Reinterpretation of Finnmarkian deformation on western Sørøy, northern Norway

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New field observations of the relationships between dikes of the Seiland Igneous Province and psammites of the Klubben Group on western Sørøy have led to the interpretation that the psammites were not deformed or folded by orogenesis either before or during intrusion of the dikes. Folds with axial planes parallel to the dikes developed after dike intrusion, and the dikes appear to cut undeformed sedimentary bedding and intrusion-related migmatitic textures and fold structures, not orogenic foliations and folds. These results contrast with previous studies which concluded that the Late Cambrian to Early Ordovician Seiland intrusions on Sørøy were syn-orogenic, interpretations originally used to define the Finnmarkian phase of the Caledonian orogeny. Relationships between Seiland intrusions and country rocks elsewhere in Finnmark, and other evidence for Finnmarkian regional metamorphism and thrust tectonics in northern Norway, should thus be re-examined. The syenites, carbonatites, layered gabbros and ultramafic rocks of the Seiland Igneous Province may be related to continental rifting and development of the Iapetus ocean; not mantle diapirism within a subduction zone, as previously interpreted.

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The Finnmarkian orogenic phase and the Seiland Igneous Province

The island of Sørøy in western Finnmark is the classic locality of the Finnmarkian phase of the Caledonian orogeny. This phase has even been referred to as the 'Sørøyan event' (Gee & Wilson 1974). Structural and petrographic studies on Sørøy concluded that regional metamorphism and deformation occurred before, during, and soon after the intrusion of rocks of the Seiland Igneous Province into psammites of the Klubben Group (Stumpfl & Sturt 1965, Sturt & Ramsay 1965). Isotopic dating of the Seiland intrusions to 540–490 Ma established the Late Cambrian to Early Ordovician age of this Finnmarkian event (Sturt et al. 1967, Pringle & Sturt 1969, Sturt et al. 1978).

The interpretation that an orogenic phase occurred well before the Scandian phase in Silurian time has greatly influenced tectonic models for the northern Scandinavian Caledonides (Sturt et al. 1975, 1978). Deformation of the Scandian phase, though locally intense (Ramsay & Sturt 1976), has not been widely recognized in Finnmark and it has been assumed that most of the thrusting, folding, and regional metamorphism in northern parts of the Caldeonides are of Finnmarkian age (Ramsay et al. 1985, Roberts 1985).

The most compelling evidence of Finnmarkian orogenesis appears to have been the intrusion of Seiland igneous rocks across Finnmarkian foliations and parallel to the axial planes of Finnmarkian folds (Sturt & Ramsay 1965). Such a discordance has also been recognized on the macroscopic scale (Speedyman 1972). Although the Seiland intrusions presumably post-dated the first stage of Finnmarkian thrusting (Sturt et al. 1978), they cut no exposed thrust contacts, and are only found within the Sørøy-Seiland Nappe (Ramsay et al. 1985). In other nappes, Finnmarkian folding, metamorphism and thrusting have been mainly demonstrated by structural and stratigraphic correlations, especially with the rocks of Sørøy, where the Finnmarkian age of the orogenesis is considered to be best documented.

The Seiland Igenous Province includes layered gabbros and ultramafites, alkaline rocks, and carbonatites, in an association which appears to be tectonically unique. These rock types are characteristic of extensional environments, yet on Sørøy they are supposed to be syn-orogenic, produced during the compressional Finnmarkian deformation. The rocks would seem to have formed in a consuming or collisional plate-tectonic regime, and have been thought to represent mantle diapirism within the geosyncline (Ramsay 1973) or above the Benioff zone (Robins & Gardner 1975; Gayer et al. 1985; Roberts et al. 1985).

Background for the present study

Two separate research interests have led us to critically evaluate the field evidence for Finnmarkian orogenesis on Sørøy. The problems can be summarized as follows:

1. The stratigraphy of Sørøy was previously correlated with the stratigraphy of the Nordreisa area, about 100 km to the southwest (Ramsay 1971; Zwaan & Roberts 1978). In both areas the stratigraphic sequence was thought to be continuous, progressing upward from fluvial psammites through shallow-water semi-pelites, pelites, and carbonates to deep-water turbidites and volcanites. Correlation of the upper stratigraphic units was abandoned, however, when Upper Ordovician or Silurian fossils were found in the carbonates of the Nordreisa area (Binns & Gayer 1980). The main unit of carbonates on Sørøy, known as the Falkenes marble, was still thought to be pre-Ordovician, because the entire Sørøy sequence was presumably affected by the Finnmarkian orogenic phase. In addition, marble rafts in one of the gabbros were thought to be derived from the Falkenes marble and to contain Cambrian fossils (Holland & Sturt 1970). These fossils have now been discredited (Debrenne 1984) and the stratigraphies on Sørøy and Nordreisa again might be correlated; if so, the Falkenes marble is too young to have undergone Finnmarkian deformation or to have been intruded by rocks of the Seiland province, as earlier interpreted (Speedyman 1983).

