The Surnadal syncline revisited

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New, detailed mapping near Rindal confirms the old view that the Støren volcanics continue into the Surnadal syncline. Therefore, the syncline is Caledonian and not Precambrian, as considered by Råheim 1979. The prevailing view that the rocks above Late Precambrian metasandstones only form two main nappes, the 'Gula' Nappe and the Støren Nappe, should be modified. Between the lower part of 'Gula' – amphibolitefacies rocks, termed the Surna Nappe – and the low-grade Støren greenstone, there are metasediments and volcanics of an intermediate metamorphic grade termed the Rinna schist and greenschist, while the Upper schist has an uncertain tectonostratigraphic position. In the Romundstad area east of Rindal a distinct thrust is present at the contact between greenschist and greenstone.

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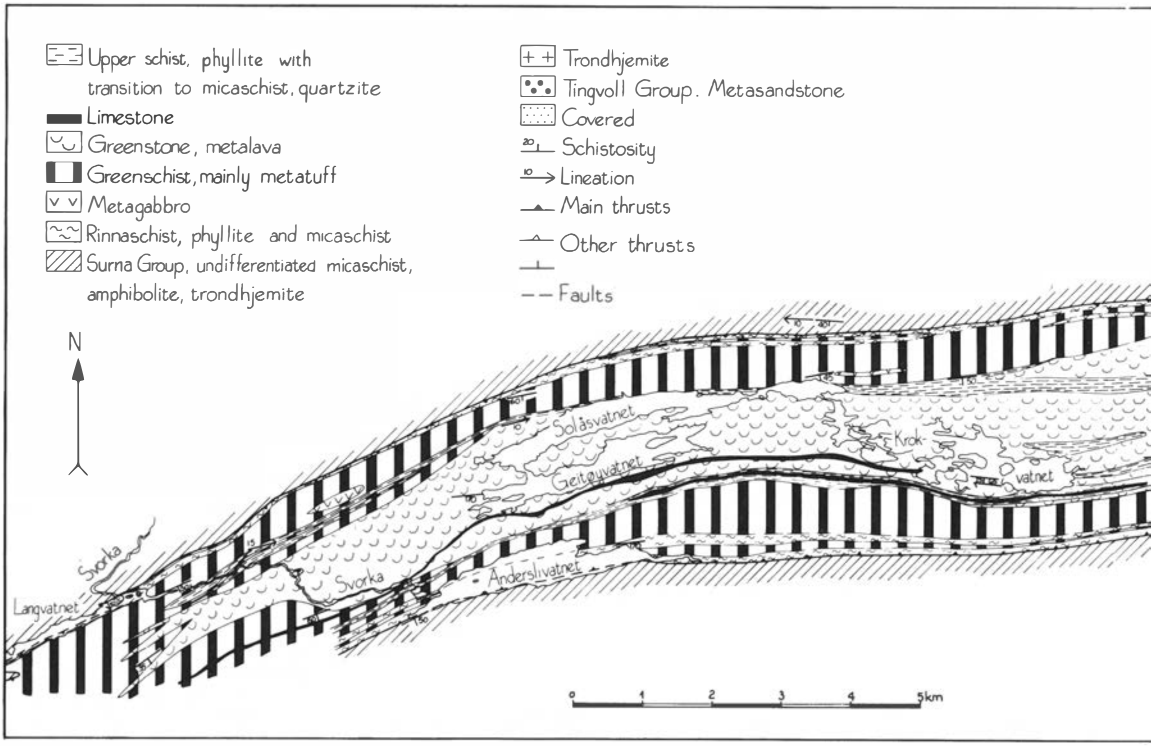
The Surnadal syncline in western Norway was first recognized by Kjerulf in 1871 to be an extension from the Trondheim depression. Later it has been studied by several geologists. From investigations in the western part of the syncline, Strand (1953) stressed the lack of discordance between Precambrian basement gneisses and overlying metasediments. Hernes (1956) divided the rocks above the homogeneous gneisses into the following three groups: 1. The Tingvoll Group with augen gneisses and quartzites (or metasandstones) as characteristic members. 2. The Røros Group, later called the Gula Group, with mica schists as the main constituent. Below, the local name Surna will be used for the lower, highest metamorphic past of these rocks (compare Råheim 1979, Krill 1984). 3. The Støren Group with mainly basic metavolcanics. The ages of these three groups were considered to be Late Precambrian, Cambrian to Lower Ordovician and Lower Ordovician, respectively. The ENE-WSW striking syncline is isoclinal and overturned to the north.

