollement plane of the Vemdal nappe (Strand & Kulling 1972, p. 7) the Moelv Tillite is underlain by a thick Eocambrian section (Skjeseth 1963, plate II). These parautochthonous or allochthonous sections show the same general relations between Moelv Tillite and underlying thick sparagmite sections as are present at allochthonous Moelv Tillite localities within the Valdres Group area. For example, beneath the tillite in the allochthonous section in southern Mellane there are 3,000 meters of Valdres Group (Nickelsen 1967, Table 1; Loeschke 1967a). Even though no tillite can be found in the allochthonous Dokkvatn litho-tectonic unit 1 (Fig. 5, section 1) it is clear that a thick section of equivalent or older rocks is present.

The tillite exposed in Dokkvatn litho-tectonic unit B is less than 2 meters thick. It is a light olive gray weathering paraconglomerate which is dark gray on fresh surfaces. Listed under Specimen 199 in Table 1 is a point count showing the mineralogic composition of the sand and clay fraction of the till. The fine clay and silt-sized matrix between sand-sized particles comprises 45% of the rock. Pebbles, cobbles and boulders are variable in abundance but generally do not make up more than 30% (Fig. 14). They consist mainly of diorite, granite, gneissic granite, gabbro and marble. The tillite is a thin, unusual, lensing, deposit containing matrix and exotic pebbles not seen elsewhere in the section; a remarkably good key bed for correlation throughout the region.

A few meters of shale equivalent to the Ekre Shale are found directly above the tillite in Dokkvatn litho-tectonic unit B (Fig. 5, section 1). It is a dark greenish gray silty slate with floating very fine sand grains, and ubiquitous laminations spaced .5–1 millimeters (Fig. 15). Similar grayish green slate has been observed between the Ormtjernskampen Conglomerate and the Hornsjøkampen Sandstone of Dokkvatn litho-tectonic unit A on Hornsjøkampen (Fig. 5, section 4) but it has not been definitely correlated with the Ekre Shale because of the absence of tillite in this section.

Vangsås Formation, Hornsjøkampen Sandstone Member, Eocambrian

The Hornsjøkampen Sandstone Member is well exposed in all sections shown on Fig. 5, which were measured in Dokkvatn litho-tectonic units A and B. It has not been recognized in Røssjøkollan litho-tectonic units. It ranges from 50–140 meters thick and is transitional between the coarser, less mature Valdres Group sparagmite below and the overlying more quartzose Obleikhaugen Quartzite.

The most characteristic field aspect of the Hornsjøkampen Sandstone is its uniform whitish weathering color probably resulting from abundant feldspar, medium to fine grain size, and matrix composition. Fresh surfaces of the sand-

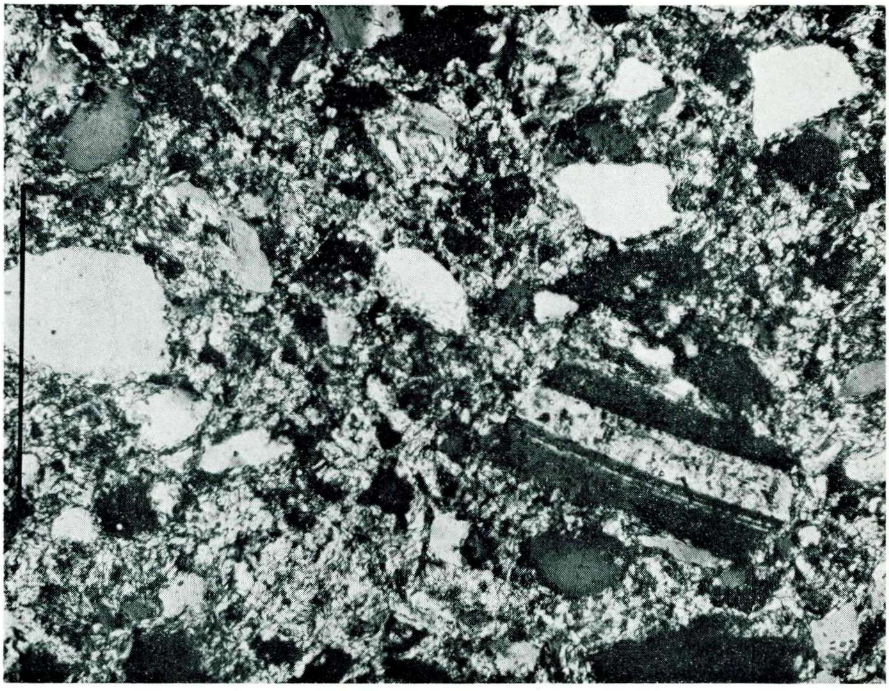


Fig. 15. Shale member of Snærevatn Formation. bar = .25 mm. (Photo).

Fig. 16. Hornsjøkampen feldspathic wacke (Spec. 161), Hornsjøkampen section. bar = .5 mm. (Photo).

stone are medium dark gray, in places medium greenish gray or light olive gray. Some beds have 2–5 mm laminations of dark gray slate which give weathered surfaces a very distinctive lined appearance. Grain size varies from fine- to coarse-grained but is generally finer than the Valdres sparagmite or the overlying Obleikhaugen Quartzites. Grains are subangular to subrounded and coated with chlorite or sericite which penetrates grain boundaries or extends along cracks through feldspars. Hornsjøkampen sandstones plot across the boundary of the feldspathic and arkosic fields of the classification diagram (Fig. 10). Because matrix content is also variable they may be either arenites or wackes. Most of the specimens point counted were approximately feldspathic wackes (Table 1, Fig. 16).

Vangsås Formation, Obleikhaugen Quartzite Member, Eocambrian

The Obleikhaugen Quartzite Member consists of two, light to dark gray, medium-grained quartzites, each 20–30 meters thick, embedded in red-purple or greenish-gray sandy or silty slates. Both the Upper and the Lower Obleikhaugen Quartzites are quartz arenites (Specimens 157, 171, 193, Table 1; Fig. 10), are flecked with white feldspar grains, and coarsen upward to very coarse sandstone or grit. They cannot be differentiated unless seen in a complete sequence as in structure section III extending from Ormtjernskampen to the Dokka (Fig. 5) or as in the area west of Hornsjøen. The quartzites and parts of the interbedded slates are exposed in Dokkvatn litho-tectonic units A and B (Fig. 5, sections 1, 2, 3) but have not been identified in Røssjøkollan litho-tectonic units. The quartzite exposed in Dokkvatn litho-tectonic unit C at the bridge (Holsbru) where the Fagernes–Vestre Gausdal road crosses the Dokka is thought to be the Upper Obleikhaugen Quartzite because of the green slate that underlies it along the road to the east of the bridge. This slate section is broken by a thrust fault that places the green slate upon the Holsbru Slate. The quartzite is illustrated in Fig. 17.

The salient features and position of the slates between the arenaceous units of the Vangsås Formation are summarized in the column for the Røssjøkollan–Dokkvatn region in the Region Correlation Chart, Table 4. In Dokkvatn litho-tectonic units, red-purple slates appear to be restricted to stratigraphic positions below the Lower Obleikhaugen Quartzite but in Gausdal, Bjørlykke (1893, p. 15) reported green and red-violet or dark gray to brown-violet slates above the sparagmitsandsten (= Vangsås Formation?) and below quartzites ('den såkaldte blåkvarts' = Quartzite in the Dokkvatn Formation ?). It is possible that he incorrectly correlated the similar Obleikhaugen Quartzite and Quartzite in the Dokkvatn Formation.

Dokkvatn Formation, Cambrian to Lower Ordovician (?)

The Dokkvatn Formation consists of a lower laminated slate, a middle blåkvarts-type quartzite and an upper sequence of gray and green slates.

The lower laminated slate is a distinctive, silty, medium greenish gray, slate with 1–4 mm thick laminations of lighter gray silt or very fine sandstone

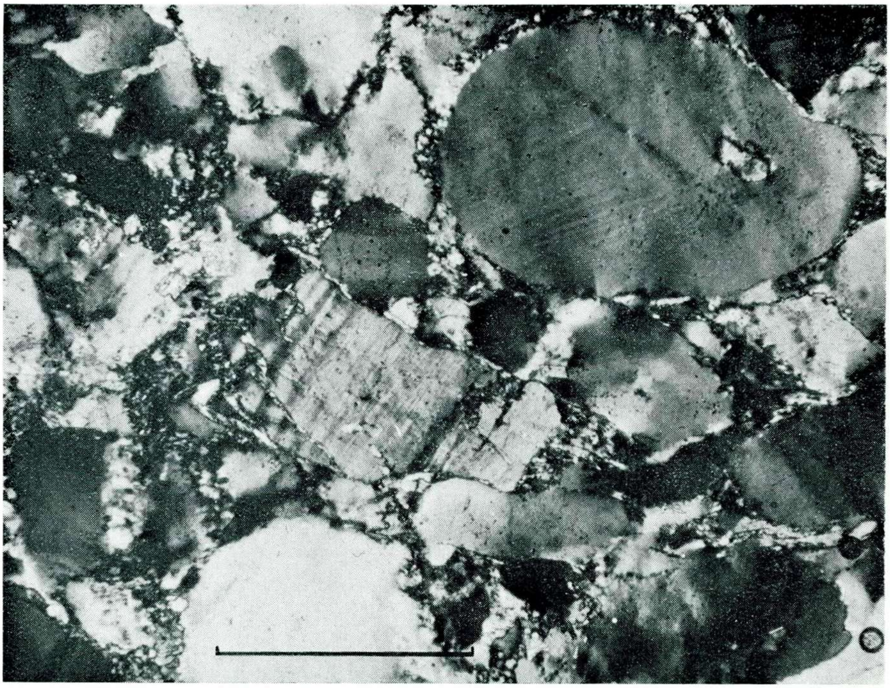


Fig. 17. Obleikhaugen Quartzite at Holsbru. Quartz shows deformation lamellae and slightly elongated grains parallel to S_0/S_2 intersection. bar = .5 mm. (Photo).

Fig. 18. Laminated slate member of Dokkvatn Formation. (Photo).

(Fig. 18). In areas to the west (e.g. Skrindseter, Svarthamarseter, Trollasseter) presumably the same stratigraphic unit contains the same slate and sandstone lamination but the grain size is coarser and the sandstone beds thicker.

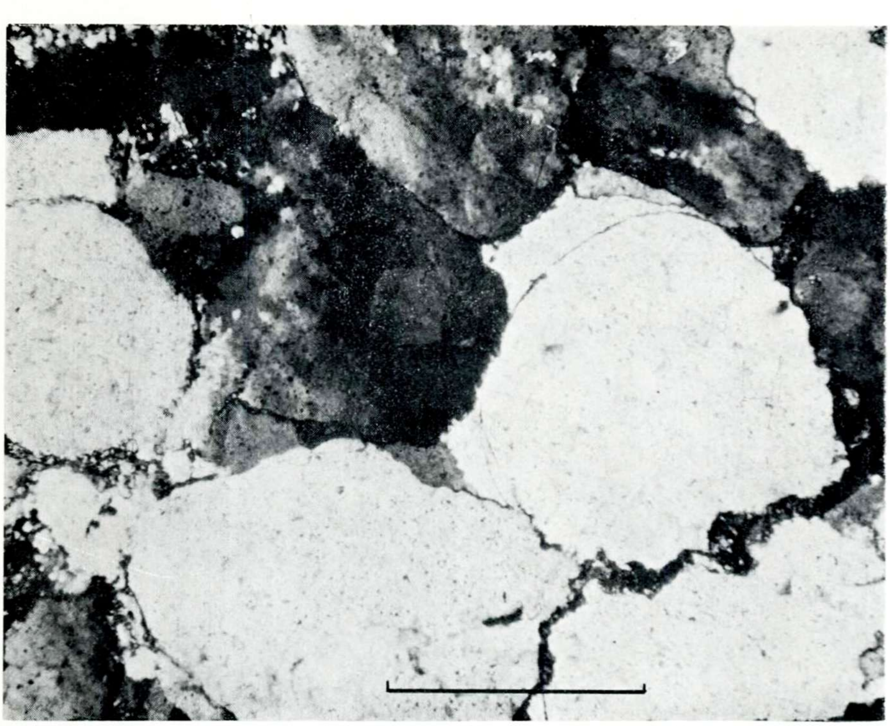


Fig. 19. Quartzite member of Dokkvatn Formation. bar = .05 mm. (Photo).

