The geology of the Torfinnsbu window, central Jotunheimen, Norway

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A sequence of metasediments (sparagmites, schists, amphibolites) are exposed in a recently discovered window (3 1/2 × 1 km) through the Jotun stem gneisses around Torfinnsbu, on the north shore of the lake Bygdin. The metasediments display three phases of deformation which correlate well with the deformation phases in the metasediments at Beito and Bygdin. The Jotun gneisses were thrusted over the sediments during the first and most intense phase of deformation. Metamorphic grade increases upward in the metasediments to epidote – amphibolite facies at the base of the Jotun gneiss. The occurrence of such a window indicates that the Jotun nappe in this region is much thinner than predictions based on gravity anomaly data would suggest.

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On the geological map of Norway (Holtedahl & Dons 1960) the lake Bygdin (Fig. 1,B) is shown to lie almost entirely within the crystalline rocks of gabbroic composition that make up the Jotun nappe. The extreme eastern tip of the lake is crossed by the thrust bounding this Nappe (the basal thrust of Hossack 1968), which separates the crystalline rocks to the west and north from the underlying conglomerates and feldspathic sandstones (sparagmites) of the Valdres Group to the east and south. Torfinnsbu tourist hostel stands on the northern shore of the lake, 10 km west of this thrust. At Torfinnsbu and westwards from it along the lakeside for 3 1/2 km a tract of metasedimentary rocks has been discovered emerging from beneath the Jotun rocks and constituting a tectonic window within the Jotun nappe. This paper describes the principal features of the Torfinnsbu window.

Form of the window

The window (Fig. 1,A) is generally elongated in an east-west direction with a north–trending minor axis approximately 0.6 km long. Metasediments are exposed in the numerous gullies which cut through the wedges of drift mantling the south slopes of Turfinstindane. By far the most complete section occurs in Langedalsåi, and it is here that the structure of the sediments and their relationship to the Jotun rocks are most clear.

Small exposures of metasediments are seen in the lake shore 200 m east and 150 m west of Torfinnsbu hostel, but these are partly submerged when the level of the lake is high. The metasediments on the lake shore east of the hut have within them a thin downfaulted wedge of Jotun gneiss (Fig. 2,B). The boundary faults have very little displacement so that here the base of the Jotun rocks cannot be far above lake level. The base of the Jotun rocks is at 1250 m a.s.l. in Langedalsåi, and at 1370 m a.s.l. in the Nybui section. The window is therefore of a dome-like form, and this is reflected in the disposition of lineations within the metasediments.

The arched form of the basal thrust is picked out by a feature on the south flank of Turfinstindane and the southwest slopes of Kalvåholstind. This feature also suggests that the basal thrust is very near to the lake level east of Torfinnsbu.

Structure and petrography of the Jotun rocks

The crystalline rocks above the metasediments at Torfinnsbu are meta-igneous rocks of the Bergen–Jotun Stem (Goldschmidt 1916). The Jotun gneiss which forms the frame of the window is here termed the Svartdalen gneiss (Emmett 1980) and it is separated from more highly metamorphosed rocks to the north by a major

