

CORRESPONDENCE AND NOTES

A model for stratigraphic and metamorphic inversions at Sulitjelma (Boyle 1987) – comment

SIRS – In his contribution to the interpretation of the complex structure of the Sulitjelma district Boyle (1987) argues that: (1) the Sjønstå Group is younger than the Furulund Group; (2) the Skaiti Supergroup is older than the Sjønstå and Furulund Groups; and (3) the Sjønstå Group is underlain structurally by the Pieske Marble. The Skaiti Supergroup and the Sjønstå and Furulund Groups would appear to be incorporated into a large fold nappe, the Sulitjelma Fold Nappe, which overlies with a possible thrust contact (Kirk & Mason, 1984, fig. 9, after Boyle, Mason & Hansen, 1985) the Pieske Marble.

Detailed mapping between Lomivatn and Balvatn, and to the south and west of Balvatn (Kollung 1970*a*, 1970*b*; Findlay, 1980) has shown the structural succession for the eastern and southern Sulitjelma region to be, in descending order: (1) Skaiti Supergroup (or Sulitjelma Schists; Findlay 1980); (2) Furulund Group; (3) Sjønstå Group; (4) Pieske Marble; (5) a sparagmitic unit (Sparagmite–gneiss Formation; Findlay, 1980), (6) a mica schist unit (Lower Mica Schist; Findlay, 1980); and (7) basement.

An obvious tectonic break, well exposed on the south shore of Balvatn (Findlay, 1980, fig. 4) separates the Skaiti Supergroup from the structurally underlying Furulund Group. Another tectonic break separates the Pieske Marble from the underlying rocks (Findlay, 1980, fig. 3). Both tectonic breaks cut across units, and are therefore disjunctive.

The Sjønstå Group appears to grade down into the Pieske Marble, into which it is also folded (Findlay, 1980, fig. 3) into a recumbent east-closing synform. Local thrusting disrupts the boundary between the Furulund and Sjønstå Groups where it is exposed on the north side of Basshaugen.

Structures in the Skaiti Supergroup south of Balvatn include a south-closing recumbent synform exposed in the north face of Salefjell (Findlay, 1980, fig. 4).

In none of these rocks did I note geopetal indicators; grade of metamorphism in the Skaiti Supergroup attains the kyanite zone; grade of metamorphism in the Furulund and Sjønstå Groups would appear to be that of garnet or oligoclase zones, although I reported non-oriented kyanite blades in a post-schistosity tension gash at one locality within the Sjønstå Group near Basshaugen (Findlay, 1980).

If Boyle's interpretation is correct (Boyle, 1987) then it carries the implication that his Sulitjelma Fold Nappe, or at least the lower limb thereof, extends 25 km south to the Balvatn region, and thence west some 10–15 km to or beyond Basshaugen. I would argue that the sole of the Sulitjelma Fold Nappe is the tectonic contact between the Pieske Marble and structurally underlying formations, and have argued (Findlay, 1980, table 6) that this tectonic break extends as far north as Vatnfjell. That is, Boyle's Sulitjelma Fold Nappe constitutes the whole or part of the Pieske Nappe (Kautsky, 1953), and should include the Pieske Marble.

Boyle (1987) does not discuss in detail the contact between the Skaiti Supergroup and the Furulund Group. Boyle, Griffiths & Mason (1979) regarded the rocks now

known as Skaiti Supergroup as belonging to the Gasak Nappe and it is evident from observations to the south of Sulitjelma, in the Baldoaivve region and at Balvatn (Findlay 1980, fig. 4), that the two units are separated by an extensive thrust. Given the interpretation sketched in Boyle (1987, fig. 2), it would appear that this thrust should be folded by the Sulitjelma Fold Nappe. That is, the Gasak Nappe is older than, and has been deformed by the deformation which produced the Pieske, or Sulitjelma Fold Nappe. Is such an interpretation warranted by the many post-1970 studies north of Langvatn and Lomivatn?