There has been another obstacle to the Nordreisa-Sørøy correlations. Gabbros and a swarm of mafic dikes in the Nordreisa area appear to represent a southern extension of the Seiland Igneous Province (Zwaan & Roberts 1978). However, the intrusions of the Nordreisa area are pre-orogenic (Zwaan, in prep.); they produced contact metamorphism and deformation of the country rocks, but are not related to regional deformation or orogenesis. In contrast, the Seiland intrusions on Sørøy have been interpreted to be syn-orogenic. If the rocks of Nordreisa and Sørøy are related, the Seiland intrusions on Sørøy should also be pre-orogenic.

2. Mafic dikes are abundant in the folded psammites of the Sætra (Särv) Nappe of the Oppdal area (Krill 1983, 1986). Isotopic dates and regional correlations show that these dikes are Late Precambrian and pre-orogenic; they are related to the Ottfjället dolerite dike swarms and are thought to represent continental rifting related to formation of the Iapetus ocean. A common feature of the dike-intruded psammites is the occurrence of folds adjacent to the dikes. The folds formed after the dike intrusion, but the structures can be both complex and very deceptive. The psammites are well layered, and where deformed, the planar sedimentary bedding is easily misinterpreted to represent earlier foliation. Dikes cutting this bedding may appear to cut an orogenic foliation. During later deformation, ductility contrasts between dolerite dikes and psammite produced boudinage, folding, and irregular relationships between foliations. Locally, the dikes appear to cut foliations in the psammite (figure p. 389 in Bjørlykke 1905).

The dikes of Sørøy also commonly occur adjacent to folds. The dikes have been interpreted to cut the psammite layering, representing D1 foliation, as they intruded parallel to the axial planes of the D2 folds (e.g. Fig. 16 in Sturt & Ramsay 1965, Fig. 88 in Roberts 1968). Whereas in Oppdal, the dikes appear to influence the development of folds in the psammite, on Sørøy the folds have been interpreted to influence the intrusion of the dikes. Since the interpretation of these structures forms a main line of evidence that much of the regional deformation of northern Norway was roughly coeval with Seiland magmatism, a re-examination of the field relations seemed appropriate.

The present study

This paper reports observations of the Klubben psammite and dikes of the Seiland province along the well exposed coast and road sections between Hasvik and Sørvær on Sørøy (Fig. 1). Many tens of dikes were closely observed within the psammites. Some of the observations and locations are listed in Table 1. Dikes are rarely more than a metre thick. The degree of deformation varies in the different dikes, and some dikes cut others.

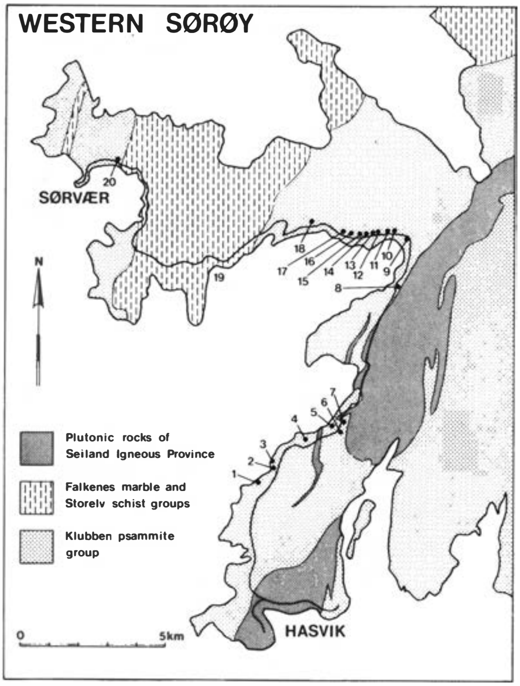

Fig. 1. Geological map of Western Sørøy (simplified from Roberts 1972) showing numbered locations (see Table 1).

Structures in the psammitic host rocks appear to be similar adjacent to both felsic and mafic dikes. Although only two days were available for this field study, the relationships were surprisingly clear and the implications may be far-reaching.

Bedding and foliation in psammite and dikes

Bedding in the psammites varies in thickness from a few centimetres to a few tens of centimetres. Thin micaceous partings separate the meta-sandstone beds and may give the metamorphosed, layered rocks the appearance of being strongly sheared and foliated. However, cross-bedding is commonly observed in the recrystallized sandstone, and helps to identify areas where penetrative deformation was not extensive (Figs. 2, 3, 4). In the less deformed psammites, micas within the cross-bedded layers and within the micaceous partings are not oriented parallel to the bedding, but the micas are commonly so fine grained that they are not easily observed in the field.

Table 1. Numbered locations on Western Sørøy. UTM reference coordinates refer to 1:50,000 map sheets Sørvær and Sørøya.