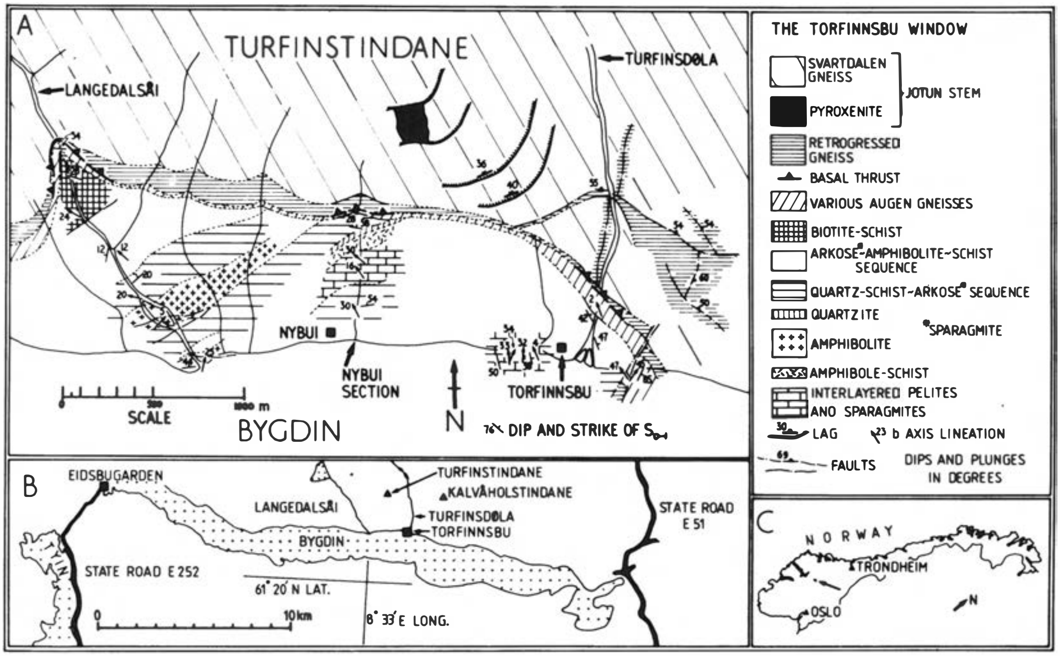


Fig. 1. The location and geology of the Torfinnsbu window.

fault, the Tyin–Gjende fault (Battey & McRitchie 1973), which passes 13 km north-north-west of Torfinnsbu. The Svartdalen gneiss is the only Jotun stem rock seen in the frame of the metasedimentary window.

Pyriclasite gneisses. – The typical Jotun rock of this area is a medium to coarse – grained pyriclasite gneiss (Berthelsen 1960) with weak or moderate foliation. The less well-foliated representatives, which are analogous to the Mjølkedøla purple gabbro of Battey & McRitchie (1973), preserve relict igneous (ophitic) texture. The mineral paragenesis is cpx + clinoamphibole + K – feldspar + plag ± opx. The cpx is augitic and rimmed with green, strongly pleochroic clinoamphibole (pargasite) close to the basal thrust (Fig. 3). Opaque grains often have a rim of pale yellow – brown to dark brown pleochroic biotite.

Ultrabasic rocks. – Two ultrabasic bodies occur in the vicinity of Torfinnsbu, one in the south slope of Turfinstindane, the other 3 km north of Torfinnsbu, in Turfinsdøla. They are believed to represent a single body disrupted by lag-faulting. The rock is a clinopyroxenite, composed essentially of cpx + opx + clinoamphibole ± olivine.

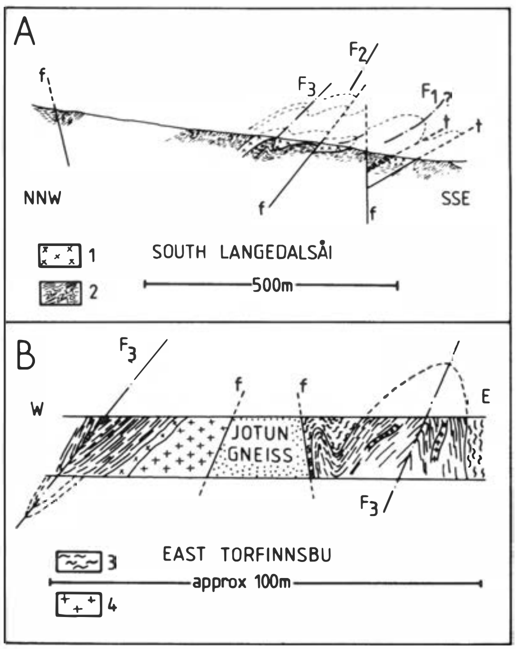


Fig. 2. Geological cross-sections:
A. Langedalsåi. 1 = amphibolite, 2 = schists etc, B. Shore section 200 m east of Torfinnsbu (sketch only). 3 = augen gneiss, 4 = pegmatite.