Similar laminated slate is found in unit 4 of the type Mellsenn section at Mellane (Table 4, column 5; Nickelsen 1967, Table 1). At these localities it occurs between equivalents of the Upper Obleikhaugen Quartzite and a 'blåkvarts' quartzite. Thus, this laminated slate unit is almost as useful for regional correlation as the distinctive Moelv Tillite. In Table 4 I have correlated this laminated slate with the Svartskar Slate of Englund (1966, p. 81) in the Fåvang district, a unit which he has since discarded (personal communication).

Both Bjørlykke (1893, p. 15, 1905, p. 453) and Englund (1966, p. 81) have previously recognized blåkvarts-type quartzites in this region and Skjeseth (1963) has correlated them with the Lower Ordovician blåkvarts on Hardangervidda. The middle blåkvarts-type quartzite of the Dokkvatn Formation is a 20-meter thick quartzite ranging from medium-grained, medium gray, quartz arenite (spec. 218 or 32, Fig. 19) at the base to very coarse-grained medium dark grây, white-flecked, calcareous, limonite-stained lithic arenite (spec. 168) at the top. Chert and igneous rock fragments occur at the top and the contact with the overlying slate has some attributes of a disconformity: abundance of iron oxides, exotic rock fragments, calcareous cement but absence of the limy sandstone and limestone found at this stratigraphic position by Bjørlykke (1893, p. 16). It is possible that this zone is the same as the erosional surface recognized beneath the Orthoceras Limestone by Holtedahl (1921, p. 37) in the eastern sparagmite region or that it is part of the post-blåkvarts erosional discordance recognized by Skjeseth (1963, p. 102). I have suggested correlation of this quartzite with Englund's Kvitfjell Quartzite although there is now some question if that unit exists in the Fåvang district (Englund, personal communication, 1973).

Above the quartzite in the overturned Ormtjernskampen–Dokka section are four units of dark gray or greenish gray, or laminated slate, partially separated by gaps in exposure and not exceeding a total of 20 meters in thickness (Fig. 5, section 2). These units, though not limy, are probably correlative of gray-green slates at the same stratigraphic position in Gausdal as reported by Bjørlykke (1893, p. 16). They were not described by Englund in the Fåvang district. These slates are at the top of the continuous Eocambrian–Lower Palaeozoic section exposed in Dokkvatn litho-tectonic unit A. The section above them is broken by a thrust and it is not possible, anywhere in the Røssjøkollan–Dokkvatn area, to find a continuous sequence into the overlying Ordovician slates and sandstones.

Holsbru Slate, Ordovician (?)

The medium dark gray, light-brown weathering slate of this unit is exposed in a small area along the Dokka in Dokkvatn litho-tectonic unit D. Best exposures are on both banks downstream from Holsbru and at the base of the cliffs above the road east of Holseter. The structure of the area is complex and the base of the Holsbru slate is covered by an overthrust so no estimate of thickness was made. Although the base of the Holsbru Slate is covered on the west by the overthrust Dokkvatn litho-tectonic unit C, the slate grades toward the east into the stratigraphically higher Holseter Sandstone. The Holsbru Slate at the base of the cliff east of Holseter is overturned, similarly overthrust by the Obleikhaugen Quartzites and slates of Dokka litho-tectonic unit C, and grades up section into Holseter Sandstone. At both places gradational contacts between Holsbru Slate and Holseter Sandstone consist of beds of sandstone increasing up section as slates diminish in thickness and abundance.

Holseter Sandstone, Ordovician

The only exposures of the Holseter Sandstone in the area occur in stratigraphic sequence above the Holsbru Slate in Dokkvatn litho-tectonic unit D. This sandstone appears to be the unit described by Bjørlykke (1905, p. 453) who thought these exposures along the Dokka resembled the 'Gausdal Sandstenskifer' that he had previously seen in Gausdal (Bjørlykke 1893, p. 19). It is correlative with Englund's Svinslaen Sandstone (Englund 1966, p. 82) as shown in the Regional Correlation Chart (Table 4). The best exposure is in steeply dipping beds striking northwest and facing northeast in the vicinity of Holseter, This exposure is the core of a recumbent syncline opening to the northeast. Here a flysch-like sequence of fine- to medium-grained argillaceous sandstone interbedded with slate contains obscure graded bedding, rare cross bedding near the top of same sandstone units, excellent slaty cleavage showing cleavage refraction from sandstone to slate beds and some beds of medium-grained quartzite near the top of the section. The argillaceous sandstone beds

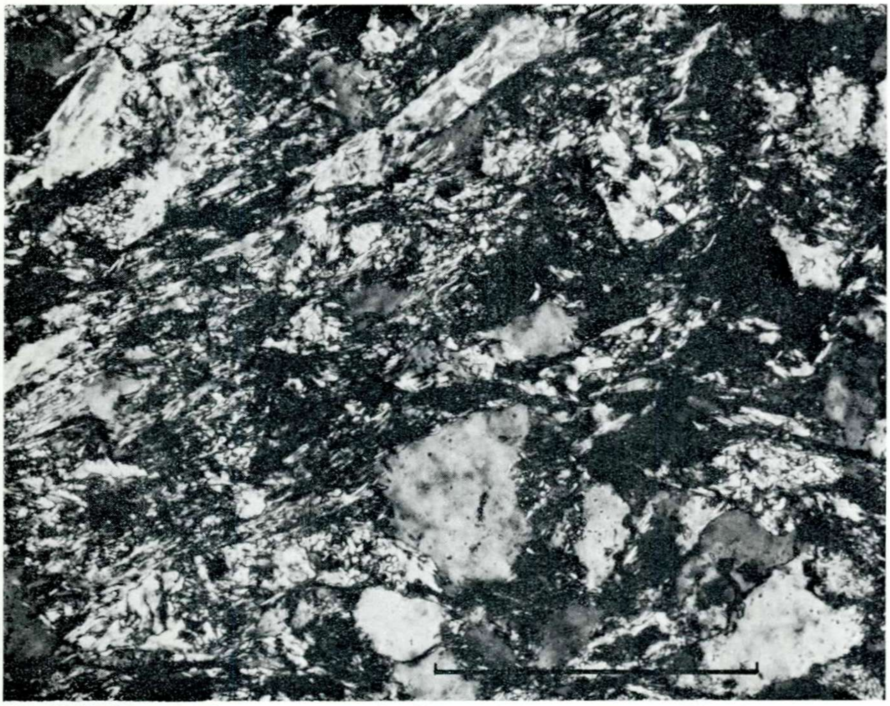


Fig. 20. Holseter sandstone quartz wacke (Spec. 38). bar = .25 mm. (Photo).

are slightly limy and weather to a characteristic light gray, but are dark gray on fresh surfaces. Rich in sericite matrix and poor in rock fragments or feldspars, they are classed as quartz wackes (Fig. 20).

Unnamed Cambrian (?) slates and quartzites of Røssjøkollan litho-tectonic units

Slates and quartzites occurring in Røssjøkollan litho-tectonic units have not been subdivided or precisely correlated with rocks of other areas or with other litho-tectonic units, even though it is obvious that they belong to the 'Cambrian slate, sandy slate and sandstone' and the Mellsenn Division of Strand (1938, pp. 12–28 and geologic map, Nordre Etnedal). Most well exposed, fossiliferous, sections in these rocks are 10 or 20 kilometers to the west of this region and it is not presently clear if the same detailed stratigraphy persists in the Røssjøkollan area. Strand's Mellsenn Division (now referred to as the Mellsenn Group, Nickelsen 1967, Loeschke 1967, and considered Eocambrian and Cambrian) is present only as a thin, highly tectonized, quartz mylonite in Røssjøkollan litho-tectonic unit 2, the eastern, tectonically-thinned equivalent of a more representative Mellsenn section exposed 4 and 9 kilometers to the west at Djuptjernskampen and Reinehamran. This quartz mylonite is quite obvious at the main cliff on the south face of Røssjøkollan and is well-exposed and less tectonized on the south face of Solskiva (Fig. 21).

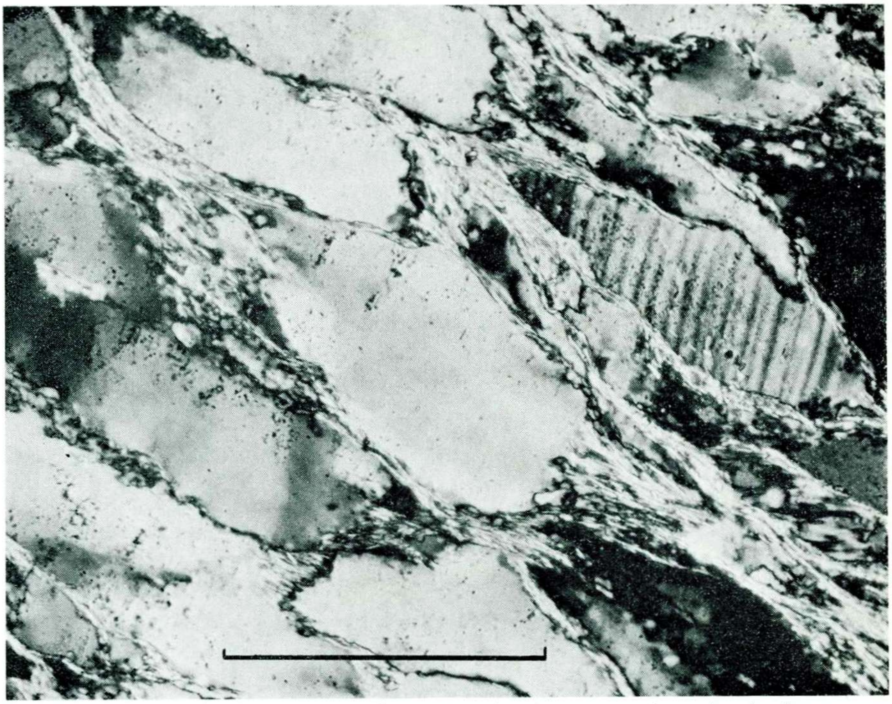


Fig. 21. Mellsenn feldspathic arenite (Spec. 156) showing quartz elongation in thrust zone at Solskiva. bar = .25 mm. (Photo).

The larger area of folded slates and quartzites in Røssjøkollan litho-tectonic unit 4 is considered Cambrian by Strand (1938) but does not correlate precisely with sections of that age in Dokkvatn litho-tectonic units. Because of the tight folding and poor exposures it is difficult to piece together a composite section of the rocks in Røssjøkollan litho-tectonic unit 4. However, one part of the section which is believed to be continuous and which is repeated elsewhere is fairly well exposed northeast of the bend in the Gausdal–Fagerness Road which one kilometer north of Sæbu–Røssjøen and 500 meters west of Storlæger. The dip averages 30 degrees to the northeast and the section is not overturned because it is the same as a normal section measured at Helleset seter, 14 kilometers to the west. In descending sequence it contains:

1. Light gray, yellow-stained, coarse-grained, calcite-cemented, well-rounded quartz arenite. This is characteristically a well-winnowed unit, elsewhere containing planar cross bed units up to 1 meter thick. Approximately 20 meters thick.
2. Light greenish gray slate with 1 cm thick fine- to medium-grained quartz arenite beds. Approximately 5 meters thick.
3. Grayish red purple slate. Approximately 5 meters thick.
4. Mottled greenish gray to light greenish gray slate. Approximately 5 meters thick.

5. Grayish red purple slate. Approximately 10 meters thick.
6. Covered interval – 20 meters.
7. Medium gray, medium-grained, quartz arenite forming the hill northeast of the road. Approximately 20 meters thick.
8. Greenish gray silty slate on slope leading down to road. Approximately 5 meters exposed.