	UTM Ref	Observation, figure number
1.	433254	Figs. 7, 9.
2.	439260	Flattened psammite layering deflects around remnant of felsic dike. Cross-bedding is preserved only in strain-shielded area adjacent to dike.
3.	437260	Folds adjacent to quartz-feldspar vein.
4.	449268	Well preserved cross-beds and mafic and felsic dikes. Fig. 2.
5.	457271	Contact-metamorphosed psammites showing anatexis and cross-bedding. Felsic dikes cut mafic dikes, and vice versa. Fig. 10.
6.	459270	Fig. 11.
7.	459272	Fig. 12.
8.	480319	Cross-bedding preserved against mafic dike.
9.	489342	Bedding cut at high angle by mafic dike.
10.	485343	Strongly foliated psammite, and concordant schistose amphibolite layers representing sheared mafic dikes.
11.	484343	Folds with axial planes parallel to schistose amphibolite.
12.	479343	Well preserved cross-beds and dikes.
13.	477344	Figs. 5, 8.
14.	475343	Sedimentary layering is less deformed in thicker, strain-shielded bed adjacent to remnant of felsic dike.
15.	473343	Fig. 4.
16.	466342	Psammite showing strong layering, muscovite lineation and cross-bedding; bedding cut by mafic dike. Fig. 3.
17.	465343	Bedding and cross-bedding cut by mafic dike.
18.	448348	Fig. 6.
19.	425340 385365	No Seiland intrusions seen in Storelv schist or Falkenes marble groups.
20.	382369	Cross-bedding preserved adjacent to mafic dike.

Fig. 2. Cross-bedded psammite. Note micaceous partings between beds that locally produce schistose appearance. Loc. 4.

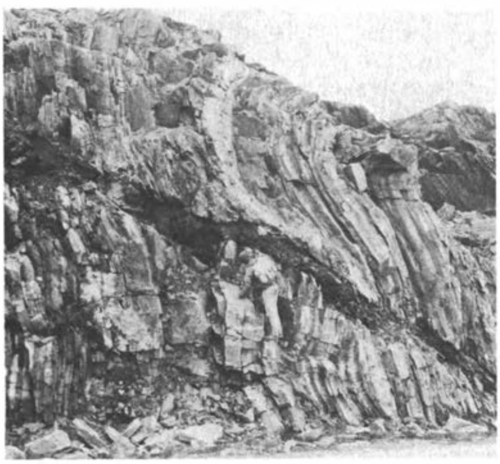

Fig. 3. Steeply dipping bedding in psammite, cut by mafic dike. Bedding may appear to represent pre-dike foliation, but cross-bedding in some layers indicates lack of penetrative deformation. Loc. 16.

In areas without strong penetrative deformation, metamorphosed dikes and veins commonly cut the psammite layering or bedding at high angles (Figs. 3, 4). In general, such discordant dikes show only a relatively weak cleavage or foliation. Foliation in both dikes and psammite is generally subparallel to the bedding of the psammite.

Most of the dikes are strongly foliated, and many are sheared, especially along the margins, with a strong foliation parallel to the contact (Fig. 5).

Strain shielding of psammite adjacent to dikes

Sedimentary structures such as cross-beds have been recognized on Sørøy (Figs. 1, 2 in Roberts 1974; Fig. 5 in Ramsay et al. 1985), but they have only rarely been mentioned in relation to the dikes (cf. Fig. 17 in Sturt & Ramsay 1965). In many outcrops, we found the best-preserved bedding in the psammite immediately adjacent to dikes. Especially where dikes cut the layering at high angles, they appear to represent rigid ribs that shielded the psammite from penetrative deformation and foliation (Fig. 6).

Some intrusions were irregular or stepped, intruding as both sills and dikes. Where the intrusions are locally parallel to bedding, the bedding is foliated and somewhat flattened. Where the same intrusions step upward to form a dike, the truncated psammite layering is commonly thicker and less foliated (Figs. 5, 6).