In an area bordering the Surnadal syncline to the southeast, Løset (1977) recognized three fold phases of supposed Caledonian age, affecting the Surna Group, the Tingvoll Group and the basement gneisses. Råheim (1977) made a Rb-Sr study of the Surna Group schists and of the Tingvoll Group gneiss immediately underlying the schists. A whole-rock isochron of the gneiss defined a Svecofennian age of about 1700 m.y., which was interpreted as the age of the main metamorphism. The age of the Surna Group could not be conclusively determined, but as Råheim found no structural or metamorphic break with the underlying rocks, he concluded that also the Surna Group, the Surnadal syncline itself and the associated metamorphism were Precambrian. The only possible break could be at the base of the Støren Group.

According to Rickard (1981), however, the Tingvoll 'Group' is a tectonolithic complex rather than a stratigraphic sequence, strongly influenced by isoclinal folding and accompanying slicing. He considered the gneiss which Råheim studied most likely to be a basement gneiss. Rb-Sr dating of Tingvoll augen gneisses from the Oppdal area south of Surnadal has also yielded high ages, in the range 1450–1750 m.y. (Solheim 1977, Krill 1983a). For the metasandstones of the Tingvoll Group, Solheim (1980) obtained from Rb-Sr dating in the Oppdal area an age of about 1050 m.y., interpreted as a resetting age for a much older sediment. Krill (1983b) questioned the reliability of this dating. Rb-Sr study defined the age of pre-tectonic dolerite dykes penetrating the sandstones to be about 745 m.y. Krill also regarded the sediments to be of Late Precambrian age, in accordance with the age for similar rocks in the Sparagmite region to the southeast of the Trondheim depression. After the dyke intrusion the sediments were thrust-emplaced and metamorphosed together with surrounding rocks during the Caledonian orogeny. Both Krill (1980, 1984) and Rickard (1981) recognized the nappe character of the rocks above the Tingvoll Group. According to Krill (1984), these are simi-

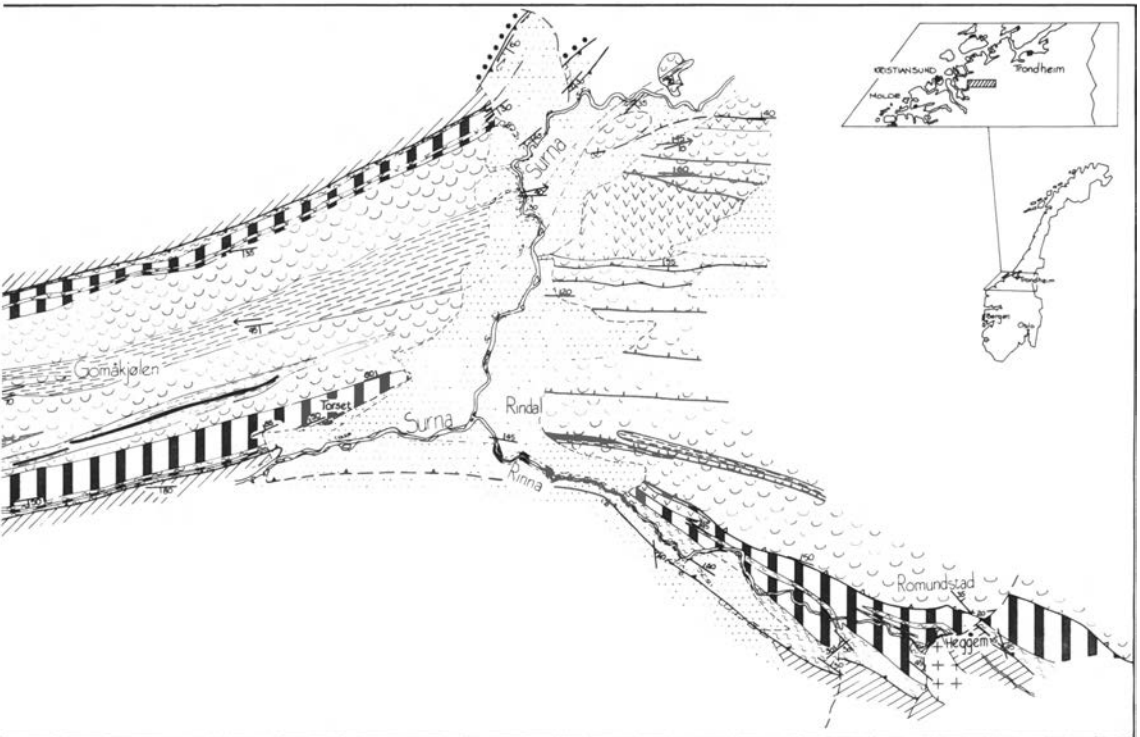


lar types of rocks from two separate tectonic units, the Blåhø Nappe (below) and the Surna Nappe (above).