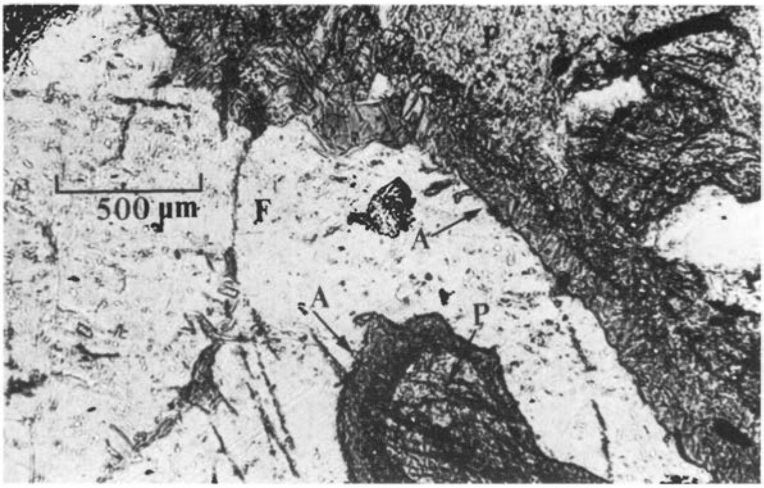


Fig. 3. Photomicrograph of Svartdalen gneiss showing amphibolisation due to F_1 thrusting. F = plagioclase, P = pyroxene, A = amphibole.

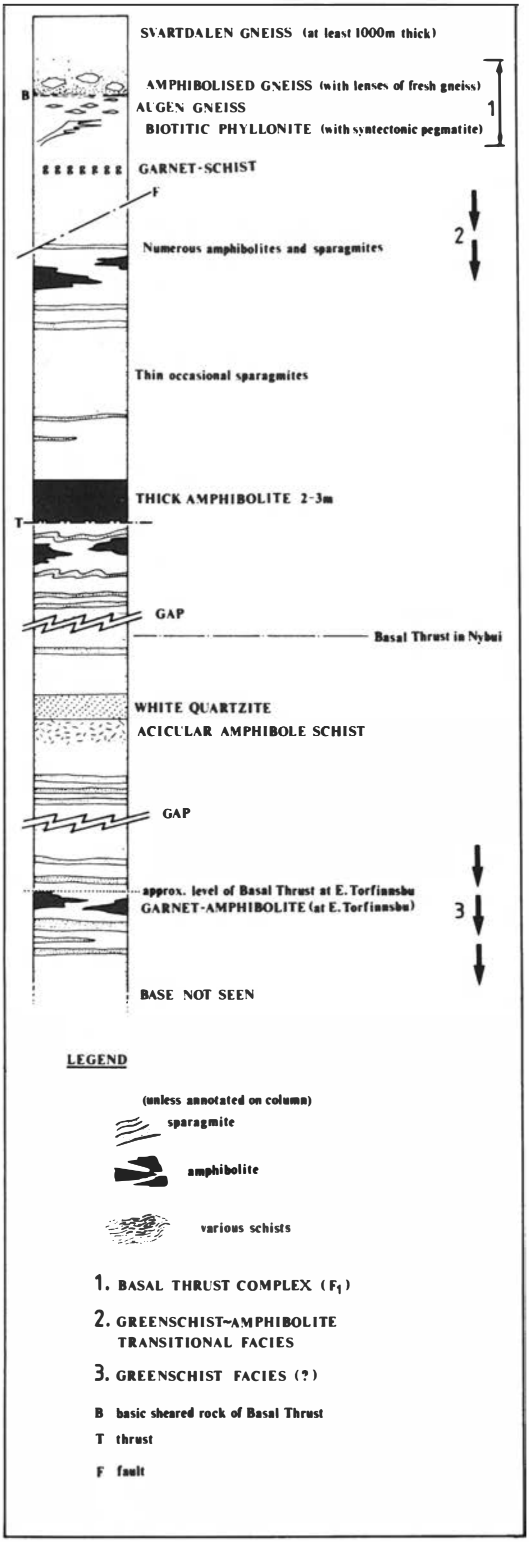
The olivine occurs as sparse, subrounded crystals. The clinoamphibole is a green, strongly pleochroic pargasite. Plagioclase is a common trace mineral, occurring as finely granular rims to oxide grains (compare Battey & Davison 1977). In conformity with this finding, McRitchie (1965) reports that, around the west end of Bygdin, ultrabasics associated with the Mjølkedøla purple gabbro have plag + olivine assemblages which are stable.

