Inferred Mesozoic faulting in Finnmark: current status and offshore links

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An earlier compilation of the post-Caledonian fault system in the Caledonian domain of Finnmark is reassessed in the light of more recent diverse data acquired from a combination of general geology onshore, well data and seismic reflection profiling in the offshore areas of the Finnmark Platform, and evidence of multiphase faulting farther south in Troms and Nordland. While age determinations on fault rocks are still lacking in Finnmark, the character and trends of faults on-land, to the south, and offshore in the Barents Sea domain, allow deductions to be made regarding the likely ages and reactivation histories of some of the major faults. Taking the specific example of the NE-SW-trending Vargsund-Langfjorden fault, a component of Mesozoic reactivation is inferred, and it is suggested that Mesozoic sedimentary rocks may lie concealed beneath outer Altafjorden in a half-grabenal structure in the hangingwall of this major fault. Other, small, fault-controlled basins containing possible Mesozoic sedimentary rocks may also exist in the near-shore areas of western Finnmark.

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Introduction

The lineament patterns of Finnmark county in northern Norway, based on satellite imagery, have been documented by Gabrielsen & Ramberg (1979), and updated more recently by Gabrielsen et al. (2002). Detailed ground control of such remotely sensed structures is restricted to northeastern areas, with investigations extending into the Kola Peninsula of NW Russia (Karpuz et al. 1993, 1995, Roberts et al. 1997). Field studies and, in particular, systematic bedrock mapping have shown that many lineaments, though by no means all, coincide with major faults. In this respect, the compilation of fault systems in Finnmark by Lippard & Roberts (1987) provides our main coverage and description of faults in this part of mainland Norway. Together with an earlier study by Gabrielsen (1984), the work of Lippard & Roberts (1987) also attempted to show how some of the principal faults or fault zones could be traced into shallow shelf areas of the southern Barents Sea.

Unlike some of the more intensively studied onshore areas farther south in Norway, little is known of the precise ages of faulting in Finnmark. Based on logical reasoning, aided by the ages of some mafic dykes and short-distance links with known offshore faults, Lippard & Roberts (1987) concluded that faulting had occurred intermittently in the Caledonian domain from Late Palaeozoic to Cenozoic times. Faulting of Archaean to Neoproterozoic age, with subsequent reactivations, is also registered within and marginal to the Precambrian crystalline basement (Karpuz et al. 1995, Roberts et al. 1997). During the last decade, much evidence has come to light from areas farther south, in Troms and Nordland (Fig. 1) and also from Mid Norway, that calls for a reassessment of the situation in Finnmark. This short contribution is aimed at filling in a geographic gap in this thematic 'Mesozoic' volume of the Bulletin, providing an update on the previous compilation, and suggesting areas where further studies might be directed in the future.

Aspects of regional geology

The principal features of the bedrock geology of Finnmark are shown on the 1:500,000 compilation by Siedlecka & Roberts (1996). The greater part of the county, particularly in the west and north, is underlain by the metamorphic allochthon of the Caledonides (Ramsay et al. 1985, Gayer et al. 1987). Southeast of the Caledonian front there are diverse magmatic and supracrustal complexes ranging in age from Late Archaean to Palaeoproterozoic (Marker 1985, Siedlecka et al. 1985, and several papers in Roberts & Nordgulen 1995).

The youngest supracrustal rocks exposed onshore in Finnmark are on Magerøya, in the Magerøy Nappe (Fig. 2), part of the Upper Allochthon (Roberts & Gee 1985), where fossiliferous pelites and limestones are indicative of an Early to early Mid Llandovery age (Føyn 1967, Andersen 1984, Bassett 1985, Krill et al. 1993). The lithostratigraphical succession is cut by granites, gabbros and ultramafic bodies, including the Honningsvåg Igneous Suite (Robins 1998), which are also of Silurian age (Torsvik et al. 1992, Corfu et al. 2005). There are also NW-SE-trending dolerite dykes which have yielded an Early Carboniferous age based on both $^{40}Ar/^{39}Ar$ dating (Lippard & Prestvik 1997) and palaeomagnetic data (R.J.Roberts et al. 2003). The main Caledonian, Scandian orogeny in this part of Finnmark is considered to have started in the Silurian (Dallmeyer 1988) and terminated in Early Devonian time (Roberts & Sundvoll 1990). Mafic dykes on the Varanger Peninsula, in East Finnmark (Fig. 2), have yielded both Vendian and Late Devonian ages