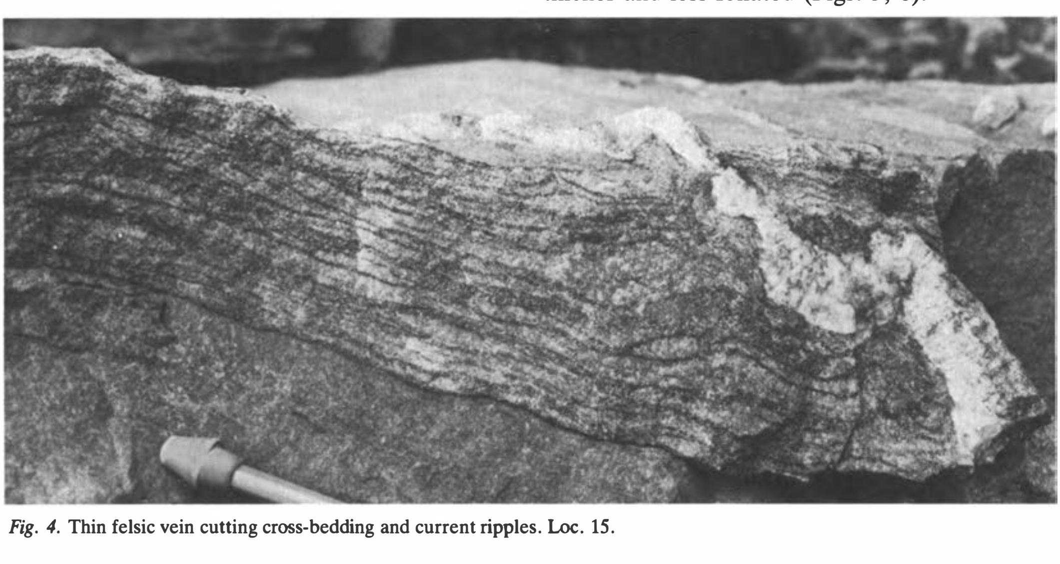

Fig. 4. Thin felsic vein cutting cross-bedding and current ripples. Loc. 15.

(a) (b)

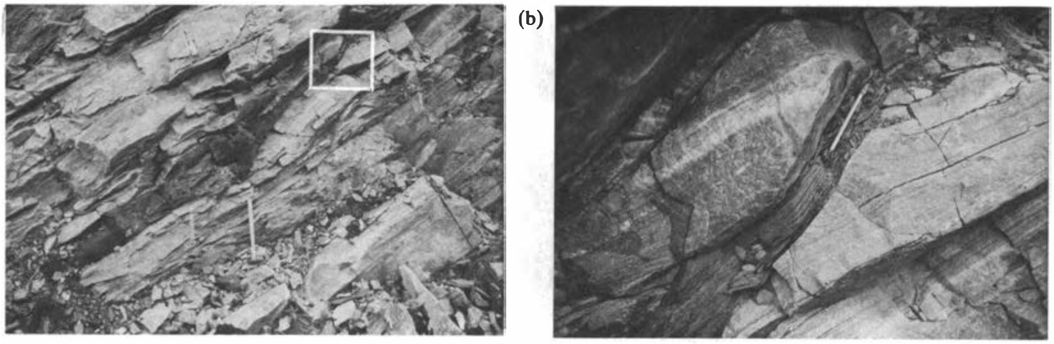

Fig. 5. Strongly foliated mafic dike. Bedding in psammite is best preserved where truncated by dike and shielded from strain (5b—detail). Loc. 13.

Fig. 6. Foliated mafic dike. Where dike is strongly discordant near hammer, bedding in psammite is more massive and better preserved. Loc. 18.

In more intensely deformed rocks, the psammites are strongly foliated. Sedimentary structures are generally destroyed in such rocks, but cross-bedding may be locally preserved where discordances are still present in the sheared dikes (Fig. 7a, b). Remnants of dikes are also found as boudins or resistent pods in the foliated psammites. In the strain-shadows adjacent to such igneous pods, the bedding is also thicker and less deformed, and cross-bedding may be preserved (Locs. 3, 14).

Folding of psammite adjacent to dikes

Folds in the psammites on Sørøy have been well studied and described (e.g. Ramsay & Sturt 1963, 1973a, 1973b), but the relationship between dikes and folded psammites have not been described in detail. Our work showed that foliated dikes are commonly subparallel to the axial planes of all types of mesoscopic folds: open to isoclinal, and upright to flat-lying. All the dikes seen in psammite were foliated, and in general it appears that

(b)

(a)

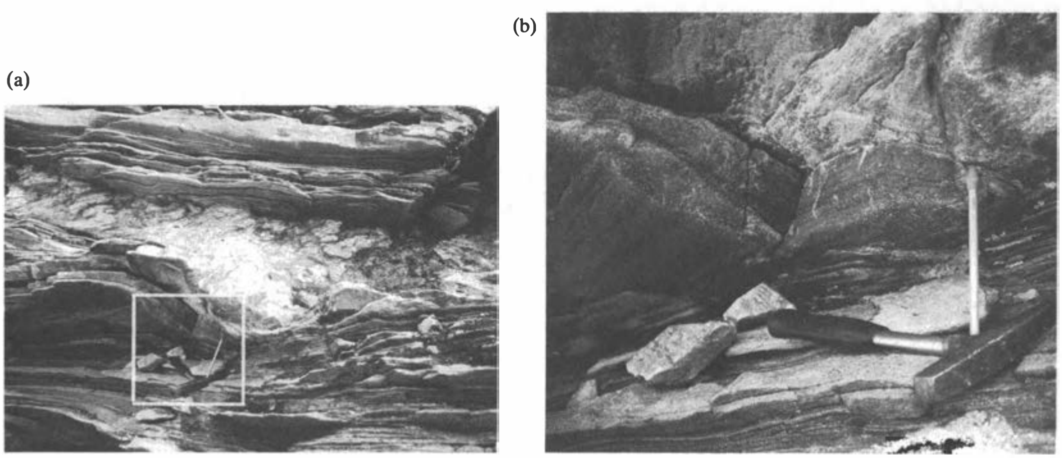

Fig. 7. Strongly sheared felsic dike. Cross-bedding is preserved only where truncated and shielded by dike (7b—detail). Loc. 1.