Metamorphism. – The co-existence of olivine and plagioclase in ultrabasic members of the Svartdalen gneiss group implies that the conditions of metamorphism did not exceed those assigned to the plagioclase–lherzolite facies of O'Hara (1967) or the low-pressure granulite subfacies of Green & Ringwood (1967). The Svartdalen gneiss must therefore be distinguished from 'the undifferentiated jotunites' of McRitchie (1965) north of the Tyin–Gjende fault which show extensive evidence of a prograde metamorphism which has carried them into the spinel–lherzolite facies (O'Hara 1967, Battey & McRitchie 1975, Emmett 1980). This is equivalent to the intermediate pressure granulite subfacies of Green & Ringwood (1967). In summary, the Svartdalen gneiss can be distinguished from 'the undifferentiated jotunites' by their less thorough degree of recrystallisation, and their lower grade of metamorphism.

The mechanical effects of the thrust that bring the Svartdalen gneiss above the metasediments are restricted to a narrow band just above the basal thrust. The deformation has reduced the grain size and induced trails of cataclasis throughout the rock and altered feldspars to saussuritic aggregates. Away from the basal thrust, the Svartdalen gneiss shows little evidence of Caledonian deformation. This is similar to the effects of thrusting in the Vang window area (Heim et al. 1977).

Base of the Svartdalen gneiss

Approximately 1.3 km north of the mouth of Langedalsåi the overthrust nature of the Svartdalen gneiss is displayed. Fresh Svartdalen gneiss passes downwards into a highly epidotised and strongly amphibolised zone in which lenses of fresher gneiss are sometimes found. Relict foliation is sometimes seen. The amphibolised zone is approximately 4 m thick and rests on a 1–2 m thick zone of intensely sheared basic rock which passes downward into an acidic augen gneiss. Similar occurrences of augen gneiss are recorded in Espedalen (M. R. Garton, pers. comm. 1979). A biotitic phyllonite separates the augen gneiss from underlying quartz–biotite schists. A pink feldspar pegmatite was found in the biotite–phyllonite zone which cross-cuts and intrudes along the foliation in part. This is interpreted as representing intrusion of pegmatitic liquids during the formation of the phyllonite. A similar relationship has been found at Eidsbugarden (Battey & McRitchie 1973) and at Bygdin (Hossack 1968). The total thickness of the rocks described in this section, from the



upper limit of the retrograded Svartdalen gneiss to the base of the biotitic phyllonite is about 20 m.

The Torfinnsbu metasediments

The rocks occurring within the Torfinnsbu window are regarded as metasediments rather than highly sheared Jotun rocks for the following reasons: Quartz is ubiquitous in the metasediments and rare in the Svartdalen gneiss. In addition, bands of pure white quartzite occur in the Nybui section. Similarly, muscovite is omnipresent in the sediments and almost totally absent from the Svartdalen gneiss.

Nodules of pink calcite and stringers of brown carbonate are common in certain horizons within the metasediments (Fig. 4). Carbonates are rare in the Jotun rocks.

The metasediments are very schistose. Even close to mylonitic shear zones the Svartdalen gneiss does not take on a prominent schistosity.

The metamorphic grade of the sediments increases upward towards the most intensely deformed zone at the base of the Svartdalen gneiss, whilst the latter shows increasing retrogression downward towards the same zone. This argues against the Torfinnsbu rocks being intensely deformed representatives of the Svartdalen gneiss.

Petrography of the metasediments

Description. – The rocks below the basal thrust consist of a variety of sparagmites, quartz–mica schists, and amphibolites (Fig. 4).

Quartz – mica schist is the commonest rock type and, although the exact mineral proportions are variable, the paragenesis is biotite + epidote + quartz + plagioclase ± muscovite ± K-feldspar. The biotite is pleochroic from very pale yellow-brown to deep olive green. It usually has a very strong preferred orientation parallel to the main foliation in the rock. The plagioclase is commonly about An_{10}. The centres of feldspar grains are often saussuritised, suggesting that the present albitic plagioclase has been produced by metamorphism of plagioclase with initially more calcic cores.

