Discussion

Reinterpretation of Finnmarkian deformation on western Sørøy, northern Norway: some comments

DAVID ROBERTS

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Comments are made on certain controversial aspects of a recent contribution to this journal, involving mafic dyke/host rock relationships from southwestern Sørøy, West Finnmark. Plutonic rocks of the Seiland Igneous Province are likely to have intruded during ongoing deformation in an overall transpressive regime, with local transtension facilitating magma upwelling and emplacement, rather than in a simple passive rifting situation. An exclusive 'flow-fold' origin for widespread fold structures believed to be restricted to contact-metamorphic aureoles of gabbros is improbable. Isotopic dating studies in the region are outlining two separate high-grade metamorphic events during the period Middle Cambrian to Early Ordovician.

D. Roberts, Norges geologiske undersøkelse, Postboks 3006-Lade, N-7002 Trondheim, Norway.

In a recent contribution, Krill & Zwaan (1987) have questioned the validity of a current model for the Caledonide tectonometamorphic evolution of western Finnmark, with particular reference to mafic dyke/host rock relationships along a stretch of coastline in southwestern Sørøy. In essence, they argue firstly for pre-tectonic intrusion of the dykes, noting that (p. 20) the latter 'appear to have intruded undeformed rocks at high angles to the bedding'. Where folds are found pre-dating the dyke swarm, then these structures are interpreted by Krill & Zwaan (op. cit.) as intrusion-related 'flow-folds' quite divorced from regional orogenic development. A second conclusion, deriving from their belief in solely pre-orogenic mafic dyke emplacement, is to extrapolate these relationships to the entire Seiland Igneous Province (SIP) (Robins & Gardner 1975); i.e. the SIP is judged as being wholly pre-tectonic and thus pre-Finnmarkian. The third point of Krill & Zwaan's contribution is to dispute the existence of the Late Cambrian to Early Ordovician Finnmarkian phase of the Caledonian orogeny (Sturt et al. 1978).

The crux of Krill & Zwaan's thesis, that of metadolerite dyke/metasediment relationships, concerns an area originally mapped and described by Sturt & Ramsay (1965). As these latter authors have responded to the proposed reinterpretation (Sturt & Ramsay 1988), only a couple of additional points need be raised here regarding mafic dykes and the Sørøy stratigraphy before proceeding to matters of more regional significance.

Mafic dykes intruding medium- to thick-bedded arkosic metasandstones are easily recognised by virtue of colour difference. They thus attract immediate attention. Where lithologies become gradually more pelitic in aspect, as in the Storelv, Aafjord and Hellefjord Groups, then these same dykes are considerably thinner and commonly lie subparallel to the regional foliation. Moreover, in this higher strain situation they are usually reduced to chlorite-biotite schists, barely detectable on colour difference from the host pelitic or semipelitic metasediments. On Sørøy, as well as in several other parts of the Kalak Nappe Complex in West Finnmark, mafic dykes are common not only in the Klubben psammites but throughout the entire 'Sørøy stratigraphy'; and more than one set of dykes can be recognised. Allied to this is the observation, made by several workers in the Seiland – Sørøy province (cited in Sturt & Ramsay, this volume), that the larger gabbros, diorites and syenites cut through, contact-metamorphose, and engulf rafts of all recognisable regionally metamorphosed lithologies in the 'Sørøy stratigraphy'. The attempt by Krill

& Zwaan (op. cit., p. 16, also p. 22) to divorce the Falkenes Group (and in consequence the succeeding Aafjord and Hellefjord Groups) from the older groups of sediments, and deny their participation in any pre-Scandian orogenesis, thus cannot be taken seriously. Having the gabbro- and dyke-intruded metasedimentary sequence extend up into the Silurian is one interpretation; yet Krill & Zwaan are at the same time advocating a latest Precambrian to Cambrian age for these same SIP plutonic and mafic hypabyssal rocks. Obviously one cannot have it both ways.