Elements of this stratigraphy can be traced southwest to the east end of Sæbu–Røssjøen where red and green slates overlie a lower quartzite which crosses the Gausdal–Fagernes road just south of the east end of the lake. This quartzite contains beds of a very distinctive dark gray and white quartz–feldspar grit that is believed to be the lowest unit recognized so far in Røssjø-kollan litho-tectonic unit 4. The grit does not appear north or east of here but occurs in Synnfjell and southwest of Steinsetfjord in areas mapped as Synnfjell sandstone by Strand (1938). Later Strand (1954, p. 22) questioned continuing the name Synnfjell Sandstone and used the name Quartz Sandstone instead for Eocambrian rocks similar (Strand 1954, p. 28, 29) to the quartz–feldspar grit at Sæbu–Røssjøen. In summary, Røssjøkollan litho-tectonic unit 4 contains a sequence of quartzites and red purple or greenish gray slates underlain by quartzites with beds of characteristic quartz–feldspar grit identified elsewhere as a component of the Eocambrian Quartz Sandstone (now called Vangsås Formation). The section seems to represent the Eocambrian–Cambrian transition recognized in the Mellsenn Group on Mellane and in Dokkvatn litho-tectonic units described above. Because it is a different facies of this succession no exact correlation of subunits is possible.

SUMMARY OF ROCK CORRELATIONS AND CHARACTERISTICS

Since all litho-tectonic units are thought to be allochthonous it is appropriate to summarize their gross similarities or differences to suggest what units may have been derived from the same or different sources. The sequence in each of the litho-tectonic units may include rocks from some or all of the following groups: 1. Crystalline basement, 2. Valdres–Moelv sedimentary rocks, 3. Eocambrian Vangsås or Cambrian sedimentary rocks and their equivalents. Each litho-tectonic unit may take on distinctive characteristics either because it is comprised of different combinations of the three basic rock groups or because it is comprised of distinctive facies of the groups. Table 2 shows the three group headings and the different facies (A, B, or C) that have been recognized. Litho-tectonic units where the facies have been identified are listed as examples under each facies.

Table 3 shows the various combinations of groups and facies that have been identified in the eight litho-tectonic units.

Røssjøkollan litho-tectonic units 1 and 3 are both comprised of similar gabbroic basement and thick Valdres sections containing the Ormtjernskampen Conglomerate facies. These characteristics persist for at least 10 km along strike to the northwest and demonstrate the affinity of the two units. They

Table 2. Definition of rock groups and facies in litho-tectonic units

1. Basement	2. Valdres–Moelv	3. Eocambrian Vangsås, Cambrian, and equivalents
A. Gabbro ex. Røssjøkollan 1 Røssjøkollan 3 B. Quartz syenodiorite ex. Dokkvatn B	A. Thick Valdres section with Ormtjernskampen Conglomerate; Tillite absent ex. Røssjøkollan 1 Dokkvatn A B. Valdres absent; Tillite rests on basement ex. Dokkvatn B	A. Section including: Quartzite and slate of the Dokkvatn Fm. Two Obleikhaugen Quartzites Hornsjøkampen feldspathic sandstone ex. Dokkvatn A Dokkvatn B Dokkvatn C (partial) B. Mellsenn section ex. Røssjøkollan 2 C. Cambrian(?) section equivalent to sections at: Synnfjell, Steinsetfjord, and Helleset seter ex. Røssjøkollan 4

Table 3. Rock groups and facies identified in each of the eight litho-tectonic units

Litho-tectonic units	Groups (1, 2, 3) and facies (A, B, C)		
	1. Basement	2. Valdres–Moelv	3. Eocambrian–Cambrian above Moelv Tillite
Røssjøkollan 1	A	A	–
Røssjøkollan 2	–	–	B
Røssjøkollan 3	A	A	–
Røssjøkollan 4	–	–	C
Dokkvatn A	–	A	A
Dokkvatn B	B	B	A
Dokkvatn C	–	–	A

are apparently derived from the same source area and could not be differentiated except for the mylonitized thrusts and the Mellsenn quartzites and slates of Røssjøkollan litho-tectonic unit 2 that separate them. On the other hand, both basement igneous composition (gabbro versus quartz-bearing syenodiorite) and the thickness and composition of sedimentary rocks overlying basement (thick section of Valdres Group sparagmite and Ormtjernskampen Conglomerate versus Moelv Tillite resting unconformably upon basement) indicate that the source for Røssjøkollan litho-tectonic units 1 and 3 is somewhat different from Dokkvatn litho-tectonic unit B. By analogy with Moelv Tillite, older Sparagmite relationships at the interior and margins of the Mjøsa Sparagmite Basin to the east (Skjeseth 1963, Plate II), Røssjøkollan litho-tectonic units 1 and 3 are thought to be derived from the interior, and Dokkvatn litho-tectonic unit B derived from the margin or an interior high, of an

Eocambrian sedimentary basin. If all litho-tectonic units mentioned above are allochthonous then we must hypothesize a tectonic root in a sedimentary basin to the north or northwest, perhaps a western extension of the west--northwest trending Sparagmite Basin margin suggested by a gravity survey (Ramberg & Englund 1969, p. 317, Fig. 6) along upper Gudbrandsdalen.

But Dokkvatn litho-tectonic unit B may also be autochthonous. Because of regional stratigraphic (Skjeseth 1963, Pl. II), sedimentologic (Løberg 1970, pp. 171–173) and geophysical (Ramberg & Englund, Fig. 6) reasons, previous workers in the region have placed the southwest margin of the classical Eocambrian Mjøsa Sparagmite Basin east of the Dokka, passing north through Gausdal and northwest along Gudbrandsdalen. It is thus possible that the Moelv tillite resting upon basement in Dokkvatn litho-tectonic unit B is an exposure in an autochthonous window on the basement platform southwest of the Mjøsa Sparagmite Basin. Two sets of observations oppose this interpretation. First, Løberg (1970, pp. 170–171) has described the Biskopåsen conglomerate along the western margin of the Mjøsa Sparagmite Basin in Vestre Gausdal, only 10 kilometers east of the Dokka. Here increase in boulder size and imbrication of boulders both indicate a western source for the grains in the Biskopåsen conglomerate but the boulder composition of gray granite, gneiss, and quartzite is different from what would be expected to be derived from the quartz-bearing syenodioritic basement of Dokkvatn litho-tectonic unit B. Second, the Vangsås Formation stratigraphy of both Dokkvatn litho-tectonic units A and B is the same and apparently allochthonous because it does not conform to the autochthonous section that is suggested for this area by an extension of the Skjeseth map (1936, Pl. II). Thus, on sedimentologic and stratigraphic grounds, Dokkvatn litho-tectonic unit B is thought to be allochthonous and derived from the margin of the same Eocambrian basin whose center served as the tectonic root for the Røssjøkollan (1 and 3) and Dokkvatn (A) litho-tectonic units.

Dokkvatn litho-tectonic unit A differs from Røssjøkollan 1 and 3 in not containing any basement rock massifs, although the coarseness, thickness, and immaturity of the Ormtjernskampen Conglomerate certainly suggests a nearby basement source during the deposition of the Precambrian sediments in the unit. More disturbing to suggestions that there is an approximate equivalence of source for Røssjøkollan 1 and 3 and Dokkvatn A and B are the differences between the Eocambrian–Cambrian parts of the sections contained in these litho-tectonic units. Indeed, the Eocambrian–Cambrian section is not present at all in Røssjøkollan 1 and 3, whereas in Dokkvatn litho-tectonic units A, B, and C it is expressed as facies A. At the present time there is just not enough stratigraphic information to compare the highly tectonized Mellsenn of Røssjøkollan litho-tectonic unit 2, which is everywhere associated with Røssjøkollan 1 and 3, with the Eocambrian–Cambrian rocks in the Dokkvatn litho-tectonic units. It is true that the stratigraphy of the Dokkvatn units and the type Mellsenn of the Mellane section can be correlated (see Table 4, columns 4 and 5) but there seems to be stratigraphic differences between the type Mellsenn and the Mellsenn mapped by Strand (1938) in Nordre Etnedal at

Table 4. Regional correlation chart

	Gausdal K. O. Bjørlykke, 1893, N.G.U. 13, pp. 13–20	Fåvang district J. Englund, 1966, N.G.U. 238, pp. 79–82	South Norway Eocambrian K. Bjørlykke et al. 1967, N.G.U. 251, p. 7		Røssjøkollan–Dokkvatn area Dokkvatn litho-tectonic units	Mellane R. Nickelsen 1967, N.G.U. 243 C, Table 1, p. 116	
	Sandstenskifer, 2–300 m interbedded dark gray sandstone and slate or sandy slate	*Svinslåen Sandstone*, gray sandstone with interbedded slate			*Holseter Sandstone*, light gray weathering, dark gray, fine to medium grained sandstone	Unit Numbers – Table 1	
	Graptolitskifer, 150 m dark gray clay slate bearing graptolites of stages 3 and 4. Lower to Middle Ordovician	Dark gray to black clay slate, 40 m			*Holsbru Slate*, dark gray, brown weathering slate / / / / / / / / / / / / / / / section not continuous / / / / / / / / / / / / / / /	1 4a Graptolites Lower Middle Ordovician	↑ Mellsenn Group
Quartzite Formation	Gray slate, limy sandstone, limestone, green slate, ½ m plus			Dokkvatn Formation	Gray laminated slate, 2–4 m dark gray slate (quarried locally) greenish gray slate, 2–4 m dark gray slate, 2–4 m	2	Mellsenn Group
Quartzite Formation	Quartzite, 5–50 m, white, grayish, bluish, 'so-called blåkvarts' (p. 15)	*Kvitfjell Quartzite*, 60–70 m Upper – light gray with bluish tint – Lower – gray to dark gray possibly Lower Ordovician		Dokkvatn Formation	*Quartzite*, 20 m dark to light gray, pebbly and limy at the top	3	Mellsenn Group
Quartzite Formation	Green or gray green slate, 45 m, locally red violet to brown violet[1]	*Svartskar Slate*, 15–20 m, greenish clay-silt shale, darker in upper part. Probably Lower Cambrian		Dokkvatn Formation	Slate, 30 m laminated greenish gray slate	4	Mellsenn Group
Quartzite Formation	*Sparagmitsandsten*, > 12 m	*Vemdal Sandstone*, 100–130 m, not bipartite, quartz content and grain size increase upward	Vangsås Formation: Ringsaker Quartzite Vardal Sandstone	Vangsås Fm.	*U. Obleikhaugen Quartzite*, 20–30 m greenish gray sandy slate *L. Obleikhaugen Quartzite*, 20–30 m pale red purple slate *Hornsjøkampen Sandstone*, 50–140 m	5 6 Slate Quarry 7 8, 9	Mellsenn Group ↓
Quartzite Formation	Gray or greenish leirskifer, 2–6 m	Ekre Shale, 0–15 m	Ekre Shale	Snæreskampen Fm.	Ekre Shale / Green Slate	10	Valdres Sparagmite
		Moelv Conglomerate	Moelv Tillite	Snæreskampen Fm.	Moelv Tillite / Ormtjernskampen Conglomerate of Valdres (Sparagmite) Group Sandstone Precambrian Mangerite Basement	11, 12?	Valdres Sparagmite

[1] I have seen ony gray and greenish gray slates at this stratigraphic position. It is possible that Bjørlykke did not recognize the proper position of the red purple slates of the underlying Vangsås Fm.

Svarthamar, Helleset and Synberg. At the present time, it is concluded, on the basis of basement and Precambrian stratigraphy, that the Dokkvatn A and B and Røssjøkollan 1 and 3 litho-tectonic units are derived from the interior and margin of the same Sparagmite Basin and that inadequate evidence from Eocambrian–Cambrian stratigraphy does not dispute this interpretation. The Eocambrian–Cambrian stratigraphy of Røssjøkollan litho-tectonic unit 4 does suggest another facies and precludes a common source with the other Røssjøkollan and Dokkvatn litho-tectonic units.

The triangular diagram of Fig. 10 graphically illustrates variation in grain composition and matrix content while progressing up section through the Valdres Group, Vangsås Formation, Mellsenn Group, Quartzite in the Dokkvatn Formation and Holseter Sandstone. Two up section trends are apparent – feldspar content decreases and matrix content first decreases to a minimum in the Obleikhaugen–Dokkvatn quartzites and then increases in the Holseter Sandstone.