References

- BOYLE, A. P. 1987. A model for stratigraphic and metamorphic inversions at Sulitjelma, central Scandes. *Geological Magazine* **124**, 451–66.
- BOYLE, A. P., GRIFFITHS, A. J. & MASON, R. 1979. Stratigraphical inversion in the Sulitjelma area, Central Scandinavian Caledonides. *Geological Magazine* **116**, 393–402.
- BOYLE, A. P., MASON, R. & HANSEN, T. S. 1985. A new tectonic perspective of the Sulitjelma region. In *The Caledonide Orogen – Scandinavia and Related Areas* (eds. D. G. Gee and B. A. Sturt), pp. 529–41. Chichester: Wiley.
- FINDLAY, R. H. 1980. A regional lithostratigraphy for southern and eastern Sulitjelma. *Norsk Geologisk Tidsskrift* **4**, 223–34.
- KAUTSKY, G. 1953. Der geologische Bau des Sulitjelma-Salojaure-gebietes in den nordskandinavischen Kaledoniden. *Sveriges geologiska Undersökning* **C528**, 1–233.
- KIRK, W. L. & MASON, R. 1984. Facing structures in the Furulund Group, Sulitjelma, Norway. *Proceedings of the Geologists' Association* **95**, 43–50.
- KOLLUNG, S. 1970*a*. *Geologiske undersøkelser. Området mellom Lairofjell og Balvatn*. Company report, held by A/S Sulitjelma Bergverk, Sulitjelma.
- KOLLUNG, S. 1970*b*. *Geologiske undersøkelser. Storfjella V for Balvatn*. Company report, held by A/S Sulitjelma Bergverk, Sulitjelma.

R. H. FINDLAY
Department of Mines
P.O. Box 56
Tasmania 7018
Australia

29 April 1988

Reply

In his letter, Dr Findlay correctly summarizes the main stratigraphical and structural parts of my model (Boyle, 1987) for the Sulitjelma Fold Nappe (SFN), and goes on to make three main points on the basis of his mapping with S. Kollung (Findlay, 1980).