Fig. 8. Independently developed folds on opposite sides of three mafic dikes. Shearing occurred within the dikes during folding. Loc. 13.

where psammites are more strongly deformed, dikes are more strongly foliated, and cut the psammite layering at a lower angle.

If the dikes had intruded parallel to the axial planes of pre-existing folds, it might be expected that the folds would be continuous on each side of the dike, with the only disturbance being the dilation due to dike intrusion. Instead, there is no match of psammite layers, or continuity of folds, on opposite sides of most dikes in the folded psammites (Fig. 8). Thick layers on one side of a foliated dike may occur opposite thin layers on the other side. An antiform on one side of a dike may be matched by an antiform on the opposite side, with no intervening synform. Folds on one side may be open, while folds on the other side may be isoclinal. Several tight folds may be present on one side of a dike, while no folds occur on the other. In general, folds commonly appear to have developed in response to the dikes: they do not separate folded layers on the opposite sides of the dikes which were originally in structural continuity.

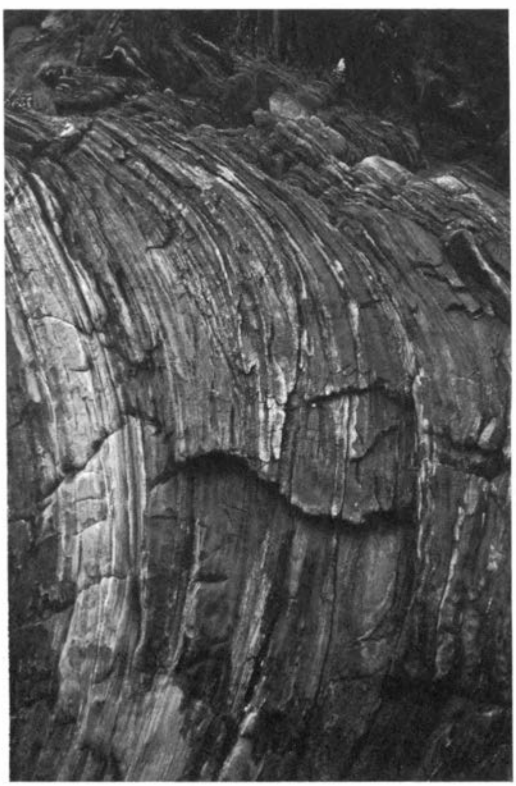

Fig. 9. Isoclinally folded felsic intrusion, warped by later folding. Loc. 1.

Outside the area of contact metamorphism (see below), dikes were not observed to dissect the axial planes of folds. Although some dikes may appear to cut axial planes, no parts of the truncated folds were present on the opposite sides of such dikes. The axial planes were either parallel to the dikes, or terminate at the sheared dike contacts. Isoclinal folds were seen in the psammites, with axial planes parallel to the margins of strongly foliated dikes.

Such characteristics suggest that the dikes did not intrude parallel to the axial planes of pre-existing folds, as earlier interpreted (Sturt & Ramsay 1965). The dikes appear to have intruded undeformed rocks at high angles to the bedding. During subsequent heterogeneous shear, folds developed in the psammite above and/or below the dikes. The characteristic structural patterns of folds that formed adjacent to dikes in psammite after dike intrusion have been described by Gayer et al. (1978), Krill (1986), and Rice (1986). In many outcrops on western Sørøy, parts of the dikes are themselves folded, and in some intensely deformed rocks, psammites and dikes appear as concordant layers in the same tight fold (Fig. 9).

Contact metamorphism, anatexis and flow-folding

The large Seiland intrusions produced high-grade contact metamorphic aureoles in the meta-sedimentary country rocks. One of the Seiland ultramafic plutons displays a 3 km wide aureole with extensive anatexis and granulite-facies metamorphism (Sturt et al. 1980). Experience in the Nordreisa area shows that within such aureoles,

(a)

(b)

Fig. 10. Anatectic psammite within contact aureole. Two views of the same outcrop (a, b) show orthogonal surfaces (note corresponding neosome veins marked by arrows). Cross-bedding is visible in both surfaces despite strong recrystallization. Loc. 5.

Fig. 11. Anatectic, flow-folded psammite, cut by unfoliated felsic dikes. The thin dike in the lower left corner is weakly folded together with the tightly folded psammite, suggesting that the dike intruded during flow-folding. Loc. 6.