In the central parts of the Surnadal syncline, as in the Trondheim region, it has been customary to separate the volcanic Støren Group from the mainly sedimentary 'Gula' Group (Hernes 1956). Later they have been regarded as two nappes (with the Hovin Group included in the Støren Nappe) together forming the Trondheim Supergroup (Gale & Roberts 1974). There exists, however, a thick pile of sediments and volcanics of intermediate metamorphic grade between the amphibolite-facies Surna rocks and the low-grade, undoubted Støren rocks. Krill (1984), who correlated the underlying Surna Nappe with the Gula Nappe of the central Trondheim region, included these rocks in his Tronget-Støren Nappe. Råheim (1979) considered the whole sequence in the central Surnadal syncline as retrogressed Surna rocks, the 'green appearance' of its upper part being the result of much chloritization during the retrograde metamorphism. According to Råheim the Støren Group is restricted to the area east of Rindal, situated at the opening of the Surnadal syncline in the traditional sense. Here a structural and metamorphic break separates this group from the underlying rocks. Within the retrogressed zone he found 'pockets' of higher-grade rocks. He therefore concluded that his Surna Group had suffered two metamorphic events, the first of which he considered to be of Svecofennian age, while the Støren Group only had been through the later, low-grade event.

Krill (1980) accepted some faulting at Rindal, causing discordances, but as the Støren volcanics continue into the Surnadal syncline and are folded by this structure, he rejected Råheim's further ideas. A Caledonian age for the Surnadal syncline has recently also been advocated by Rickard (1981).

My own experience in this area, and neighbouring districts to the east, is from detailed mapping during the summers 1969, 1981 and 1982. The map (Fig. 1) goes as far west as Langvatnet, and also includes a smaller area to the east of Rindal, which is given some attention. I agree with Krill (1984) that a main thrust separates the amphibolite-facies rocks of the Surna Group, that is the lower part of 'Gula', from the



lower-grade rocks above. There are, however, strong indications that a separate nappe exists between the Surna Nappe and the Støren Nappe, comprising in addition to metasediments of the upper part of 'Gula' also basic volcanics which have traditionally been regarded as belonging to the Støren unit (Hernes 1956).

The mapping clearly shows that Råheim's (1979) main ideas are not tenable. Although there is much tectonization – at different levels, well recognized by Råheim – and a large covered area at Rindal, which hinders continuous observation along strike, it is possible to follow distinct rock units for long distances.

A large discordance is, however, present at Rindal on the northern side of the syncline (Fig. 1). East of the river Surna, greenstones of the Støren Group strike E–W and dip to the north, while in the north-west a phyllite and underlying rocks of the Støren Group, plus rocks down to the basement, strike NE–SW and dip to the SE. This is caused by a pile of inverted slices of volcanics and associated basic intrusive in eastern areas, and will not be further dealt with here.

Concerning the 'pockets' of higher-grade rocks in lower-grade ones, considered by Råheim (1979) as a main agreement for a two-phase metamorphism in his Surna Group, I have noticed the concentration in some areas of distinct, dark amphibolite bands in paler Støren greenstone. This may be interpreted as local variations in metamorphism, or that equilibrium has not been established.

Geophysical helicopter measurements (Dighem Ltd., report to Orkla Industrier A/S 1982) independently confirm that the Støren volcanics continue into the Surnadal syncline.

Rock types

In the mapped area (Fig. 1) five main rock units are distinguished. The lowest unit, the Surna Group of amphibolite-facies, is on the whole in sharp contact to the lower-grade metamorphic rocks above, of which the lowermost, pelitic unit is termed the Rinna schist. It is overlain by a predominantly tuffaceous greenschist formation. The two uppermost units are a sedimentary schist formation which will be called the Upper schist, and a lava formation, greenstone. From the relationships in Surnadal it is difficult to determine the relative tectonostratigraphic position of the Upper schist and greenstone. The Upper schist is intercalated within the greenschist in the western part of the syncline, whereas further to the east the Upper schist is at the contact or within the greenstone.