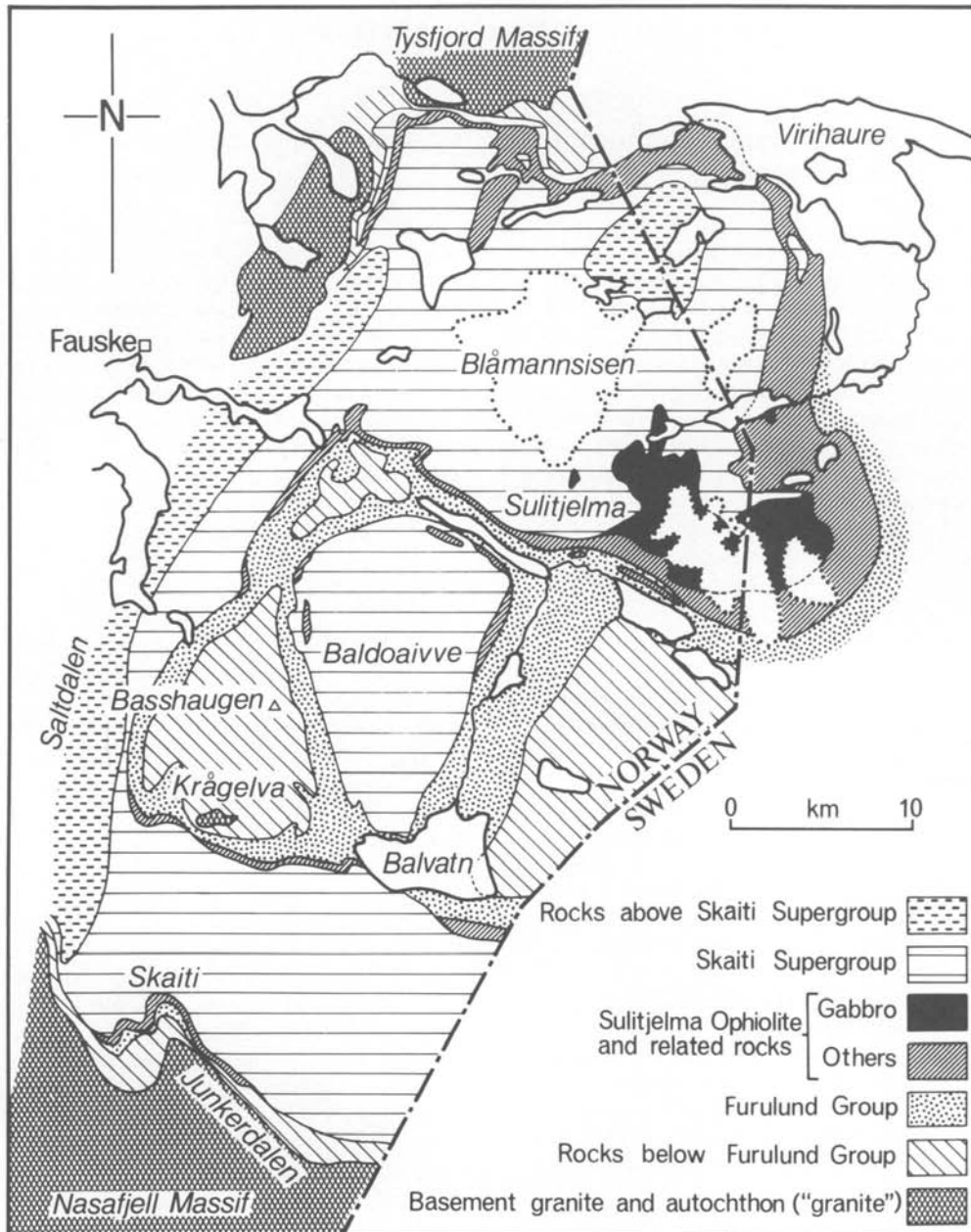


Figure 1. Summary geological map of the region around Sulitjelma (after Boyle, Mason & Hansen, 1985).

- (1) The SFN extends 25 km south to the Balvatn region and then some 10–15 km west to Basshaugen (Fig. 1).
- (2) The junction between the Sjønstå and Pieske Groups is gradational and locally folded into an east-closing synform, whereas the structural base of the Pieske Group is a thrust. Thus, he argues that the Pieske Group lies within the SFN, and that the structural base of the Pieske Group forms the sole thrust of the SFN.
- (3) The Furulund Group/Skaiti Supergroup junction at Baldoaivve and Balvatn is an extensive thrust and from my Figure 2 (Boyle, 1987) he suggests that this thrust should be early and folded by the SFN.

For the reader unfamiliar with the area, general discussion of these points is made difficult to follow by the variation in terminology used by different authors, including Findlay, when describing the geology of the Sulitjelma area. Table 1 summarizes the different usage. Figure 1 is a regional

geological map indicating the locations of place names referred to here and by Findlay.

I welcome the suggestion that the SFN is more widespread than I indicated (Boyle, 1987, Figures 1 and 4). I have a Ph.D. student (Mr Keith Westhead) looking at the Junkerdalen area south of Balvatn. Part of his remit is to investigate the nature of the SFN as it attenuates southwards beyond the area studied by Findlay (1980). This study may extend the geographical extent of the SFN yet further.

Findlay's second point concerning the status of the Pieske Group raises a number of problems. Boyle, Mason & Hansen (1985) originally placed the Pieske Group in the SFN (Köli Nappe Complex of Stephens *et al.*, 1985), and regarded its base as providing the basal décollement for the SFN. An early draft of Boyle (1987) followed this scheme. I was persuaded otherwise by an anonymous referee and Dr M. B. Stephens, both of whom placed great importance on the presence of eclogites in the Pieske Group to the east

Table 1. Summary of nomenclature for the major tectonostratigraphic units at Sulitjelma.