Fig. 12. Anatectic, flow-folded psammite, producing neosome that back-veins mafic dike. Loc. 7.

flow-folds and other deformation structures may form during intrusion of the large plutons, and that these structures may themselves be cut by younger dikes related to the same magmatic event (Zwaan, in prep.).

The Breivikbotn gabbro appears to have shielded its metamorphic aureole from strain during the later orogenic deformation. From locality 5 to the contact with the gabbro, dikes are less foliated than elsewhere. Anatexis of the psammites and contact relations with undisturbed dikes are clearly observed. Granoblastic recrystallization mimicked the psammite bedding, creating layered gneisses that, except for the presence of cross-beds (Fig. 10), might resemble strongly deformed, regionally metamorphosed rocks. Bedding within the metamorphic aureole is chaotically deformed, and flow-folds are locally observed (Figs. 10, 11, 12). This flow-folding, closely associated with formation of neosome and intrusion of dikes, produced complex relationships between veins, dikes, and folds (Figs. 10, 11, 12). Such structures have been interpreted as orogenic folds (Fig. 2 in Sturt & Ramsay 1965, Figs. 10–16 in Sturt & Taylor 1971, Fig. 4b in Sturt et al. 1980) and have contributed to the interpretation that Seiland intrusions are synorogenic. However, folds cut by dikes were found only in the contact aureole, and need not indicate an orogenic event.

Discussion

Our brief field observations in the Hasvik-Sørvær profile on western Sørøy suggest to us that these psammites were not subjected to regional metamorphism and deformation until after the intrusion of the Seiland igneous rocks. Two deceptive structural relationships appear to have led to the earlier interpretation that the Seiland intrusions were syn-orogenic:

1. Sheared dikes commonly occur parallel to the axial planes of folds in the psammites. Such folds were thought to have formed mainly before intrusion of the dikes, but the relationships between bedding, folds, and dikes described above show that these folds formed after intrusion.
2. Flow-folds resembling orogenic folds affect the psammite and are cut by Seiland dikes, which may therefore appear to be syn-orogenic. However, these flow-folds were found only within the contact aureole of the large Breivikbotn gabbro: they are related to gabbro intrusion and not orogenesis.

The rock association of the Seiland Igneous Province is characteristic of extensional tectonics, and it seems rather unlikely that it developed in a collision- or subduction environment. It now seems likely that the Seiland rocks are related to continental rifting; that they intruded the Precambrian basement and the Klubben psammite before the formation of the Iapetus ocean and the deposition of the marginal- to deep-marine sediments and volcanites.

If this model of Seiland rifting is correct and the dates of 490–540 Ma from magmatic and contact-melted rocks (Sturt et al. 1978) represent the ages of intrusion, then the orogenic event on Sørøy must be younger than Finnmarkian. However, other possible interpretations must also be considered. A date of 612 ± 17 Ma from unfoliated Seiland rocks at Øksfjord (Brueckner 1973, 1975) and apparent dates of c. 600 Ma from alkaline rocks on Sørøy and Seiland (Pringle 1975) are probably valid magmatic ages. If the dates of 490–540 Ma could be re-interpreted as having been reset during orogenesis, a model could be developed incorporating both Late Precambrian rift magmatism and Finnmarkian orogenesis. Another suggestion, by Bergström & Gee (1985), is that Seiland magmatism might be related to Cambrian transform faulting prior to Early Ordovician thrusting.

In our working hypothesis for rocks of the Nordreisa and Sørøy areas, continental rifting and rift-related magmatism of the Seiland province began in Late Precambrian time. Most of 'Finnmarkian' time was characterized by extensional tectonics, including rift magmatism and formation of oceanic crust. Subduction probably initiated in early Ordovician time, as suggested by dates of c. 490 Ma for remnants of high-pressure, eclogite metamorphism now displayed in one of the Caledonian nappes (Dallmeyer & Gee 1986; M. B. E. Mørk pers. comm. 1986). This early Ordovician tectonic event is also indicated by an Ordovician unconformity recently recognized in the Lyngen-gabbro area, west of the Nordreisa area (Minsaas & Sturt 1985). A similar Ordovician unconformity in the southern Scandinavian Caledonides led to the designation of this event as 'the Trondhjem Disturbance' (Holtedahl 1920, Vogt 1929). Subduction and deposition probably continued in the Nordreisa and Sørøy areas, as elsewhere in the Caledonides, until Silurian collision, which is indicated by orogenic features such as nappe emplacement, regional metamorphism, and folding.

In the context of this model, there is no purpose or appropriate meaning for the designation 'Finnmarkian'; it has been clearly defined and used for the main event of polyphasal folding and metamorphism in Finnmark, which has been interpreted as having occurred in Cambrian to Ordovician time during intrusion of the rocks of the Seiland Igneous Province (Ramsay & Sturt 1976, Sturt et al. 1978). Thus, in our model, a term such as 'Finnmarkian metamorphism' might imply either Late Precambrian to Cambrian rift-related contact metamorphism, Ordovician subduction-related high-pressure metamorphism, or Silurian polyphasal regional metamorphism. Any attempt to redefine the designation 'Finnmarkian' would lead to confused terminology.