Arenaceous beds in the Valdres Group are most typically arkosic arenites or, in some cases, arkosic wackes (Figs. 12 & 13). Except for the two patches of granite north or Røssjøkollan no suitable source rock for these sediments is known within the allochthonous basement slices of the region. Interbedded with the more normal arkosic arenites are some rare sedimentary rock types such as numbers 51 and 183 containing 60–70% unstable basic rock fragments, amphibole, accessories, and some quartz and feldspar but little recognizable matrix (Table 1, Fig. 11). They were plotted on the triangular diagram by grouping: quartz and opaques, feldspar and amphibole, rock fragments. Apparently they are immature derivatives of a nearby basic igneous rock source such as the basement gabbro of Røssjøkollan.

Specimens of the Hornsjøkampen Sandstone above the Ormtjernskampen Conglomerate member plot across the boundary of the fields of feldspathic arenite and arkosic arenite but many specimens contain sufficient matrix to be classed, marginally, as wackes (Table 1; Figs. 10, 16). They clearly follow the trend toward decreasing feldspar and rock fragments as one moves up in the section.

The lowest feldspar and matrix content is found in the Obleikhaugen and Dokkvatn Quartzites of Dokkvatn litho-tectonic units A and B (Figs. 17, 19). The presumably equivalent Mellsenn Quartzite from Røssjøkollan litho-tectonic unit 2 at Solskiva (specimen 156) is slightly more feldspathic (Fig. 21). Specimen 168 of the upper part of the Dokkvatn Quartzite is rich enough in matrix and exotic rock fragments to be classed a subfeldspathic lithic wacke. This horizon perhaps denotes a period of tectonic unrest referred to as the Trysil Disturbance of Arenig (3b) time (Skjeseth 1963, p. 111).

Holseter Sandstone specimens are feldspar-poor but rich in matrix, comprising a petrographically distinct group of quartz wackes (Fig. 20). Their textural immaturity but paucity of feldspar suggests a new source area, and supports the impression gained from field observation of graded bedding and flysch-like slate-sandstone interbeds that processes of sedimentation were different from those which existed previously.

Fig. 22. Røssjøkollan rising above Veslefjell, Storlæger in the foreground. (Photo).

Structure

FAULTS

Two major genetic grouping of faults are present in the Røssjøkollan–Dokkvatn area; thrust faults that bound the allochthonous litho-tectonic units and steeply dipping faults of small separation that are best observed as lineaments on air photos.

Thrust faults

Eight litho-tectonic units are differentiated in the Røssjøkollan–Dokkvatn area on the basis of differing stratigraphy, definite structural boundaries, and physical separation (Fig. 2). In the 'Summary of Rock Correlations and Characteristics' it was concluded that the Dokkvatn A and B and the Røssjøkollan 1 and 3 litho-tectonic units could have been derived from the same general root zone, but no physical connection between Dokkvatn and Røssjøkollan litho-tectonic units can be made across the northwest-trending drift-filled valley of Snærevatn. Within both the Dokkvatn and Røssjøkollan groups there are well-marked boundaries between litho-tectonic units.

The best exposure of thrust faults in the area is on the south face of Røssjøkollan where all Røssjøkollan litho-tectonic units are present (Fig. 22). The Eocambrian–Cambrian quartzites and slates of Røssjøkollan litho-tectonic unit 4 are complexly folded on west northwest trending fold axes in the Veslefjell plateau above Storlæger (foreground of Fig. 22). Fig. 23 is a closer view of Røssjøkollan rising above the quartzites of Veslefjell. Near the base of the slope leading up to Røssjøkollan is highly-sheared green schist dipping uniformly 20 to 30 degrees to the north northwest and clearly discordant with

Fig. 23. South face of Røssjøkollan from Veslefjell. Three thrusts bounding four litho-tectonic units are marked by arrows. (Photo).

the underlying slates and quartzites. These rocks are the highly tectonized gabbro basement and Valdres Sparagmite of Røssjøkollan litho-tectonic unit 3 which lies in thrust contact above unit 4. Above unit 3 is less than one meter of quartz mylonite, which is interpreted to be the feather edge of Røssjøkollan litho-tectonic unit 2, a unit which to the west is thicker and comprised completely of Mellsenn quartzites and slates. In thin section the quartz mylonite is extremely fine-grained with the aphanitic crushed rock between porphyroclasts averaging .01 mm. Porphyroclasts which make up less than 10% of the rock are commonly less than .1 mm in diameter but a few reach .2 mm. Recrystallized zones which anastamose through the rock approximately paralleling the megascopic foliation have grain size of .03 to .05 mm and are spaced .1 to .5 mm. Composition is dominantly quartz with a few % of mica. Feldspar, known to occur in the Mellsenn group, was not identified. The rock is an ultramylonite in the terminology of Higgins (1971, p. 9). Above the quartz ultramylonite is the gabbro of Røssjøkollan litho-tectonic unit 1 which is well-foliated parallel to the thrust contact but passes into massive gabbro as one ascends to the peak of Røssjøkollan. Approximately the top half of the mountain, extending upward from the base of the cliff, is comprised of Røssjøkollan unit 1 (Fig. 23).

A similar clear definition of Røssjøkollan litho-tectonic units is available in the stream that flows south into Sæbu–Røssjøen from Solskiva. Ascending this stream toward the base of Solskiva one crosses the folded Eocambrian–Cambrian sequence of Røssjøkollan unit 4. The last exposure is a quartzite striking 310 and dipping vertically. Across a small marsh the Valdres and/or gabbro, expressed as hignly sheared green schist, crops out dipping 30 degrees north west, in what is apparently the base of Røssjøkollan unit 3. Gabbro and Valdres sediments within this unit cannot be differentiated in the field because of intense shearing but thin sections from samples collected at different places within the unit have revealed both relict clastic and igneous textures. The unit thickens and is less deformed 9 km to the northwest in the Svarthamar, Fullsenn, Reinehamran area where it is dominantly comprised of Valdres arkosic arenites or wackes but also contains a few beds of conglomerate with gabbro detritus and some slices of gabbro basement which are confined to the basal thrust plane.

Above unit 3, Røssjøkollan unit 2 is represented by a thicker, less mylonitized section of Mellsenn quartzite and slate than is present on Røssjøkollan itself. A quartzite from the Mellsenn has been described in Table 1 (specimen 156) and illustrated in Fig. 21. The photomicrograph was prepared from a cut parallel to quartz grain elongation and perpendicular to the foliation which parallels the thrusts at the borders of units. This quartzite illustrates the quartz elongation, crushed quartz, undulose extinction, and acutely intersecting shear and mica-growth planes that are characteristic of protomylonites (Higgins 1971, p. 7).

The gabbro of Røssjøkollan unit 1 occurs in thrust contact above the section of mylonitized quartzite. Clearly, the same sequence of litho-tectonic units occurs on both Solskiva and Røssjøkollan but it is interesting to speculate on the changing character of units 2 and 3 as they are traced the two kilometers westward from Røssjøkollan and then correlated with the same litho-tectonic units occurring 9 kilometers farther to the west in the Fullsenn area. The trend in both units is toward greater thickness and less intense mylonitization as they are traced westward. Thus, as they are traced eastward through and beyond Røssjøkollan, if this trend continues, they may be expected to thin to highly mylonitized selvages and finally to disappear or be replaced by other tectonic units. Because a steeply dipping fault in the valley between Røssjøkollan and Snuen displaces the thrust planes down to the east they are generally not visible along the south face of Snuen. Only at Rokkvomseter is it possible to see highly folded slate discordant below the Valdres Sparagmite which is exposed in the cliffs and steep slopes behind the seter. On the basis of this one incomplete exposure it is impossible to decide which of the Røssjøkollan litho-tectonic units is exposed here. Because Røssjøkollan litho-tectonic units 2 and 3 both seem to be thinning toward the east, it is possible that unit 1 is resting directly on unit 4, or perhaps unit 1 is in thrust contact with unit 2 which is thickening again to the east in contradiction to the eastward thinning trend described above. Of the two possibilities, the former seems to be the better interpretation.

Although thrust faults must occur at the base of Røssjøkollan litho-tectonic units 1 and 3 to explain the juxtaposition of rocks, it is not certain in the Røssjøkollan area that a thrust separates the Mellsenn group of unit 2 from the underlying Valdres and basement rocks of unit 3. However, when these tectonic units are observed in the Fullsenn area, where they are thicker and

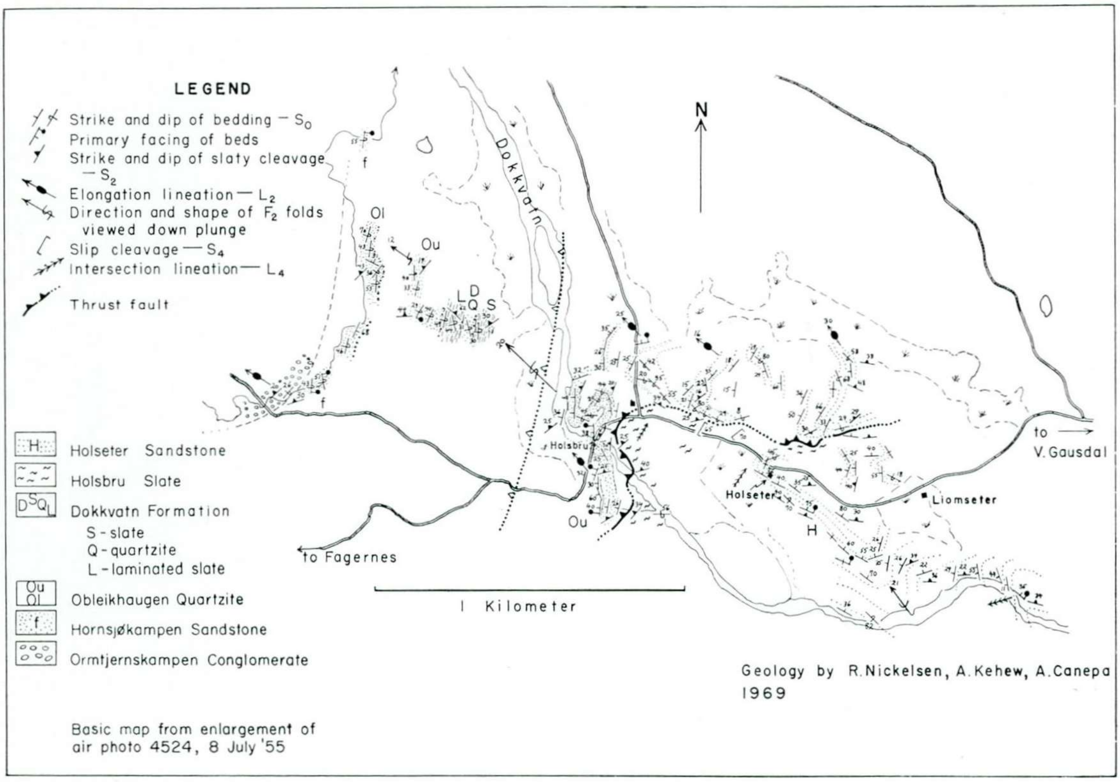


Fig. 24. Geologic map of Holsbru area.

less deformed, it becomes quite clear on the basis of structural and lithologic contact relations that Røssjøkollan litho-tectonic unit 2 is bounded at both top and bottom by thrust faults.

The thrust fault at the base of Dokkvatn litho-tectonic unit C is exposed at a number of places along the Dokka River and also in the cliff north of the road at Holseter (Plate 1; Fig. 24). At all exposures along the Dokka south of the bridge the thrust brings the greenish gray slate below the upper Obleikhaugen Quartzite over the dark gray Holsbru Slate. At most places along the Dokka the thrust plane is marked by lenses of quartzite but in the exposure of gray and green slates along the road east of the bridge over the Dokka the thrust is difficult to pick out because only a change in color marks its location. In the exposure in the cliff north of the road at Holseter, quartzite is thrust over an overturned section of Holsbru Slate.