Fig. 4. Approximate lithotectonic stratigraphy of the Torfinnsbu metasediments. The sequence is probably inverted (cf. Hossack 1968, Heim et al. 1977).

Garnet has been found only in one rock, a garnet-biotite-schist which occurs in Langedalsåi, a few tens of metres below the basal thrust. The garnet forms euhedral post-kinematic crystals and its paragenesis is clinoamphibole + biotite + epidote + quartz + garnet.

Amphibolites are the second most common rock type. The essential paragenesis is clinoamphibole ± epidote ± quartz ± plag. An amphibolite from the lake shore east of Torfinnsbu (and therefore not far below the basal thrust) has the assemblage clinoamphibole + biotite + quartz+ garnet. This rock contains a plagioclase (An_{25}) somewhat more calcic than is usual in the Torfinnsbu sequence. The amphibole in all the amphibolites is strongly pleochroic (very pale brown-green to deep olive green) and is probably hornblendic. The biotite is typically pleochroic from colourless to dark brown.

Sparagmites (arkoses) occur as layers varying in thickness from 50 cm to approx. 5 cm. They are commonly white or off-white in colour. Discontinuous green (or sometimes reddish) layers less than 5 mm thick are common. Occasional layers take on the aspect of an epidosite, consisting almost entirely of quartz and epidote, but generally the rock is an arkose (quartz + feldspar + epidote + muscovite). The feldspar is usually potassic and is often perthitic (?mesoperthite). Plagioclase of intermediate composition also occurs. Petrographically, the mineral assemblage indicates that the Torfinnsbu sparagmites have affinities with the Olefjell sparagmite type of Loeschke (1967).

Quartzites are of limited and sporadic distribution. A particularly prominent band 2 m thick occurs in the Nybui section. They all are quite white and apparently pure.

Mineral facies. – The non-garnetiferous assemblages appear to represent a facies transitional from greenschist to amphibolite (Turner 1968: 303–307). Similar parageneses have been recorded from the Dalradian succession in Scotland (Barrow 1912). In the AKF diagram given by Turner (1968: 305, fig. 7-22), the possible parageneses include:

K-feld + biotite + muscovite
biotite + garnet + muscovite

both with quartz, albite, and epidote as additional phases. Miyashiro (1972:129) pointed out that since AKF diagrams are not strictly constrained by the Phase Rule, it is possible for up to four phases to form an equilibrium assemblage. It seems, therefore, that the Torfinnsbu metasediments belong to the greenschist-amphibolite transitional facies.

The garnetiferous amphibolite has oligoclase as its plagioclase, rather than albite. Hence its paragenesis of clinoamphibole + biotite + epidote + quartz + garnet + oligoclase places it firmly in the amphibolite facies (Turner 1968: 309, assemblage C4).

Structure of the Torfinnsbu metasediments

Folds. – The metasediments have one dominant foliation which, although it is intensely refolded, has a regional northerly dip of approx. 30°. The formation of this foliation, which is parallel to lithological variations (isoclinally folded bedding), seems to be the earliest metamorphic-structural event in these rocks. The base of the Jotun crystalline rocks, the basal thrust, is parallel to this foliation (S_{0-1}).

Two sets of minor coaxial intrafolial folds are present, of which the earlier set, F_1, is only rarely seen. These are isoclinal in form with axial planes parallel to S_{0-1}, but they do appear to fold S_0. This is identical to the situation in the Valdres Sparagmite Group at Bygdin where Hossack (1968, fig. 4) illustrates a fold similar to the F_1 folds seen in Langedalsåi. Hossack postulates a much larger scale F_1 folding (which is actually responsible for S_1) on the basis of the vergence of F_1 minor structures. Similar evidence is not available from the Torfinnsbu area (Fig. 2).

The F_2 structures are fairly open folds, with axial planes which dip more steeply than S_{0-1}. They may be divided into major and minor representatives and they refold F_1 folds, though this is rarely seen.

F_3 folds are of an open form with upright axial planes and a wavelength of a few metres. They fold F_2 b-lineations, and also S_{0-1}. The base of the Jotun rocks is also folded by F_3. It is this phase of folding which is most obvious in the field.