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References

Bergström, J. & Gee, D. G. 1985: The Cambrian in Scandinavia. *In* Gee, D. G. & Sturt, B. A. (Eds.) *The Caledonide Orogen—Scandinavia and Related Areas*. John Wiley & Sons Ltd., pp. 247–271.

Binns, R. E. & Gayer, R. A. 1980: Silurian or Upper Ordovician fossils at Guolasjav'ri, Troms, north Norway. *Nature 284*, 53–55.

Bjørlykke, K. O. 1905: Det centrale Norges fjeldbygning. *Nor. geol. unders. 39*, 1–595.

Brueckner, H. K. 1973: Reconnaissance Rb–Sr investigation of salic, mafic, and ultramafic rocks of the Øksfjord area, Seiland province, northern Norway. *Nor. Geol. Tidsskr. 53*, 11–23.

Bruekner, H. K. 1975: A reply. Reconnaissance Rb–Sr investigation of salic, mafic, and ultramafic rocks of the Øksfjord area, Seiland province, northern Norway. *Nor. Geol. Tidsskr. 55*, 101–103.

Dallmeyer, R. D. & Gee, D. G. 1986: $^{40}Ar/^{39}Ar$ mineral dates from retrogressed eclogites within the Baltoscandian miogeocline: implications for a polyphase Caledonian orogenic evolution. *Geol. Soc. Amer. Bull. 97*, 26–34.

Debrenne, F. 1984: Archaeocyatha from the Caledonian rocks of Sørøy, north Norway—a doubtful record. *Nor. Geol. Tidsskr. 64*, 153–154.

Gayer, R. A., Humphreys, R. J., Binns, R. E., & Chapman, T. J. 1985: Tectonic modelling of the Finnmark and Troms Caledonides based on high level igneous rock geochemistry. *In* Gee, D. G. & Sturt, B. A. (Eds.) *The Caledonide Orogen—Scandinavia and Related Areas*. John Wiley & Sons Ltd., pp. 931–951.

Gayer, R. A., Powell, D. B. & Rhodes, S. 1978: Deformation against metadolerite dykes in the Caledonides of Finnmark, Norway. *Tectonophysics 46*, 99–115.

Gee, D. G., & Wilson, M. R. 1974: The age of orogenic deformation in the Swedish Caledonides. *Amer. Jour. Sci. 274*, 1–9.

Holland, C. H. & Sturt, B. A. 1970: On the occurrence of Archaeocyathids in the Caledonian metamorphic rocks of Sørøy and their stratigraphic significance. *Nor. Geol. Tidsskr. 50*, 341–345.

Holtedahl, O. 1920: Paleogeography and diastrophism in the Atlantic-Arctic regions during Paleozoic time. *Amer. Jour. Sci. 79*, 1–25.

Krill, A. G. 1983: Rb–Sr study of dolerite dikes and psammite from the Western Gneiss Region of Norway. *Lithos 16*, 85–93.

Krill, A. G. 1986: Eidsvoll quarry, Oppdal, S. Norway: A one-outcrop model for some aspects of Trollheimen-Dovrefjell tectonics. *Nor. geol. unders. 404*, 23–32.

Minsaas, O. & Sturt, B. A. 1985: The Ordovician-Silurian clastics sequence overlying the Lyngen Gabbro Complex and its environmental significance. *In* Gee, D. G. & Sturt, B. A. (Eds.) *The Caledonide Orogen—Scandinavia and Related Areas*. John Wiley & Sons Ltd., pp. 379–393.

Pringle, I. R. 1971: A review of radiometric age determinations from the Caledonides of W. Finnmark. *Nor. geol. unders. 269*, 191–196.

Pringle, I. R. 1975: A comment. Reconnaissance Rb–Sr investigation of salic, mafic, and ultramafic rocks of the Øksfjord area, Seiland province, northern Norway. *Nor. Geol. Tidsskr. 55*, 97–99.

Pringle, I. R. & Sturt, B. A. 1969: The age of the peak of the Caledonian orogeny in west Finnmark, north Norway. *Nor. Geol. Tidsskr. 49*, 435–436.

Ramsay, D. M. 1971: Stratigraphy of Sørøy. *Nor. geol. unders. 269*, 314–317.

Ramsay, D. M. 1973: Possible existence of a stillborn marginal ocean in the Caledonian orogenic belt of north-west Norway. *Nature Phys. Sci. 245*, 107–109.

Ramsay, D. M. & Sturt, B. A. 1963: A study of fold styles, their association and symmetry relationships from Sørøy, north Norway. *Nor. Geol. Tidsskr. 43*, 411–430.