Along the Dokka, the cleavage in the greenish gray sandy slate above the thrust parallels the thrust but the cleavage (S_2) in the underlying Holsbru Slate meets the thrust at an acute angle. The thrust changes attitude from northeast strike and northwest dip to northwest strike and northeast dip as it is traced through the Dokka valley and also goes through local abrupt changes in strike and dip, all of which suggest that it has been folded after formation.

The major thrust at the base of Dokkvatn litho-tectonic unit A is not

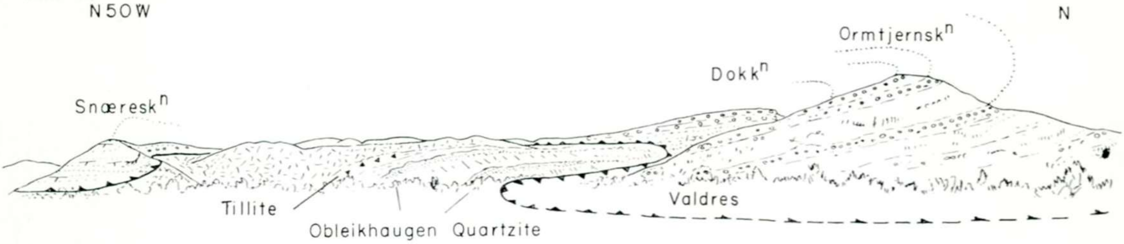


Fig. 25. Drawing of panoramic view Snæreskampen to Ormtjernskampen from road near Uppsjøhytta.

exposed anywhere in the region although there is good evidence of its existence at a number of places. It is known to exist along the Dokka in the line of structure section 4, Plate 2 because the Eocambrian–Cambrian section at the east front of Dokka unit A is overturned and rests upon an incomplete section of similar age in unit C that is right side up. On the southwest shore of Hornsjøen at a small cove the thrust brings sandstones and the Ormtjernskampen Conglomerate of the Valdres Group into contact with Obleikhaugen and Hornsjøkampen quartzites and slates (Plate 1). Here the thrust rolls over to a north or northeast dip and the underlying units are exposed in a half window on the peninsula southeast of the cove. There are excellent exposures of deformed conglomerate above the thrust on the shore of the peninsula south of the cove.

Fig. 25, a sketch from photographs of the panoramic view of Snæreskampen and Ormtjernskampen, shows the trace of the basal thrust along the south side of Dokkvatn litho-tectonic unit A. It is clear that the essentially vertical beds of Dokkvatn unit B must be terminated upward by a folded thrust in the half window west of Ormtjernskampen. What is not so clear is the relationship between Dokkvatn litho-tectonic units B and C. They cannot be traced into one another due to the lack of exposures in the Snærevatn–Uppsjøen valley and I have inadequate information on the complete rock sequence in the two units outside of the small areas that have been mapped. They have been classed as two separate litho-tectonic units because physical continuity cannot be established, because the basement-tillite relationship in the apparently allochthonous Dokkvatn litho-tectonic unit B is unique in the region, and because of fold facing evidence that is discussed in the section on Structural History.

Steeply-dipping faults

On Røssjøkollan, steeply dipping faults trending northeast (5) and northwest (320) displace Røssjøkollan litho-tectonic units down to the northeast or east. The separation of the fault trending 320 in the valley between Snuen and Røssjøkollan has displaced the thrust planes at least 60 meters down to the northeast. It is this fault which brings the gabbro basement of Røssjøkollan into contact with the Ormtjernskampen Conglomerate and Valdres Group sparagmite of Snuen (Plate 1).

These faults are paralleled by many other topographic lineaments of similar trend along which no faulting has been proven. Eight kilometers to the west at Røssjøen the north-south topographic lineament forming the south arm of lake parallels a Permian essexite dike which is an en-echelon continuation of a dike zone extending 130 kilometers north-northwest from the Oslo region (Strand 1938, 1954; Holtedahl & Dons 1960). Other north and northwest trending topographic lineaments in the North Etnedal and Aurdal map areas parallel the trend of this dike and these topographic lineaments appear much like those in the Røssjøkollan–Dokkvatn region. The trend, steep dip, displacement down to the east, and lack of relationship to Caledonide structures all point to a post-Caledonide, possibly Permian age for these structures.

PENETRATIVE STRUCTURES

Introduction

The rocks of the area are mildly to intensely deformed low grade metamorphics in which little recrystallization has occurred. Consequently, there is good preservation of relict structures and textures. Bedding can be observed even in slates or phyllites with well-developed slaty cleavage and earlier S-planes have not been obliterated by the several later slip cleavages. One is initially surprised at the intensity of strain and many phases of deformation recorded in some of these rocks (Table 5). Intense strain is demonstrated by folds with isoclinal limbs and U-shaped hinges lying in the prominent foliation, as well as the thick zones of mylonite, protomylonite and polygonally sheared rock near the major thrust faults. Bedding (S_0) is readily visible in all sedimentary rocks except the coarse Ormtjernskampen Conglomerate and Obleikhaugen or Dokkvatn Quartzites. Primary sedimentary facing directions have been determined from: graded beds in the Ormtjernskampen Conglomerate Member and the Holseter Sandstone, and cross-bedding in the Valdres Sparagmite, the Ormtjernskampen Conglomerate, the Obleikhaugen Quartzite and the Holseter Sandstone.

They have been particularly important in establishing fold geometry and facing directions around the U-shaped hinges. The quartz-bearing syenodiorite of Dokkvatn litho-tectonic B has prominent primary (?) foliation comprised of both textural banding and compositional differences between layers (more or less amphibole abundance). Where amphiboles are present they are oriented randomly in the plane of foliation. The gabbro of Røssjøkollan does not contain primary layering or foliation. The first Caledonian metamorphic foliation in this area is a penetrative slaty or phyllitic (S_2) cleavage which is the plane of pebble flattening and elongation (Table 5). It is followed by as many as three (S_3, S_4, S_5) different sets of steeply dipping slip cleavages striking north-northwest, northeast and east-west.

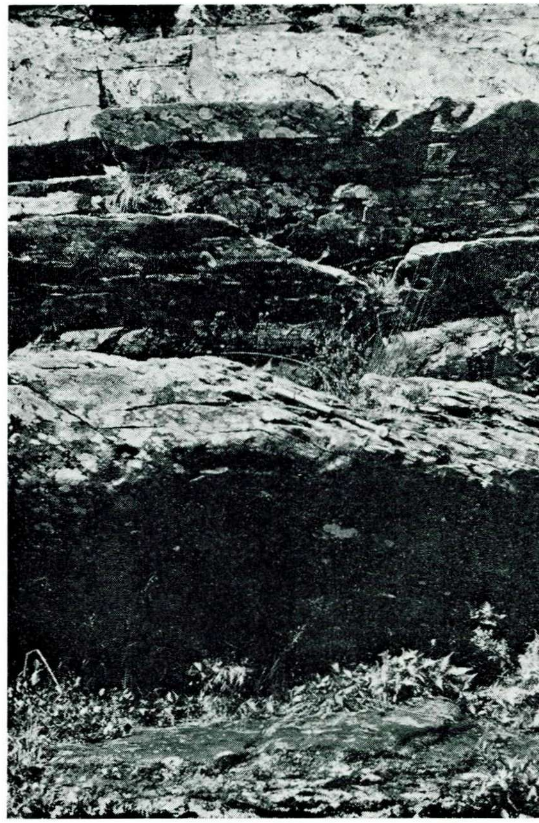
Linear structures include the pervasive northwest elongation of grains, pebbles and boulders, intersections between various S-planes, small scale fold hinges, and slickensides associated with either thrust boundaries or grain boundaries. The latter minute slickensides recording slip between grains during elongation and intergranular adjustment are parallel to grain elongation.

Table 5. Deformation phases

Age	Designation	Description and orientation	Where observed
Precambrian	P	Primary foliation of textural and compositional layering.	Precambrian basement, quartz-bearing syenodiorite, Dokkvatn litho-tectonic Unit B.
	D_1	Thrusting, emplacement and overturning of sedimentary rocks of allochthonous nappes. No penetrative cleavage or lineation; F_1 folds of hypothesized NE trend.	Precambrian, Eocambrian and Paleozoic rocks of all litho-tectonic units
	D_2	Penetrative flattening and flow, producing north-dipping slaty cleavage (S_2) and northwest elongation lineation. Large and intermediate F_1 fold hinges rotated toward the northwest and new F_2 folds created with S_2 axial plane and L_2 cleavage-bedding intersection. F_1–F_2 folds face both northeast and southwest.	Precambrian, Eocambrian and Paleozoic sedimentary rocks of all litho-tectonic units.
Caledonide	D_3	Minor fold crenulations and slip cleavage (S_3) striking 335 to 350 with dip to northeast.	Slates and phyllites of litho-tectonic units – Røssjøkollan 4 and Dokkvatn D. Perhaps folding of thrust plane at Holseter on the Dokka.
	D_4	Most common late structure with fold crenulations and slip cleavage (S_4) striking 25–50 and dipping southeast.	Slates and phyllites of litho-tectonic units. Røssjøkollan 3 and 4 and Dokkvatn C and D.
	D_3+	Locally developed fold crenulations and slip cleavage (S_3+) striking 75 to 90.	Holsbru Slate in Dokkvatn litho-tectonic Unit D.
	D_2+	Folding of a thrust and renewed thrusting producing drag and rotation of bedding (S_0) slaty cleavage (S_2) and cleavage-bedding ($S_0 \wedge S_2$) intersections.	Slates of Røssjøkollan litho-tectonic Unit A on Snæreskampen. Perhaps correlates with D_3 above.
Post Caledonide (Permian?)		Steeply dipping faults of northeast (5) and northwest (320) strike.	Displace all Røssjøkollan litho-tectonic units.

Folds range in scale from the large overturned to recumbent folds that control the map pattern within Dokkvatn litho-tectonic unit A, through folds of intermediate size that are most apparent within the Eocambrian–Cambrian sequence of Røssjøkollan litho-tectonic unit 4, the Obleikhaugen Quartzite of Dokkvatn litho-tectonic unit C or the Holseter Sandstone of Dokkvatn unit D, to small crinkles associated with the various slip cleavages in slates or phyllites. Outcrop-sized or smaller parasitic folds congruent with the movement pattern and known facing of large or intermediate size folds are rare, having been noted at only one locality shown in Fig. 24. The large and intermediate sized folds show evidence of early initiation during emplacement of allochthonous nappes followed by distortion during pervasive elongation in a northwest–southeast direction.

Fig. 26. Upper Obleikhaugen quartzite viewed down dip perpendicular to bedding (S_0) slaty cleavage (S_2) intersection. Holsbru. (Photo).



Structural history

The oldest structure recorded in the rocks of the area is the foliation of the basement rocks in Dokkvatn litho-tectonic unit B which is clearly Pre-Cambrian, not Caledonide, because it is truncated by Pre-Moelv (Eocambrian) erosion at the unconformity east of Ormtjernskampen (Fig. 3). Granite and gabbro basement was probably the source of the Precambrian Valdres Group and Ormtjernskampen Conglomerate, the Eocambrian Hornsjøkampen/Sandstone, Obleikhaugen Quartzite, and the Cambrian Dokkvatn Formation. The first Caledonian deformation episode (D_1) brought both source rocks and derived sedimentary rocks to the Røssjøkollan/Dokkvatn area, where they now exist as a number of thrust-bounded allochthonous nappes.