Yogt (1927)		Kautsky (1953)	Nicholson & Rutland (1969)	Findlay (1980)		Boyle (1987)	Stephens <i>et al.</i> (1985)
Upper Sulitjelma Schists	Rodtind Schist (North) Baldoivve Schist Skaiti Schist (South)	Gasak Nappe	Sulitjelma Schist Sequence with Sulitjelma Gabbro	Upper Sulitjelma Schists	G a s a k N a p p e	Skaiti Supergroup	Köli Nappe Complex
Sulitjelma Gabbro				Lower Sulitjelma Schists			
Amphibolite				Yasten Nappe	Sulitjelma Amphibolites	Tectonic break	
Lower Sulitjelma Schists	Furulund Schist Sjønstå Gneiss (West) Muorki Schist (East)	Pieske Nappe	Furulund Group Sjønstå Group Pieske Marble Juron Quartzite	Amphibolites Furulund Group Sjønstå Group Pieske Marble	Ophiolite Furulund Group Sjønstå Group Tectonic Break Pieske Group	Seve Nappe Complex	
				Tectonic Break			

Note that Boyle (1987) places all of the rocks above the Pieske Group into one structural unit, the Sulitjelma Fold-Nappe. Note also that Stephens *et al.* (1985) essentially place thrusts between all of the major lithological units, but that these are not indicated for simplicity.

and southeast of Sulitjelma (Stephens & van Roermund, 1984; Nicholson, 1984). These eclogites occur as metabasic lenses hosted by schists and marbles showing no evidence of migmatization. Stephens & van Roermund describe the contacts of the lenses as 'intensely foliated' and estimate metamorphic conditions for eclogite formation to be $610 \pm 90^\circ \text{C}$ and $14.9 \pm 1.5 \text{ kbar}$. Nicholson (1984) suggested metamorphic temperatures of $500\text{--}625^\circ \text{C}$, favouring the lower value. The presence of these eclogites in the Pieske Group led Stephens (personal communication and Figure 1 in Stephens & van Roermund, 1984) to think that it must be metamorphically distinct from the adjacent Sjønstå Group and that the two groups must be separated by a thrust. He regards this thrust as the major thrust which separates the Köli Nappe Complex from the underlying Seve Nappe Complex, thus placing the Pieske Group in the Seve Nappe Complex (Stephens & van Roermund, 1984, Stephens *et al.*, 1985, pp. 144–5). The anonymous referee concluded rather categorically, 'There is now no doubt that the Pieske Group was *not* deposited on top of the Sjønstå

Group...' because, in his opinion, the eclogites indicate a much more complex tectonothermal history for the Pieske Group; implying from his conclusion that the host rocks as well as the eclogites have suffered eclogite facies metamorphism. This conclusion favouring a thrust contact is at odds with Findlay's observation that the junction between the Sjønstå Group and the Pieske Group is 'gradational' and therefore perhaps stratigraphic in the Balvatn–Baldoivve area, a fact confirmed by Keith Westhead in the Junkerdalen area. It could be, as discussed generally in Boyle (1987), that the thrust the anonymous referee and Stephens favour between the Pieske and Sjønstå Groups is pinned in the Balvatn–Baldoivve–Junkerdalen area, preserving a stratigraphic relationship between the two Groups there which is elsewhere sheared out. Of course, this does not explain the existence of the eclogites.

Stephens & van Roermund (1984) do not indicate P–T conditions for the eclogite host-rocks, other than commenting on the lack of migmatization and the presence of garnet in schists and calcite (not aragonite) in marbles. My

impression from their paper, and from walking over the ground with Stephens, is that the host rocks do not preserve evidence of eclogite facies metamorphic conditions, and quite probably never suffered them. The 'intensely foliated' nature of the eclogite margins and their lensoid shape suggests to me that the eclogites may be exotic tectonic inclusions of high grade metabasite in the more typical lower grade Pieske Group metasedimentary rocks. This would explain the 'intensely foliated' margins, the hydrous retrogression of the eclogites, and the lower metamorphic grade of the schists and marbles; water for eclogite retrogression could be made available by prograde dehydration reactions in the Pieske Group schists after emplacement of the eclogites. If this view of the eclogites being exotic tectonic inclusions is correct, then there is no need for a profound metamorphic break between the Pieske and Sjønstå Groups and the evidence of Findlay and Westhead for stratigraphic continuity can be taken on board. This would place the Pieske Group in the SFN, as suggested by Findlay.