The postulate by Krill & Zwaan (op. cit.) that all the folds preserved in the contact aureoles of SIP plutons, and cut by dykes, must be of 'flow-fold' origin has to be rejected. True, there are locally developed incoherent fold structures associated with anatectic melting; but the majority of folds can be readily related to regional structures, and mesoscopic to mappable folds can commonly be traced directly from the aureoles into non-hornfelsed country rock where they are, in places, also cut by mafic dykes. These features have been observed by the present author in different parts of Sørøy during regional mapping and structural studies, and underline the dangers inherent in reaching major conclusions from the type of rapid, 2-day traversing conducted by Krill & Zwaan.

Extrapolation of the notion of pre-tectonic intrusion of mafic dykes to embrace the entire plutonic development of the SIP is also difficult to justify. Casting doubt on this aspect of Krill & Zwaan's proposals does not, however, necessarily reject the idea (also Andreasson 1987) that the SIP magmatic rocks may have originated in a continental marginal setting. It is important here to consider field relationships within the Seiland Province reported in many publications (e.g. Robins & Gardner 1975; Speedyman 1983; Sturt et al. 1980; Bennett et al. 1986; and references therein). From these descriptions it is evident that the plutonic development occurred during a period of episodic deformation at moderately deep crustal levels, locally with contact-metamorphic parageneses overprinting upper amphibolite facies mineralogies, regional folds and stretching lineations, and mylonitic fabrics. Moreover, several generations of mafic dyke intrusion have been detected; not just the *one*, which is the basis of Krill & Zwaan's (op. cit.) proposed pre-orogenic evolution for the SIP. Here, it can be noted that interpreted pre-tectonic mafic dykes from Finnmark were a basis for the 'pre-oceanic' rifting stage of Iapetus Ocean evolution of Roberts & Gale (1978).

How, then, is it possible to reconcile this picture of coeval and ongoing orogenic deformation with the proposed 'rift' model of Krill & Zwaan (op. cit.) and Andreasson (1987)? Current, proposed, plate-tectonic reconstructions for this time-period, involving continent-arc or continent-microcontinent collision in a gradually developing accretionary prism (Dallmeyer & Gee 1986; Gayer et al. 1987), have generally assumed that the pre-collision plate drift vectors were roughly orthogonal to the axis of the evolving mountain chain; yet there is evidence to suggest (Roberts, in prep.) that a more oblique collision with orogen-parallel strike-slip or oblique-slip shear displacements may have been operative. In this scenario, the initial deformations of the most outboard of the Baltoscandian miogeoclinal sequences were probably of a regionally transpressive nature. Where local transtensional situations developed temporarily within this transpressive regime, then a crustal weakness may have been created for the intrusion of large volumes of magma. Had such an extensional setting been localised upon the site of a covered paleo-transform fracture (cf. Bergström & Gee 1985), then the process of magma pluming would conceivably have received added impetus.

Questioning the timing of evorogenic deformation and metamorphism in this northern part of the Baltoscandian miogeocline, and specifically repudiating any major regional deformation in these Sørøy–Seiland Nappe rocks before Late Silurian, Scandian time (Krill & Zwaan op. cit.; Krill et al. 1988) requires elaboration. This is a matter which has been discussed at some length elsewhere (Sturt et al. 1978; Gee & Roberts 1983; Dallmeyer 1988; Hall & Roberts 1988), and so only a few pertinent points need to be raised here.

There would now appear to be abundant evidence for Early Ordovician metamorphism and deformation in this northern part of the Caledonides, though largely restricted to Middle and lowermost Upper Allochthon levels of the tectonostratigraphy. Locally, in areas so far studied, this metamorphism attained high-P eclogite facies (van Roermund 1985; Mørk et al. 1988; and in press), e.g. in Norrbotten, northern Sweden, at around 505 Ma; and with hornblendes from retrogressed eclogites giving ca. 490 Ma cooling ages (Dallmeyer & Gee 1986). In West Finnmark, and the Kalak Nappe Complex, high-grade metamorphism also occurred at around this time and is recorded in SIP rocks (Dallmeyer 1988 and in prep.; Mørk in press, pers. comm. 1988). Moreover, amphibolite facies parageneses, highly ductile deformation and SSE-directed ductile thrusting (but not the later, ESE brittle thrusting) are considered to be manifestations of this tectonothermal event. Thus, while Krill & Zwaan (op. cit.) (also Krill et al. 1988) evidently prefer to dismiss all field and isotopic evidence for *any* major regional metamorphism in Cambro-Ordovician time, there would appear, in fact, to have been at least two, separate, tectonothermal events during this time-period. The question, then, is for which one of these events do we retain the term 'Finnmarkian'?