Ramsay, D. M. & Sturt, B. A. 1973a: An analysis of non-cylindrical and incongruous fold pattern from the Eo-Cambrian rocks of Sørøy, northern Norway. I. Noncylindrical, incongruous and aberrant folding. *Tectonophysics 18*, 81–107.

Ramsay, D. M. & Sturt, B. A. 1973b: An analysis of non-cylindrical and incongruous fold pattern from the Eo-Cambrian rocks of Sørøy, northern Norway. II. The significance of synfold stretching lineation in the evolution of noncylindrical folds. *Tectonophysics 18*, 109–121.

Ramsay, D. M. & Sturt, B. A. 1976: The syn-orogenic emplacement of the Magerøy Nappe. *Nor. Geol. Tidsskr. 56*, 291–307.

Ramsay, D. M., Sturt, B. A., Zwaan, K. B., & Roberts, D. 1985: Caledonides of northern Norway. *In* Gee, D. G. & Sturt, B. A. (Eds.) *The Caledonide Orogen—Scandinavia and Related Areas*. John Wiley & Sons Ltd., pp. 163–184.

Rice, A. H. N. 1986: Structures associated with superimposed inhomogeneous shearing of basic dykes from Finnmark, Norway. *Tectonophysics 128*, 61–75.

Roberts, D. 1968: The structural and metamorphic history of the Langstrand–Finfjord area, Sørøy, Northern Norway. *Nor. geol. unders. 253*, 1–160.

Roberts, D. 1973: *Geologisk kart over Norge, berggrunnskart. Hammerfest 1:250,000. Nor. geol. unders.*

Roberts, D. 1974: Hammerfest. Description of the 1:250,000 geological map. *Nor. geol. unders. 301*, 1–66.

Roberts, D. 1985: The Caledonian fold belt in Finnmark: a synopsis. *Nor. geol. unders. 403*, 161–177.

Roberts, D. Sturt, B. A. & Furnes, H. 1985: Volcanite assemblages and environments in the Scandinavian Caledonides and the sequential development history of the mountain belt. *In* Gee, D. G. & Sturt, B. A. (Eds.) *The Caledonide Orogen—Scandinavia and Related Areas.* John Wiley & Sons Ltd., pp. 919–930.

Robins, B. & Gardner, P. M. 1975: The magmatic evolution of the Seiland Province, and Caledonian plate boundaries in northern Norway. *Earth Planet. Sci. Lett. 26*, 167–178.

Speedyman, D. L. 1972: Mechanism of emplacement of plutonic igneous rocks in the Husfjord area of Sørøy, west Finnmark. *Nor. geol. unders. 272*, 35–42.

Speedyman, D. L. 1983: The Husfjord plutonic complex, Sørøy, northern Norway. *Nor. geol. unders. 378*, 1–48.

Steiger, K. H. & Jäger, E. 1977: Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology. *Earth Planet Sci. Lett. 36*, 359–362.

Stumpfl, E. F. & Sturt, B. A. 1965: A preliminary account of the geochemistry and ore mineral parageneses of some Caledonian basic igneous rocks from Sørøy, northern Norway. *Nor. geol. unders. 234*, 196–230.

Sturt, B. A., Miller, J. A. & Fitch, F. J. 1967: The age of alkaline rocks from west Finnmark, northern Norway, and their bearing on the dating of the Caledonian orogeny. *Nor. Geol. Tidsskr. 47*, 255–273.

Sturt, B. A., Pringle, I. R. & Ramsay, D. M. 1978: The Finnmarkian phase of the Caledonian orogeny. *J. Geol. Soc. London 135*, 597–610.

Sturt, B. A., Pringle, I. R. & Roberts, D. 1975: Caledonian nappe sequence of Finnmark, northern Norway, and the timing of orogenic deformation and metamorphism. *Geol. Soc. Amer. Bull. 86*, 710–718.

Sturt, B. A. & Ramsay, D. M. 1965: The alkaline rocks of the Breivikbotn area, Sørøy, northern Norway. *Nor. geol. unders. 231*, 1–142.

Sturt, B. A., Speedyman, D. L. & Griffin, W. L. 1980: The Nordre Bumandsfjord ultramafic pluton, Seiland, north Norway. Part 1: field relations. *Nor. geol. unders. 358*, 1–30.

Sturt, B. A. & Taylor, J. 1971: The timing and environment of emplacement of the Storelv gabbro, Sørøy. *Nor. geol. unders. 272*, 1–34.

Vogt, Th. 1928: Den norske fjellkjedes revolusjonshistorie. *Nor. Geol. Tidsskr. 10*, 97–115.

Zwaan, K. B. & Roberts, D. 1978: Tectonostratigraphic succession and development of the Finnmarkian nappe sequence, north Norway. *Nor. geol. unders. 343*, 53–71.