Lineations. – The b-axes of F_1, F_2, and F_3 folds all define a linear element within the rock fabric. Whenever F_1 is seen, F_1 and F_2 are coaxial. F_1 and F_2 lineations all lay in S_{0-1}. Mineral defined lineations are poorly developed. Early lineations are refolded by later folds, and this accounts for the anomalous disposition of lineations (mainly b-axes of F_2 folds) in the mouth of Langedalsåi.

The form of the culmination which has been dissected to expose the window may be discerned in the regional disposition of lineations. The lineations dip approximately 20° northwest in upper Langedalsåi and Nybui, northwards west of Torfinnsbu and east in the exposures east of Torfinnsbu. This disposition may be explained by assuming the formation of a somewhat elongate post-F_3 dome which has its highest point somewhere between Langedalsåi and Nybui. Its flanks will dip fairly steeply away from its crest and it is this dome which has been eroded at its crest to give the window.

These data can be summarised in the following way: three phases of deformation are recognised in the Torfinnsbu window and these are identical to those recorded at Bygdin by Hossack (1968). The Svartdalen gneiss was emplaced over the metasediments during the first (and most intense) phase of deformation. The areal distribution of lineations can be related to the semi-ellipsoidal form of the window.

Discussion

Despite the work of several geologists (Battey & McRitchie 1973, Gjelsvik 1946, Dietrichson 1950, Hossack 1968, 1978, Heim et al. 1977) our understanding of the emplacement of the Jotun nappe is still rather incomplete. Field evidence from the sub-Jotun units in Valdres (Hossack 1978) and from the northwest margin (Roberts 1977) conflicts with the geophysical (Smithson et al. 1974) and some structural (Banham et al. 1979) evidence. What is needed is much more data both from the Jotun stem rocks themselves and from the nappes beneath Jotunheimen. Especially it must be determined whether sediments of the Jotun-Valdres nappe (Heim et al. 1977) reappear along the northwest margin of Jotunheimen, and whether such units can be traced right round the ends of the Jotun nappe.

The Torfinnsbu window demonstrates that the sheet of crystalline rocks around the middle part of Bygdin, which is the southeastward extension of the Jotun nappe, is thinner than that shown on the geophysical profile of Smithson et al. (1974).Moreover the structures in the metasediments within the window may be correlated closely with the deformational regime deduced by Hossack (1968) in the Valdres Sparagmite Group of the Bygdin-Vinstra region 10 km to the east and below the crystalline nappe. Taken in conjunction with the deep embayment into the crystalline massif along Sjodalen, the new evidence lends strong support to the view that the southeastern and eastern part of the Jotun massif is a comparatively thin sheet.

Unfortunately, lithological correlation between the metasediments of the Torfinnsbu window and the established successions outside the crystalline massif is not easy. The rocks are broadly dissimilar to the Olefjell and Hecklefjell formations (Hossack 1976) which are immediately adjacent to the Jotun nappe at Bygdin, nor do they resemble the dark slates and shales of Sjodalen. However, quartzite + arkose + pelite ± amphibolite sequences are fairly common in central Norway (e.g., Dietrichson 1950) and any attempt at lithological correlation must be very tentative at this stage. D. Twist (pers. comm. 1978) has noted that the rock types and sequences at Torfinnsbu appear to be similar to the much thicker successions he has studied from the northwest margin of the Jotunheimen massif in Bøverdalen (D. Twist 1979), whilst M. R. Garton (pers. comm. 1979) has indicated that very similar rocks are to be found in the highest thrust sheet of the Valdres nappe.

The Jotun crystalline rocks were undoubtedly emplaced during F_1, as is shown by the structural conformity of the basal thrust with S_{0-1}. This was accompanied by low-grade progressive metamorphism in the sediments and by retrogression in the Jotun rocks. As I. Bryhni (pers. comm. 1978) has pointed out, the basal thrust is a zone of metamorphic convergence, with the metamorphic grade of the metasediments increasing upwards towards the thrust (prograde metamorphism) and the grade of the Jotun crystalline rocks decreasing downward (essentially retrograde). The effect of retrogression within the Jotun rocks is, however, essentially confined to a narrow zone immediately above the basal thrust.

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