During the last decade the Finnmarkian, a convenient designation for Late Cambrian to Early Ordovician evorogenesis, has been recognised widely in Scandinavia (see above; also Gee 1987) with the help of isotopic dating methods. In Finnmark the term is usually linked directly with the local SIP situation, sometimes forgetting that it relates equally to the high-grade, foliation-producing, Barrovian metamorphism recognised throughout the Kalak. Lower thrust-sheets, on the other hand, with their markedly different ESE-directed brittle thrusting and low-grade assemblages, may not have been involved in this early Caledonian nappe transport (Dallmeyer & Reuter 1987).

Crucial to this discussion is the recent U-Pb zircon dating from late-stage nepheline syenite pegmatite dykes from Seiland and Stjernøy, with crystallisation ages of 531 ± 2 and 523 ± 2 Ma, respectively (Pedersen et al. in press), which effectively provides a minimum age (ca. 523) for the orogenic deformation and metamorphism broadly coeval with SIP magmatism. The alkaline rock complex and other SIP and Kalak rocks then show evidence, from K–Ar and ^{40}Ar–^{39}Ar mineral dating, of the Early Ordovician, ca. 500–490 Ma tectonothermal event (Sturt et al. 1978; Dallmeyer 1988 and in prep.) which is generally termed Finnmarkian in other areas of the Baltoscandian part of the Caledonides. We thus have two 'Finnmarkian' events, which for pure convenience will here be called 'Finnmarkian I' and 'Finnmarkian II' – akin to comparable divisions, though not strictly in age, of the Pan-African and Cadomian orogenies in Africa and NW France, respectively.

Pedersen et al. (in press) have, in effect, constrained the *sensu stricto* definition of the original Finnmarkian to the earlier, ca. 540 to 523 Ma event, i.e. Finnmarkian I. My personal preference is to retain and redefine the term Finnmarkian for the younger 'Finnmarkian II' event, which is now recognised widely, by isotopic methods, along the Baltoscandian margin. For the earlier 'Finnmarkian I', which may possibly be restricted to the Sørøy–Seiland Nappe and SIP rocks, a more convenient and appropriate solution might be to revive the designation 'Sørøyan' suggested by Gee & Wilson (1974). More isotopic data are, however, required before we can map out the extent of individual tectonometamorphic events. There are, for example, preliminary radiometric data which suggest that some of the very earliest deformation in the Kalak Nappe Complex may be of pre-Caledonian, Late Riphean age (Daly et al. 1987). Contrary to the opinion of Krill & Zwaan (op. cit.) (also Krill et al. 1988), who apparently see all metamorphism in Caledonide Finnmark as having occurred only in Silurian time, I consider that the period from Middle Cambrian to Early, and indeed Middle Ordovician time was one of the most creative and constructive in terms of polyphase orogenic deformation and metamorphism in the northern Scandinavian Caledonides.

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References

Andreasson, P. G. 1987: Early evolution of the Late Proterozoic Baltoscandian margin: inferences from rift magmatism (extended abstract). *Geologiska Föreningens i Stockholm Förhandlingar 109*, 336–340.

Bennett, M. C., Emblin, S. R., Robins, B. & Yeo, W. J. A. 1986: High-temperature ultramafic complexes in the North Norwegian Caledonides: I – Regional setting and field relationships. *Norges geologiske undersøkelse Bulletin 405*, 1–40.

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, Chichester, 247–271.

Dallmeyer, R. D. 1988: Polyphase tectonothermal evolution of the Scandinavian Caledonides. *In* Harris, A. L. & Fettes, D. J. (Eds.), *The Caledonian–Appalachian Orogen. Geological Society of London Special Publication 38.*

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. *Geological Society of America Bulletin 97*, 26–34.

Dallmeyer, R. D. & Reuter, A. 1987: Scandian vs. Finnmarkian terrane accretion in the northwest Norwegian Caledonides (extended abstract). *IGCP 'Project 233' Symposium, Nouakchott, Mauritania*, 77–81.