Description of deformation phases D_1 and D_2. Structures of these phases are thrusts that bound the litho-tectonic units, and F_1 folds that have been modified by the second deformation phase, D_2. F_1 folds now have arcuate hinges, convex to the southeast, and verge to the east, southeast, and southwest. They probably originally trended northeast but have been rotated during progressive deformation toward the longest axis of the deformation ellipsoid, the elongation lineation oriented 300° ± 20° (Flinn 1962). Fig. 28a, a stereonet plot of slaty cleavage (S_2) and elongation lineations in the whole

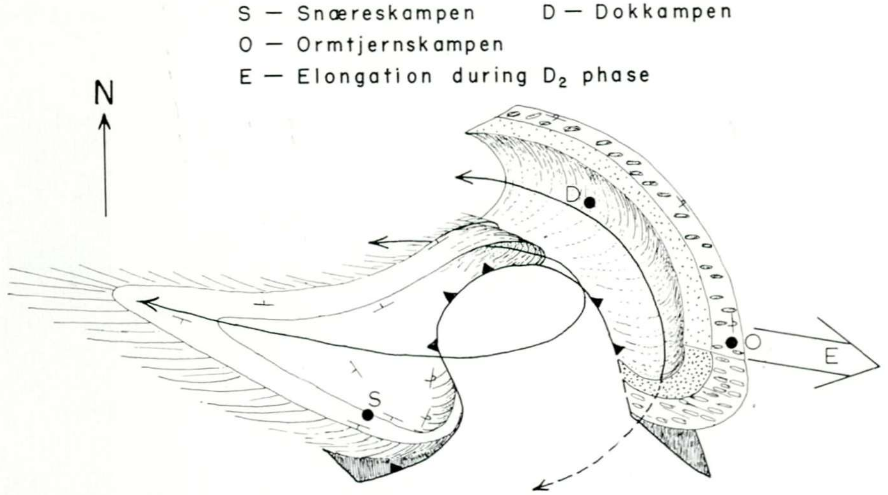


Fig. 27. Three-dimensional sketch of Ormtjernskampen–Snæreskampen fold.

Røssjøkollan/Dokkvatn area, shows the spread in orientation that occurs in these structures which played such an important role in the second deformation phase.

The only example of a large scale F_1 fold with an arcuate hinge resulting from the second phase of deformation is exposed on Ormtjernskampen, Dokkampen, and Snæreskampen (Plate 1; Fig. 27). Bedding poles on Ormtjernskampen and Dokkampen define a π axis which strikes 322 (Fig. 28b). This portion of the fold is overturned to the southeast, east, and northeast and bounded in all these directions by the thrust fault at the base of Dokkvatn litho-tectonic unit A. Fig. 28b shows the π axis for the half of the fold that is exposed on Snæreskampen, plunging toward 284 and asymmetric to the southwest. Most elongation lineations of the region trend between the two ends of this arcuate fold (Fig. 28a) and it is inferred that the lineations developed during D_2 simultaneously with the arcuate fold hinge. Fig. 27 is a diagrammatic view of the whole arcuate fold and the elongation lineations within the arc. It is, of course, debatable whether one or two periods of deformation created the fold geometry. Because there is only one foliation, a slaty cleavage labeled S_2, and because there are no examples of F_2 folds superposed on F_1 in this area, it is tempting to suggest only one deformation. On the contrary, two deformations are supported by evidence: 1. that some rocks along the Dokka had been thrust and overturned before penetrative cleavage and elongation lineations formed, 2. that superposed folding and S_2 cleavage or elongation lineations transect F_1 folds in other parts of the region, notably near Steinsetfjord (unpublished personal observation).

No other fold can be traced around an arcuate hinge as in the above example. However, directly north of the Dokka bridge near Holseter in the Obleikhaugen quartzite, an isoclinal, recumbent, medium-sized fold conforms to part of the fold pattern in overlying rocks (Place 1; Fig. 24). The fold

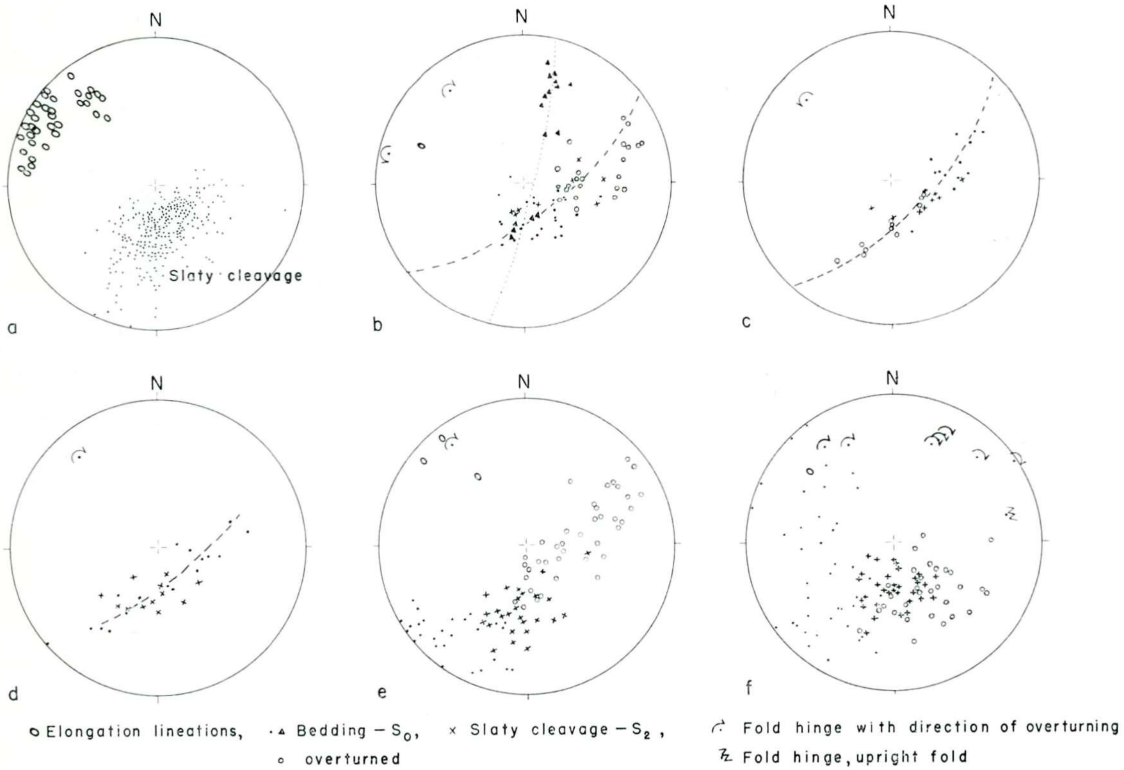


Fig. 28. Stereonet plots of field data.

faces southwest and plunges 20 on a bearing of 314 (Fig. 28c). Primary tops are documented by cross-bedding at the east end of Dokka bridge and at several points west of the Dokka and south of the road (see Fig. 24 for location). The section in Dokkvatn litho-tectonic unit C is predominantly right side up, in contrast to the overturning in unit A above, but is folded on the same northwest axis and contains a similar slaty cleavage orientation. Quartz grains in the quartzite south of the road are elongated (see Fig. 17) parallel to the cleavage-bedding intersection, which here trends 315 parallel to the fold axis of the isoclinal fold. Fig. 26 is a view of the quartzite looking down the plunge of the cleavage-bedding intersection. Thus, there are both similarities and marked contrasts between the structures in Dokkvatn litho-tectonic units A and C. The orientations of fold hinges, elongation lineations and slaty cleavages in the two units are essentially the same but the rocks in unit A are overturned and face east or northeast, whereas in unit C they are right side up and asymmetric to the southwest. Without the excellent primary facing criteria in unit C it would be impossible to establish this interesting geometry.

The alternating pattern is again repeated in the Holseter Sandstone of Dokkvatn litho-tectonic unit D (Figs. 24, 28d), where a fold hinge trending 320 through Holseter is asymmetric toward the northeast. Both cross-bedding and graded beds from outcrops southeast of Holseter prove that this fold faces northeast, and this primary facing evidence is also important in establishing the stratigraphic relationship of the Holseter Sandstone to the Holsbru Formation. Northwest of Holseter the sandstone crosses the road and folds sharply to the east around a steep fold hinge. This part of the structure was not plotted on the stereonet of Fig. 28d because it appeared to be a local anomaly possibly related to the proximity of the thrust above.

The question of the relationship between Dokkvatn litho-tectonic units B and C, left open at the end of the section on Faults, now can be considered in the light of evidence on fold facing directions. Dokkvatn litho-tectonic unit B strikes north and faces east and is thus difficult to correlate with the northwest plunging, southwest-facing fold structures in Dokkvatn litho-tectonic unit C (Plate 1). This line of evidence persuaded me to establish two separate litho-tectonic units beneath Dokkvatn litho-tectonic unit A.

The Valdres Group on Snuen, the eastern half of Røssjøkollan litho-tectonic unit 1, is interpreted as the northeastern half of another arcuate fold such as occurs on Ormtjernskampen–Snæreskampen. Sandstones and beds of Ormtjernskampen Conglomerate dip steeply or are overturned and face northeast as indicated by cross-bedding at three localities. The generalized trend of the π pole determined from 67 bedding attitudes is 320, and 2 smaller downward facing folds in the lower area east of Snuen have π poles trending 324 and plunging 10° northwest (Fig. 28e). Elongation lineations have approximately the same attitude as the π poles and the mean slaty cleavage attitude is 280, dipping 40 degrees northeast. The gabbro basement of Røssjøkollan apparently makes up the core-salient of a fold with limbs trending approximately 320 and asymmetric to both northeast and southwest. Whereas the northeast facing limb is exposed on Snuen, the southwest facing limb is removed by erosion along the south face of Røssjøkollan and can only be seen northwest of Fullsenn at Mybarhamran, 22 kilometres along strike.

The position of the Valdres Group on Snuen relative to the gabbro basement of Røssjøkollan is the same as at Grønsennknipa (Loeschke & Nickelsen 1968, Fig. 10; Hossack 1972). Structural elements of both areas also show similar relationships, and it is reasonable to suggest a similar structural history which includes early thrusting (D_1) followed by (D_2) folding and cleavage-lineation formation along northwest axes. Hossack (1972) has chosen not to separate the early thrusting from his S_1 period of schistosity and elongation lineation formation but it is clear that we are dealing with the same relative sequence. Narrow salients with northeast and southwest facing limbs which trend across the range parallel to the elongation seem to occur at Ormtjernskampen–Røssjøkollan, Grønsennknipa, and at Mellane (Nickelsen 1967) as a unique manifestation of the combination of early thrusting and later penetrative elongation and schistosity formation. More study will be required in additional areas where good evidence of primary up direction is available to decide if these structures are as important in other regions as they appear to be here.

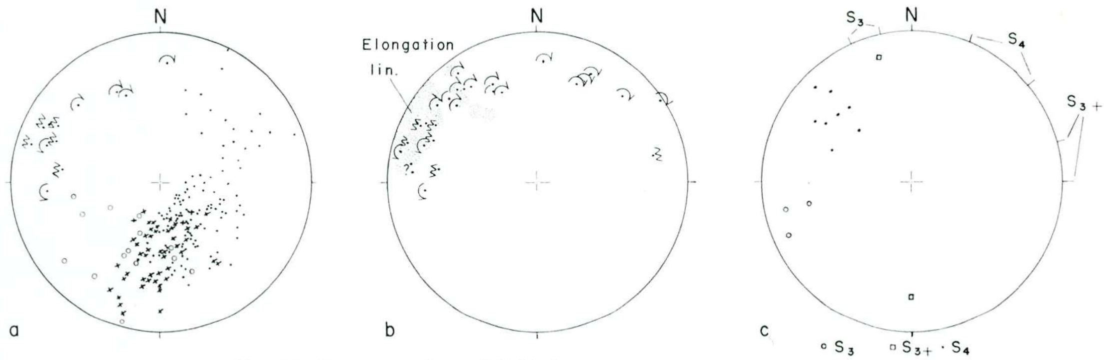


Fig. 29. Stereonet plots of field data.

The only part of the Røssjøkollan–Dokkvatn area where a majority of the F_1 folds retain their northeast axial trend is at the north end of Hornsjøen in Dokkvatn litho-tectonic unit A. Here, although several folds have been rotated to a northwest plunge, all folds face easterly (Fig. 28f). Slaty cleavage (S_2), which is more consistent in orientation than other structures, dips northerly and is parallel to the axial plane of the folds, an observation which is demonstrated by the stereonet plot of Fig. 28f, which shows that most fold hinges lie close to the trace of the mean slaty cleavage plane. Folds face easterly because the Hornsjøen area is on the northeast-facing limb of the large arcuate fold of Ormtjernskampen–Snæreskampen (Plate 1), and because all fold hinges trend northeast of the elongation lineation (Fig. 28f). The data from the north end of Hornsjøen are consistent with the regional interpretation and somewhat unusual because relict fold hinges of northeast trend are present, and because the fold hinges of diverse orientation (335 to 80, a spread of 115°) have been shown to lie approximately on the mean slaty cleavage plane.