1. The Surna Group is composed of mica schists and amphibolites, the schists dominating the upper part of the group. Because of abundant biotite the mica schist has a brownish colour, while both rocks often are rich in garnet. White trondhjemites profusely intrude the supracrustals. Apart from the area north of Rindal only the upper limit of the group has been drawn on the map.

2. The Rinna schist, which varies in apparent thickness from 200 metres on the south side of the syncline to 20 metres in the north, consists of two separate units: The lower unit has a rather coarse, quartz-rich chlorite-mica schist showing a grey, greenish or brownish colour according to varying proportions of muscovite, chlorite and biotite. Garnet may be abundant, especially in the west, where the metamorphism is highest. The upper unit, mostly lacking in the north, consists of a green, fine-grained phyllite with biotite porphyroblasts. Towards the west, biotite also increases in the groundmass, so that the rock here is more characteristic of a mica schist. Garnet may be present. Thin limestones and quartzites occur in the north. The white trondhjemite so typical for the Surna schist is lacking in the Rinna schist.

Within the upper part of the formation there is a zone of dark greenschists, in the south continuous all along the syncline. It may, however, be a part of the overlying greenschist, tightly folded together with the Rinna schist.

3. The greenschist unit has a maximum apparent thickness of about 500 metres. It is a dark green, amphibolitic, partly finely banded metatuff. Subordinate in some areas are more massive and often lighter coloured bands, thought to be metalava. A 20–30 m thick hornblende gabbro in the north is continuous for about 10 km. The distinction between the greenschist and the overlying greenstone is somewhat more pronounced in the area east of Rindal.

4. The Upper schist unit attains its greatest apparent thickness of about 600 metres near Surna in the northeast, but from here it thins rapidly westwards. It is about 30 metres at Solåsvatnet, and disappears at Langvatnet. In the south, the schist unit appears to be lacking near Rindal. East of Krokvatnet it also occurs in the centre of the syncline.

The schist is similar to the upper Rinna schist. In the area east of Krokvatnet/Anderslivatnet it occurs mainly as a green- to grey-coloured phyllite, often with biotite porphyroblasts. Biotite-rich schists are less frequent here. Further west the biotite content increases, giving the rock a transition towards mica schist. In addition garnet occurs here. Chlorite is, however, also abundant in this western area.

Quartzite bands are frequent in the north, especially in the Gomåkjølen area. A gneissic, feldspar-rich rock, a supposed metasandstone, is also found here.

A grey/white banded limestone occurs discontinuously within the schist on the south side of the syncline, as far west as south of Geitøyvatnet. A similar limestone is found within the greenstone, from Krokvatnet and westwards. As with the schist, it passes from the greenstone to the greenschist west of Anderslivatnet. The limestone is supposed to belong to the schist formation.

At Rindal, east of the covered area, and continuous for about 2 km, there is the same type of green phyllite with a limestone above. It is not directly on strike with the phyllite west of Rindal, which is most likely due to a fold structure.

The Upper schist might be taken for Hovin Group rocks. Pelites and limestone, the latter often tectonically intercalated with greenstone, are the characteristic lithology for the Hovin Group in the whole area between Orkla and Rindal. The Hovin schist is, however, distinguished from the Upper schist by a typical low-grade metamorphic character, fissile and very fine-grained. The westernmost outcrop of the Hovin schist is 1 km east of Rindal, where it is separated from the Upper schist by a thrust and a thin greenstone. On the map, Fig. 1, the Hovin schist has been given the same symbol as the Upper schist.

5. The greenstone unit consists predominantly of metalavas, although the schistosity may be very pronounced. As mentioned above, distinct, dark amphibolite bands are characteristic for some

areas. Due to strong deformation, primary structures such as pillows do not appear to have been preserved, contrasting to the area east of Rindal, where such structures are abundant. The greenstone disappears owing to an east-plunging fold axis south of Langvatnet in the western part of the mapped area.

Structures

The Surnadal syncline is strongly influenced by early isoclinal folding, F_1, present both in the Surna Group and overlying rocks. The thinning of the rocks is pronounced in all units. Rickard (1981) considered the emplacement of the Støren Nappe to be later than the slicing and folding in the underlying rocks, and thought that the folding developed independently in each nappe. I have not been able to recognize this. The fold axes and lineations of the F_1 phase have their main orientation about E-W in both lower and higher rocks. The plunges are distinctly easterly in eastern and western parts of the syncline and for a greater part westerly in between. The strong deformation of this phase is also expressed by the marked schistosity in the greenstone.