Daly, J. S., Cliff, R. A. & Rice, A. H. N. 1987: A new Precambrian terrane in the Caledonides of Finnmark, Arctic Norway (Abstract). *Proceedings Symposium on Arctic Geology, Sept. 1987, Cardiff, Wales.*

Gayer, R. A., Rice, A. H. N., Roberts, D., Townsend, C. & Welbon, A. 1987: Restoration of the Caledonian Baltoscandian margin from balanced cross-sections: the problem of excess continental crust. *Transactions of the Royal Society of Edinburgh: Earth Sciences 78*, 197–217.

Gee, D. G. 1987: Early Caledonian Tectonothermal activity in the Scandinavian Caledonides – the Finnmarkian and Trondheimian episodes (extended abstract). *Geologiska Föreningens i Stockholm Förhandlingar 109*, 343–345.

Gee, D. G. & Roberts, D. 1983: Timing of deformation in the Scandinavian Caledonides. *In* Schenk, P. (Ed.), *Regional Trends in the Geology of the Appalachian–Caledonian–Hercynian–Mauritanide Orogen.* Reidel Publ. Co. Dordrecht 279–292.

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

Hall, L. M. & Roberts, D. 1988: Timing of Ordovician deformation in the Caledonian–Appalachian orogen. *In* Harris, A. L. & Fettes, D. J. (Eds.), *The Caledonian–Appalachian Orogen.* Geological Society of London Special Publication 38.

Krill, A. G. & Zwaan, K. B. 1987: Reinterpretation of Finnmarkian deformation on western Sørøy, northern Norway. *Norsk Geologisk Tidsskrift 67*, 15–24.

Krill, A. G., Rodgers, J. & Sundvoll, B. 1988: New isotopic dates and Scandian–Finnmarkian correlations in the Caledonides of Finnmark (abstract). *18th Nordiske Geologiske Vintermøde, København 1988*, 230–231.

Mørk, M. B. E., Kullerud, K. & Stabel, A. 1988: Sm–Nd dating of Seve eclogites, Norbotten, Sweden – evidence of Early Caledonian (505 Ma) high-pressure metamorphism (abstract). *18th Nordiske Geologiske Vintermøde, København 1988*, 289–290.

Mørk, M. B. E., Kullerud, K. & Stabel, A. in press: Sm–Nd dating of Seve eclogites, Norrbotten, Sweden – evidence for Early Caledonian (505 Ma) subduction. *Contributions to Mineralogy and Petrology.*

Pedersen, R. B., Dunning, G. R. & Robins, B. in press: U–Pb ages of nepheline syenite pegmatites from the Seiland Magmatic province, North Norway. *Proceedings Symposium on Caledonian Geology, Sept. 1987, Cardiff, Wales.*

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

Roberts, D. & Gale, G. H. 1978: The Caledonian–Appalachian Iapetus Ocean. *In* Tarling, D. H. (Ed.), *Evolution of the Earth's Crust.* Academic Press, London, 255–342.

Roermund, H. L. M. van 1985: Eclogites of the Seve Nappe, central Scandinavian Caledonides. *In* Gee, D. G. & Sturt, B. A. (Eds.), *The Caledonide Orogen – Scandinavia and Related Areas.* John Wiley & Sons, Chichester, 873–886.

Speedyman, D. L. 1983: The Husfjord plutoniccomplex, Sørøy, northern Norway. *Norges geologiske undersøkelse 378*, 1–48.

Sturt, B. A. & Ramsay, D. M. 1965: The alkaline complex of the Breivikbotn area, Sørøy, northern Norway. *Norges geologiske undersøkelse 231*, 6–142.

Sturt, B. A. & Ramsay, D. M. 1988: Reinterpretation of Finnmarkian deformation on western Sørøy, northern Norway: A comment. *Norsk Geologisk Tidsskrift 68*, 213–219.

Sturt, B. A., Pringle, I. R. & Ramsay, D. M. 1978: The Finnmarkian phase of the Caledonian orogeny. *Geological Society of London Quarterly Journal 135*, 597–610.

Sturt, B. A., Speedyman, D. L. & Griffin, W. L. 1980: The Nordre Bumannsfjord ultramafic pluton, Seiland, North Norway. Part I. Field relations. *Norges geologiske undersøkelse 358*, 1–30.