How then could the eclogites get into the Pieske Group? In relation to the model I initially proposed (Boyle, 1987, Figure 11) and have subsequently developed (Burton *et al.*, *in press*), the Pieske Group would represent the stratigraphically highest sedimentary unit in the Sulitjelma ophiolite marginal-basin. I have recently presented geochemical and field evidence (Boyle, *in press*) consistent with the formation of the Sulitjelma ophiolite in an ensialic back-arc basin related to (eastward-directed?) subduction. A subduction zone environment could have provided the metamorphic conditions for formation of the eclogites. Tectonic incorporation of some of these eclogites into the Pieske Group could have occurred during closure and obduction of the marginal basin and the consequent emplacement of the SFN. In this scenario, the eclogites would begin to retrogress while the Pieske Group was beginning to undergo prograde regional metamorphism. I have not studied the Pieske Group in great detail, and so would not dogmatically adhere to the above scenario. However, I do think that it attempts to marry, in a reasonable manner, the observations of the anonymous referee and Stephens & van Roermund (1984), as well as the points raised by Findlay. Some detailed work on the eclogite host rocks is in order.

Findlay's third point is a little confusing due to the terminology used. When referring to the Furulund Group in this instance, I assume that Findlay is also referring to the non-gabbroic parts of the Sulitjelma ophiolite (represented by the Sulitjelma amphibolites of Findlay (1980)) so that he is in fact implying thrusting between the Skaiti Supergroup and the ophiolite rocks. In the Sulitjelma area the Sulitjelma ophiolite has intrusive igneous contacts with the Skaiti Supergroup as well as tectonised ones. In the context of my model (Boyle, 1987, Figure 11), obduction of the marginal basin results in overriding of the ophiolite by the Skaiti Supergroup; the hinge of the SFN rolling as the nappe is progressively oversheared. Thus, as the SFN develops the trailing half of the nappe (ie the Skaiti Supergroup) progressively overrides what was the leading half of the nappe (i.e. the ophiolite and the Furulund Group) giving rise to a tectonic contact between the two. Metamorphic evidence from garnet zoning P-T-t paths in the Furulund and Skaiti Supergroups supports this model (Burton, *in press*). In answer to Findlay, I would agree that thrusting is present between the Skaiti Supergroup and what he terms the Furulund Group, but that it is synchronous

with formation of the SFN and not before it, produced by the upper limb of the SFN overriding the lower limb. Displacement on this thrust is by necessity less than the overall displacement represented by emplacement of the SFN, in that the displacement is confined to a surface internal to the SFN. There are other structures in the Skaiti Supergroup rocks which predate the Sulitjelma ophiolite marginal basin and thus the SFN (Mason, 1971, Boyle, Mason & Hansen, 1985, Billett, 1987), but these are not analogous to the extensive thrust described by Findlay.

Findlay refers to the Gasak and Pieske Nappes in his letter. In many ways these terms, together with Vasten Nappe, are redundant. When introduced by Kautsky (1953) based on work in Swedish Sulitjelma, the Gasak Nappe comprised (using my terminology) the Skaiti Supergroup and the Sulitjelma ophiolite gabbro, the Vasten Nappe comprised the rest of the Sulitjelma ophiolite (ie the non-gabbroic parts), and the Pieske Nappe comprised the Furulund Group and lower units. The terms have been redefined and misused to such an extent (myself included), that it is now unclear what they define, even to those geologists familiar with the area. In Kautsky's (1953) original sense, they are no longer tenable. As tectonic pigeon holes into which the geology must be placed (see Stephens *et al.*, 1985, for example) they are regressive. Thus, with apologies to Gunnar Kautsky, I recommend that they are scrapped and terms such as Lower, Middle and Upper Köli Nappes used instead, as by Stephens (1986) in a recent short note.