The last major undiscussed litho-tectonic unit where structures of deformation phases D_1 and D_2 are important is Røssjøkollan 4, comprised of an Eocambrian–Cambrian sequence of quartzites and slates. No specific up criteria such as cross-beds are present in these rocks but the section in a small area west of Storlæger is known to be right side up (see section on stratigraphy). Because of this dearth of primary up criteria, facings of folds cannot be definitely established as in other litho-tectonic units. However, the axial trends and inferred rotation sense of folds are shown in Fig. 29a. The region is one of many medium-sized west or northwest plunging folds which are upright or asymmetric to the southwest (Plates 1, 2; Fig. 29a). These folds are thought to face south or southwest. In the higher plateau-like area of Veslefjell, west of Storlæger, three folds have been found which plunge north or north-northwest, and these are interpreted to face east. One such fold is particularly well-exposed on the north shore of the lake on Veslefjell, which is one kilometer west of Storlæger. If inferred facings are correct, the pattern here duplicates on a smaller scale what has already been described from Dokkvatn unit A –

that is, a fold system of northwest plunging folds that can be divided into groups of folds facing either northeast or southwest. The regional trend of elongation lineations lies between the folds of southwest facing and those which face northeast.

Fig. 29b is a summary diagram of the relations between fold trends, proven or inferred facing and asymmetry of folds, and the elongation lineation trends, taken from all litho-tectonic units of the area. Relations between fold trends, facing directions and elongation lineations from each of the sub-areas previously discussed combine to present a regional picture of elongation in a northwest direction accompanied by progressive rotation of fold axes toward a stable northwest orientation.

Description of deformation phases D_3–D_4. Late slip cleavages which produce fold crenulations of earlier S-planes are neither well-developed nor quantitatively important in the Røssjøkollan–Dokkvatn area. However, similar slip cleavage and intersection trends have been noted as far west as Fagernes, indicating that the small number of measurements here represent structures of regional extent. Observations for the whole area are recorded on Fig. 29c but most data come from the slates or phyllites of Dokkvatn litho-tectonic unit D or Røssjøkollan litho-tectonic unit 4. The following slip cleavages have been observed, each apparently denoting a separate period of deformation (see Fig. 29c).

S_3–(deformation phase D_3). These planes strike 335 to 350 and dip steeply. Although rare in the Røssjøkollan–Dokkvatn area a slip cleavage of this orientation is associated with important late folding at Etnbergi, 15 kilometers west of Røssjøkollan. The slip sense recorded on fold crenulations is commonly down to the northeast.

S_4–(deformation phase D_4). These planes strike 25 to 50 and dip steeply south. This is the most prevalent late slip cleavage in the Røssjøkollan–Dokkvatn area and it is even more prominent in areas 10 or 20 kilometers to the west, particularly at Svarthamarseter and Steinsetfjord. Englund (1966, Fig. 17) in the Fåvang district, 30 kilometers to the northeast, records small folds that correlate in timing and orientation with this deformation phase.

S_{3+} (deformation phase D_{3+}). This east-west striking slip cleavage is restricted to the Holsbru Slate along the Dokka and is known to be later than S_3. It has also been seen restricted to the Phyllite Formation above Groslii seter, 22 kilometers to the southwest of Røssjøkollan.

Deformation of unknown age (D_{2+}). Structural relations on Snæreskampen close to the basal thrust of Dokkvatn litho-tectonic unit A indicate folding of the thrust and simultaneous bending of slaty cleavage (S_2) bedding (S_0) intersections. Though this deformation is probably post (or late?) D_2 I have not

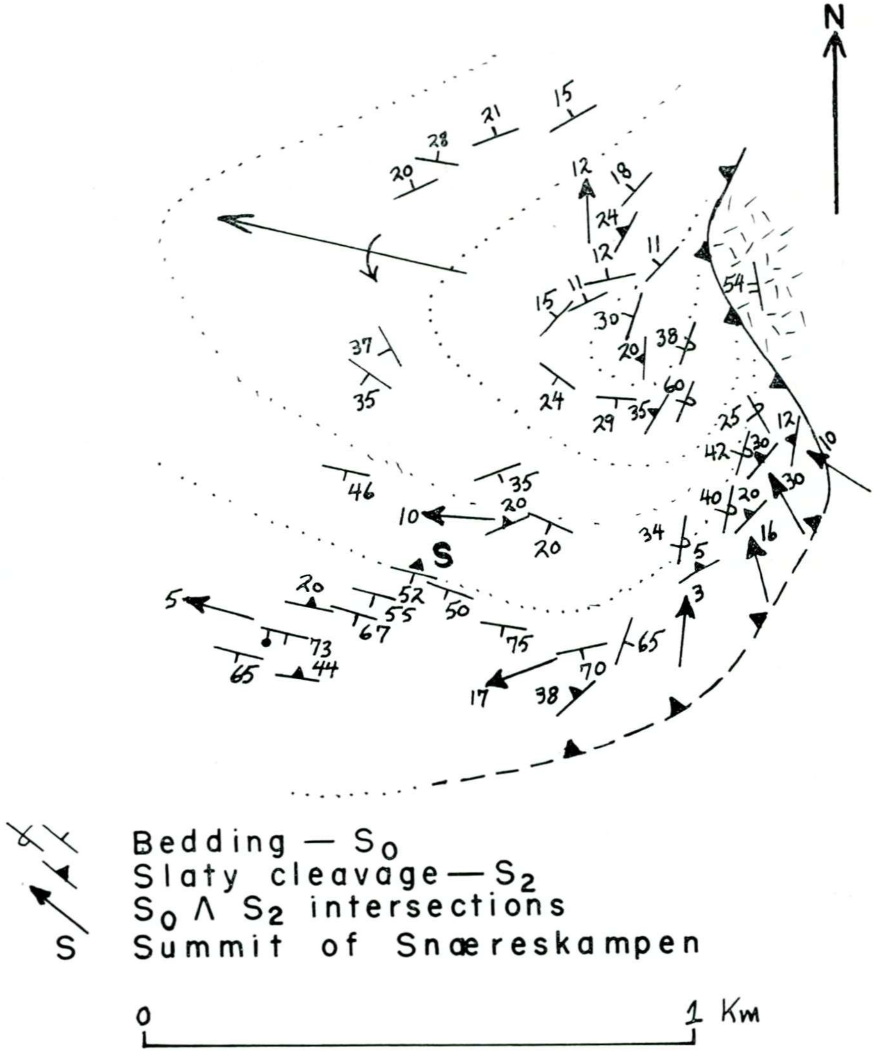


Fig. 30. Geologic map of Snæreskampen.

been able to correlate it with any of the later slip cleavages. The geometry of the deformation is illustrated in Fig. 30, which shows the change in orientation of bedding, slaty cleavage and cleavage-bedding intersections as one traces the structure from west to east to northeast around the south facing slope of Snæreskampen (Fig. 25; Plate 1). Normal cleavage bedding intersections plunge 280 but when traced eastward are seen to bend slightly to 255 then abruptly turn to a north plunge in the overturned beds approaching the thrust under the east slope of Snæreskampen. Bedding, slaty cleavage and cleavage-bedding intersections all undergo a counter-clockwise rotation but no unique axis of bending can be established. What is important here is that cleavage-bedding intersections and a slaty cleavage, presumably developed later than the D_1 thrusting which emplaced these allochthonous rocks, are here deformed by movement along the thrust. Hossack has noted rejuvenation of thrusting later than his F_3 slip cleavage folding at Bygdin (1968, Fig. 12, p. 101) and during his F_3 episode at Grønsennknipa (1972), but the kind of evidence he has used to date these movements is not available in the Dokkvatn area. At the present time it is impossible to equate phases of deformation over such long distances so no correlation with Hossack's phases is implied, although it is clear that folding of thrusts and accompanying drag of penetrative structures has occurred after D_2.

Summary discussion

This study of the Røssjøkollan–Dokkvatn area has corroborated and extended our stratigraphic and structural interpretations of Valdres Group areas to the west. The Valdres Group is Eocambrian and late Precambrian, conformably underlying Vangsås Formation that can be correlated with the Vangsås Formation in the Sparagmite Basin to the east. Despite their proximity at the present time, no direct Sparagmite Basin lithologic correlatives of the Valdres Group or the Ormtjernskampen Conglomerate have been found. An equivalent of the well-known Eocambrian Moelv Tillite is present in one of the allochthonous Valdres Nappes in the Røssjøkollan–Dokkvatn areas and provides the best correlation to the Sparagmite Basin. However, the relation of the tillite to the Ormtjernskampen Conglomerate member of the Valdres Group in this area is not certain because they are not recognized together in the same litho-tectonic unit. It is probable that the upper part, at least, of the Ormtjernskampen Conglomerate correlates with the Moelv Tillite because both units directly underlie the feldspathic Hornsjøkampen Sandstone. I have found no evidence to support the concept of an early Lower Jotun Nappe eroding in place to provide a local source for the Valdres Sparagmite. The Precambrian basement rocks of Røssjøkollan and Ormtjernseter are representative allochthonous slices of the Precambrian terrain that served as a source for the Valdres Group sparagmites. Unfortunately no unconformable sedimentary contact is exposed in this area. But both the Precambrian basement and the late Precambrian–Eocambrian Valdres are allochthonous and were brought to their present location by Caledonide thrusting. The Valdres Group cannot be correlated directly with rocks of similar age in the underlying Vemdal Nappe (Strand & Kulling 1972, p. 6) because the Valdres Group is part of a more far-travelled thrust complex, deposited initially in a separate source area. Correlatives should be sought in the metamorphic light sparagmite and the Kvitvola Nappe of the northern and eastern Sparagmite Basin. Evidence in the Røssjøkollan–Dokkvatn area supports our contention (Nickelsen 1967, p. 119; Loeschke & Nickelsen 1968, p. 363) that the Valdres Group and associated rocks exist in a complex of nappes (the Valdres Nappes) derived from different sub-areas of the same root zone. Future work throughout the region should identify the litho-tectonic attributes of the various nappes, as was attempted in Tables 2 and 3 of this paper, to provide a basis for more sophisticated paleogeographic interpretations.

Increased textural and compositional maturity proceeding upward in the Late Precambrian, Eocambrian, early Paleozoic sequence of this area is well documented and seems to record the gradual wearing down of the Precambrian Jotun basement source. Viewed regionally, Moelv tillite in different stratigraphic positions (directly on Precambrian basement vs. underlain by thousands of meters of sparagmite) suggests considerable relief within the root zone of both the Vemdal Nappe and the Valdres Nappes, up until Eocambrian time. Above the most mature Eocambrian and Cambrian Obleikhaugen and Dokkvatn Quartzites the trend toward increased maturity reverses and a new source is indicated by the texturally immature quartz wackes of the Ordovician Holseter Sandstone.