The trace of the Upper schist is very distinct. From lying within greenstone east of Krokvatnet it follows approximately the boundary between greenstone and greenschist further west, and passes into the greenschist west of Solåsvatnet/Anderslivatnet. As mentioned above, this is also the case with a limestone west of Anderslivatnet, proving that the zone of schist is a lithologic horizon and is not caused simply by shearing. A possible explanation would be large facies variations from east to west within the volcanics. This seems, however, to be improbable. The greenschist and greenstone are, on the whole, distinctly bounded units with relatively constant thicknesses throughout the syncline, and large facies variations are unlikely. Isoclinal folding would be a better explanation for this phenomenon in which the volcanics have behaved more competently than the sediments.

The main syncline is of a later period of deformation, F_2. The southern limb is inverted, and to the west turns over in a normal attitude about 7 km west of Rindal. The dip is mostly 30–70° m, flatter to the SW, and steeper to the SE.

At Langvatnet there are some south-vergent folds of the size 50–200 metres, the largest of which lies outside the map area. They are more open than those most commonly found and are presumed to be of F_2 age. They deform the boundary between the Surna Group and the overlying rocks.

Near Rindal the rocks on the south side of the syncline appear to be offset by 1 km from the rocks to the east of the covered area. A fault seems unable to explain this phenomenon, as the Upper schist on the northern limb of the syncline passes unbroken through. Therefore one must suppose the existence of a large fold. Greenstone exposures along the road under Torset also indicate this fold. The greenstone here strikes towards exposures of the same rock in Rinna.

There are numerous strongly tectonized zones in the syncline, both along boundaries and within the rock units. The amount of movement along these shear zones is difficult to determine.

One such major shear boundary is that between the Surna Group and the Rinna schist. Here amphibolite facies rocks are separated from lower-grade, chlorite-rich rocks above. Also, strong tectonization is often present at this level. In some areas, especially in the western parts of the syncline, and south of Rinna, tectonization is distributed over a wider zone and it is difficult to define the sharp contact. Discordances were not observed in the syncline itself, but are present farther east: south of Rinna, and near the farm Heggem, where at one locality the Surna schist is oriented 335/45, and the Rinna schist 380/45. It is thus logical to conclude that this boundary represents a main thrust level.

Råheim (1979) recognized a discordance at Trønsdal northeast of Rindal, between his Surna Group, including an amphibolite of the greenschist formation, and the Støren greenstone. In the Romundstad area southeast of Rindal there is a clear tectonic contact between greenschist and greenstone. Large discordances are observed here over a 4 km long distance. The greenstone above the thrust is strongly schistose and tectonized. Direct discordance at the contact can be seen above Heggem, with the greenschist oriented 320/20, the greenstone 355/35. Also, the greenschist and the underlying Rinna schist are of a medium metamorphic grade – the garnet zone – compared to the amphibolite facies of the Surna Group and the biotite zone of the greenstone. The greenschist and the Rinna schist are folded together, also in early isoclinal structures. It thus seems that the two schists in this area form one well-defined tectonic unit.

Whether the greenschist/greenstone boundary represents a continous thrust has, however, not been ascertained. No discordance between the two units has been observed in the Surnadal syncline. Here the boundary may be indistinct due to more massive bands in the greenschist, and to a somewhat higher metamorphism in the greenstone compared to the metamorphic grade found further east. Strong tectonization may, however, be present, as seen in roadcuts both in eastern and western parts of the syncline.

By pursuing the rocks from the north side of the Surnadal syncline towards the east I hope that this problem, together with the question of the tectonostratigraphic position of the Upper schist, can be solved. Such solutions would have consequences also for the tectonic interpretation of the Trondheim region as a whole.

Conclusions

1. All the main rock units below the Hovin Group continue from the Trondheim basin into the Surnadal syncline. The continuation of the Støren volcanics is also shown by geophysical data. Accordingly, the syncline is Caledonian, and not Precambrian.

2. Two main tectonostratigraphic units have been recognized within the 'Gula' Group. The upper unit probably includes basic volcanics, which have traditionally been considered as belonging to the Støren Group (Hernes 1956).

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