References

- BILLET, M. F. 1987. The geology of the northern Sulitjelma area and its relationship to the Sulitjelma Ophiolite. *Norsk geologisk Tidsskrift* **67**, 71–83.
- BOYLE, A. P. 1987. A model for stratigraphic and metamorphic inversions at Sulitjelma, Central Scandes. *Geological Magazine* **124**, 451–66.
- BOYLE, A. P. *in press*. The geochemistry of the Sulitjelma ophiolite and associated basic volcanics: tectonic implications. In *The Caledonian Geology and Related Geology of Scandinavia* (ed. R. A. Gayer). London: Graham & Trotman Ltd.
- BOYLE, A. P., MASON, R. & HANSEN, T. S. 1985. A new tectonic perspective of the Sulitjelma Region. In *The Caledonide Orogen – Scandinavia and Related Areas* (eds. D. G. Gee and B. A. Sturt), pp. 529–41. Chichester: Wiley.
- BURTON, K. W., BOYLE, A. P., KIRK, W. L. & MASON, R. *in press*. Pressure, temperature and structural evolution of the Sulitjelma Fold-Nappe, Central Scandinavian Caledonides. In *Evolution of metamorphic belts* (eds. J. S. Daly, R. Cliffe and B. W. D. Yardley). Geological Society of London Special Publication.
- FINDLAY, R. H. 1980. A regional lithostratigraphy for southern and eastern Sulitjelma, north Norway. *Norsk geologisk Tidsskrift* **60**, 223–34.
- KAUTSKY, G. 1953. Der geologische Bau des Sulitjelma-Salojaure-gebietes in den nordskandinavischen Kaledoniden. *Sveriges geologiska Undersökning* **C528**, 1–233.
- MASON, R. 1971. The chemistry and structure of the Sulitjelma gabbro. *Norges geologiske Undersøkelse* **269**, 108–41.
- NICHOLSON, R. 1984. An eclogite from the Caledonides of

- southern Norbotten. *Norsk geologisk Tidsskrift* **64**, 165–9.
- NICHOLSON, R. & RUTLAND, R. W. R. 1969. A section across the Norwegian Caledonides; Bodø to Sulitjelma. *Norges geologiske Undersøkelse* **260**, 1–86.
- STEPHENS, M. B. 1986. Terrane analysis at Sulitjelma, Upper Allochthon, Scandinavian Caledonides. *Geologiska Föreningens i Stockholm Förhandlingar* **108**, 303–4.
- STEPHENS, M. B., GUSTAVSON, M., RAMBERG, I. B. & ZACHRISSON, E. 1985. The Caledonides of Central-North Scandinavia – a tectonostratigraphic overview. In *The Caledonide Orogen – Scandinavia and Related Areas* (eds. D. G. Gee and B. A. Sturt), pp. 135–62. Chichester: Wiley.
- STEPHENS, M. B. & VAN ROERMUND, H. L. M. 1984. Occurrence of glaucophane and crossite in eclogites of the Sveve Nappes, southern Norbotten Caledonides, Sweden. *Norsk geologisk Tidsskrift* **64**, 155–63.
- VOGT, T. 1927. Sulitelmafeltets geologi og petrografi. *Norges geologiske Undersøkelse* **121**, 1–560.
- A. P. BOYLE
Department of Earth Sciences
The Jane Herdman Laboratories
Brownlow Street
P.O. Box 147
Liverpool L69 3BX
- 4 March 1988

Addendum. In reply to Dr Boyle's comments, I would like to thank him for clarifying my comments.

With respect to the 'Sulitjelma Amphibolites' I mapped southwest of Balvatn, these hornblende amphibolites lie within Furulund Group pelites close to but not at the tectonic contact between the Skaiti Supergroup and Furu-

lund Group. In view of the now obvious importance of these rocks to the regional tectonic interpretation of the Sulitjelma district, I prefer now to neither confirm nor deny their affinity to the Sulitjelma ophiolite. When mapping in 1972, it seemed a fair correlation: the correlation may be incorrect.