Since completing the study of Mellane (Nickelsen 1967) an earlier phase of deformation has been recognized at a number of places in the region of Valdres Group outcrop. The pervasive S_1 slaty cleavage and L_1 elongation lineation of Mellane are now recognized as features of the second deformation phase and have been correlated with the S_2 slaty cleavage and elongation lineations of the Røssjøkollan–Dokka area. In this region, which has been deformed at least four times during the Caledonian orogeny, only the first two phases of deformation are important in affecting the configuration or distribution of large units of rock (Table 5). Earliest folding and presumed thrusting and major overturning of sedimentary rocks were accomplished during the first deformation phase. No distinct penetrative foliation or lineation has been preserved from this D_1 phase of deformation but F_1 folds which have been rotated different amounts toward the D_2, northwest-oriented elongation lineation are found in most litho-tectonic units. The second phase of deformation produced the penetrative slaty cleavage (S_2) and elongation lineations as well as new F_2 folds, which share the same S_2 axial plane cleavages as the F_1 folds. Arcuate folds with limbs trending northwest, which face either northeast or southwest, are the result of the first two phases of deformation. The limbs of these folds approach the attitude of the elongation lineation, which, of course, is the stable position toward which lines rotate during the D_2 episode of constriction (k between 1 and ∞, Flinn 1962). In this view, the orientation of the elongation lineation ($300° \pm 20°$) is not necessarily related to the direction of tectonic nappe transport since it merely records the direction of pure shear extension. However, it cannot be denied that elongation is better developed in proven thrust zones (e.g. the Mellsenn quartz mylonite at Solskiva and Røssjøkollan) and this implies greater strain and perhaps differential slip parallel to the elongation lineation in these zones. But if this transport occurred during the D_2 creation of penetrative slaty cleavage and elongation lineation it may not be parallel with the inferred D_1 directions of thrusting or overfolding. At the present state of knowledge, it is probably not safe to assume that the direction of pervasive D_2 elongation lineation is the direction of major tectonic transport of the nappes, though future unraveling of the D_1 phase of deformation may show that the slip direction did not change between D_1 and D_2.

Students of other Caledonide areas have observed and tried to explain the ambiguous relationships between the first two deformation phases and the possible tectonic transport implications of the pervasive elongation lineations. Henley (1970) in the Sulitjelma region identifies D_2 as the time of creation of penetrative mica lineation and elongated conglomerates, recognizing that the same foliation serves as the axial plane of flattened, southwest-oriented D_1 folds and east-west oriented D_2 folds. Nicholson & Rutland (1969, pp. 67–68) demonstrate the difficulties in correlating deformation phases from east to west across a longer section of the same region. Farther north in Troms, Olesen (1971) identifies the peak of metamorphism and foliation or transverse elongation lineation creation with F_2 and states (p. 375) that the 'transverse lineation has no relation to the large scale thrusting of the allochthonous Caledonides from northwest to southwest.' Hossack's F_1 deformation at both Bygdin (1968, p. 83) and Grønsennknipa (1972) is manifested in folding, first schistosity formation and creation of elongation lineations. Thus it is equivalent in its effect to D_2 of this paper. But at Grønsennknipa Hossack has noted pre-F_1 mylonites at granite–pelite fault contacts which are folded on F_1 axes and cleaved by S_1. Thus, at Grønsennknipa there is evidence of early thrusting of unknown magitude prior to his penetrative S_1 foliation, lineation and F_1 fold development, a sequence much like what is reported in the Røssjøkollan–Dokkvatn area. In his summary on the structure of Dalradian rocks in Scotland, Rast (1963, p. 126) points out that F_1 and F_2 folds of different trend share the same axial planar schistosity and that transverse elongation lineations parallel F_2 fold hinges. In explanation, Rast suggests that both fold sets may have started together but that F_2 continued later. In the Taconic Mountains of the United States two early phases of deformation are the major Caledonide episodes. D_1 is identified by Zen (1971) as the main thrusting event but slaty cleavage and regional metamorphism did not occur until D_2 time. Wright (1969) associates the dominant F_2 folds with the pervasive axial-plane flow cleavage (S_2) and has found that F_1 and F_2 fold axes 'are dispersed along a great circle that coincides with the flow-cleavage plane'. This he ascribes to intense flattening perpendicular to the plane of (S_2) cleavage. It is clear from this incomplete summary that the early phases of deformation described in the Røssjøkollan–Dokkvatn area are not unique.

Several minor episodes of slip cleavage close out the Caledonide structural history of the region. Major topographic lineaments and fault separation of thrusts on Røssjøkollan are thought to be the result of slip on post-Caledonide, perhaps Permian, steeply-dipping faults.

Acknowledgements. – Discussions and field excursions with a number of geologists have contributed to the local and regional geologic knowledge that are expressed in this paper. These include especially Knut Bjørlykke, John Hossack, Anders Kvale and Jens-Olaf Englund, but also Brit Løberg, Hans Seip, John Rodgers and Lucien Platt. The study was funded by National Science Foundation Research Grant GA–1512.

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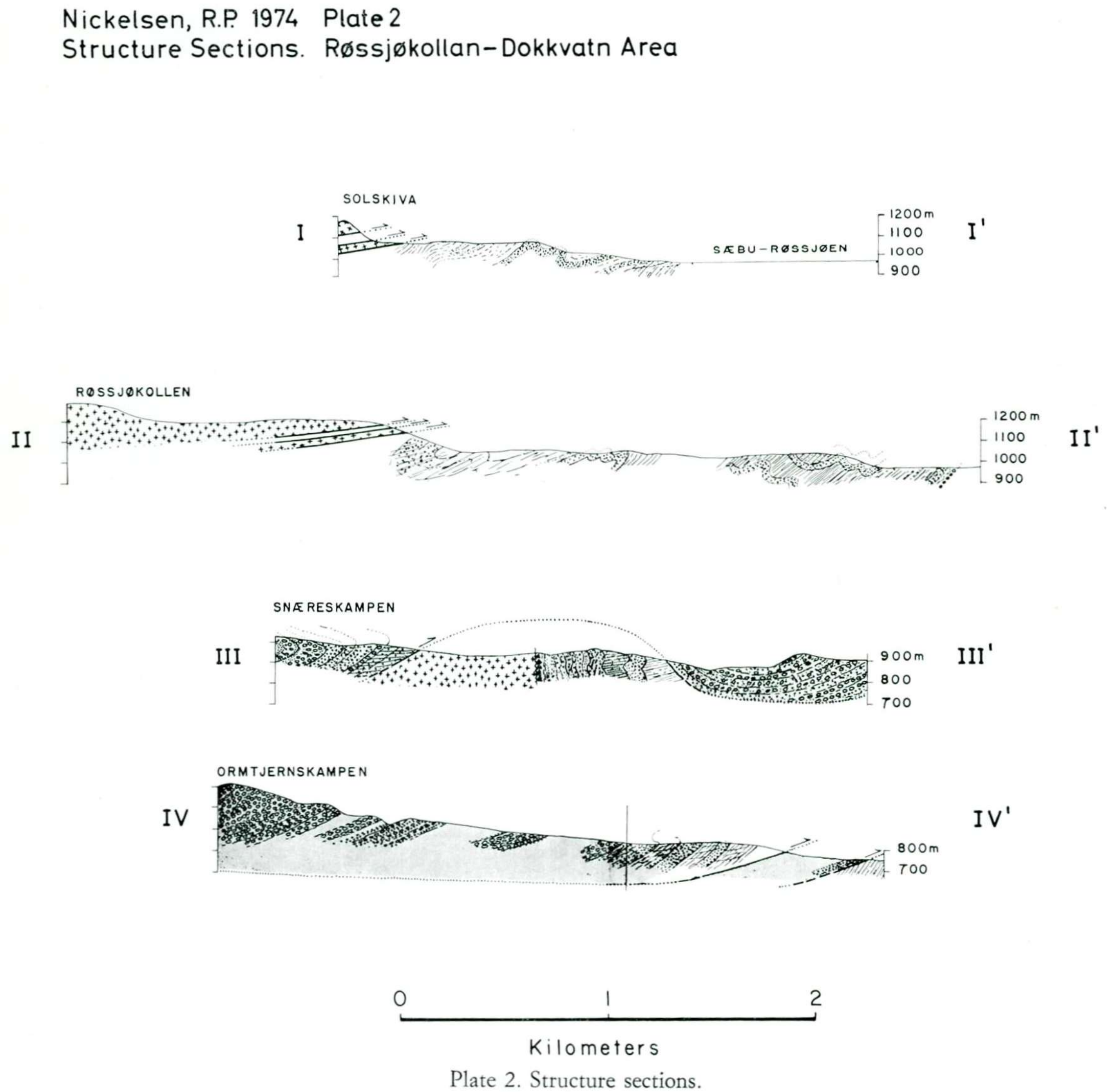
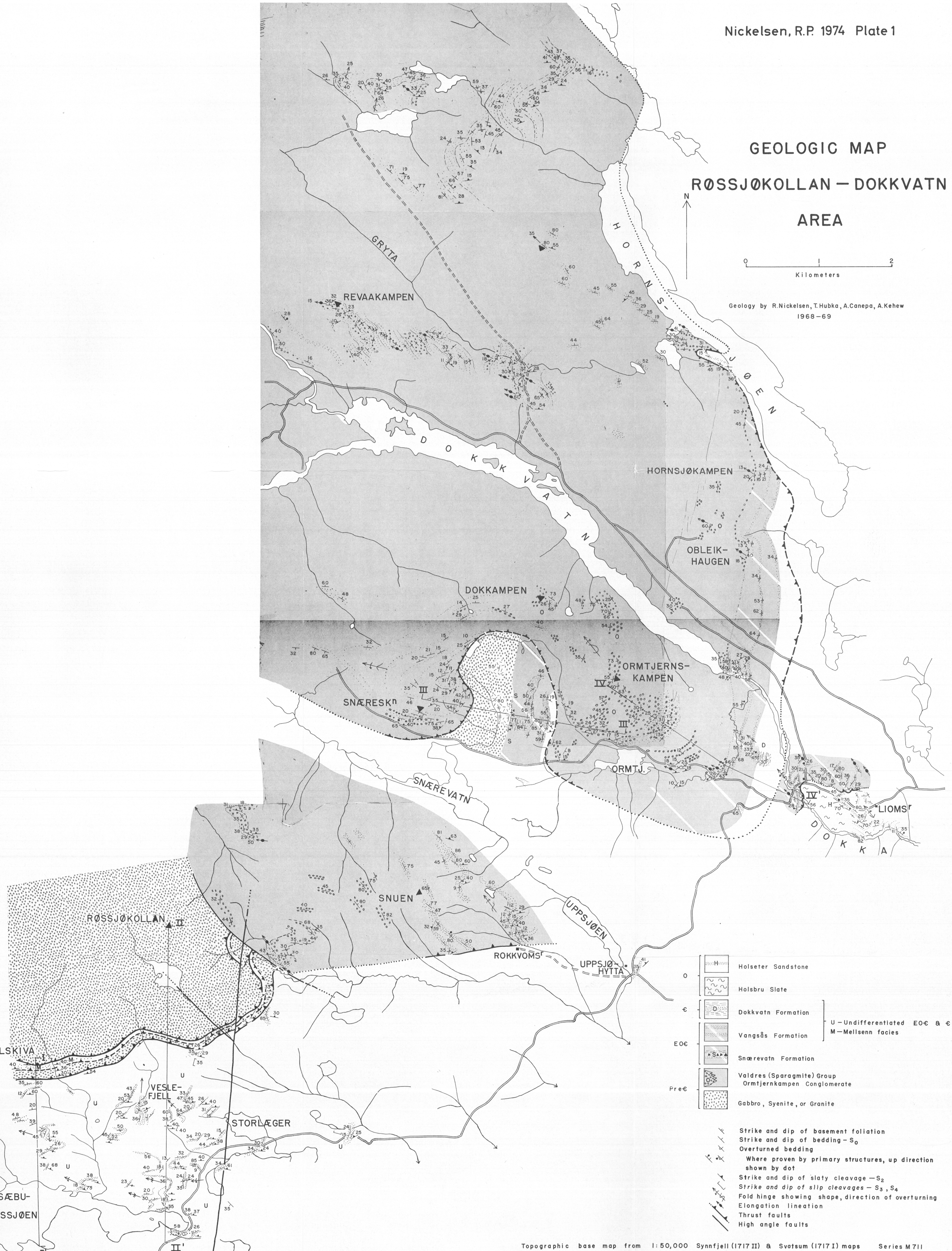


Plate 2. Structure sections.

Nickelsen, R.P. 1974 Plate 1

GEOLOGIC MAP RØSSJØKOLLAN — DOKKVATN AREA



Geology by R. Nickelsen, T. Hubka, A. Canepa, A. Kehew 1968-69

Topographic base map from 1:50,000 Synnfjell (1717 II) & Svotsum (1717 I) maps Series M711

NGU 314 — Nickelsen