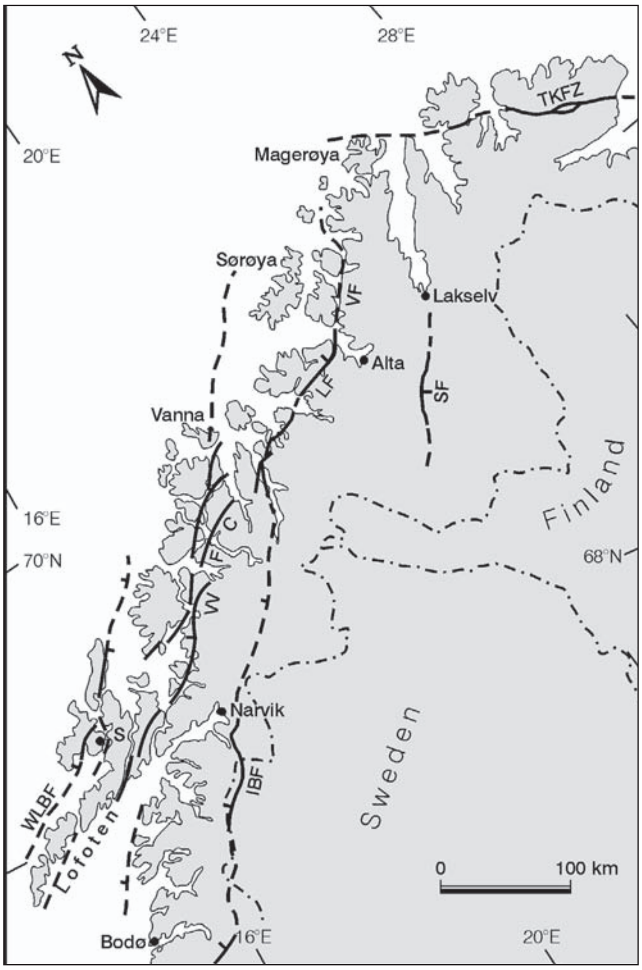

Fig. 1. Location map showing some of the principal faults, fault zones or fault complexes in Nordland, Troms and Finnmark. The area covered by Figure 2 is outlined. IBF – the Innermost Boundary Fault of Moser (2000); LF – Langfjorden Fault; VF – Vargsund Fault; TKFZ – Trollfjorden-Komagelva Fault Zone; VVFC – Vestfjorden-Vanna fault complex; WLBF – Western Lofoten border fault. Also shown is the postglacial Stuoragurra Fault (SF) (Olesen 1988). S – Sortland.

(Beckinsale et al. 1975, Roberts & Walker 1997, Guise & Roberts 2002); and there is also geochronological evidence indicating a possible Jurassic age for one particular mafic dyke (B.Sundvoll, pers. comm. 1991).

The regional geology of the offshore areas of the southern Barents Sea has been described in a number of accounts (e.g., Rønnevik et al. 1982, Faleide et al. 1984, Gabrielsen et al. 1990, Johansen et al. 1994, Gudlaugsson et al. 1998). Drillcore data and seismic lines on the shallow Finnmark Platform have shown that the post-Scandian sedimentary succession ranges in age from Early Carboniferous to Cenozoic (Bugge et al. 1995, Ehrenberg et al. 1998). Detailed investigation of several 'seismic sequences' with drilled well control in the Late Palaeozoic stratigraphic successions has demonstrated a complex evolution of these near-shore parts of the Barents Shelf (Bugge et al. 1995, Samuelsberg et al. 2003). The Carboniferous faulting on the Finnmark Platform is seen on seismic data to be truncated by the near base Permian (cf. Bugge et al. 1995, fig.14). Farther offshore in the adjacent Hammerfest and Nordkapp basins, several phases of Palaeozoic and Mesozoic crustal extension and faulting have been recognised (Dengo & Røssland 1992), with later phases of inversion and uplift (Gabrielsen et al. 1997). The principal fault trends are characterised by peak faulting activity at specific times, and as many can be linked fairly confidently with known faults on the Finnmark mainland (Gabrielsen 1984, Lippard & Roberts 1987), this provides an indirect assessment of the likely ages of onshore fault reactivation.

Principal phases of extension and rifting in the southern Barents Sea are known in the Carboniferous, in Permo-Triassic time and also in the Late Jurassic-Early Cretaceous, with Late Cretaceous-Early Tertiary inversions. In this contribution we consider the evidence for Mesozoic faulting onshore (including fjords) by recourse to events determined both in the southern Barents Sea and in areas farther south, in Troms, Nordland and near-shore areas.

Mesozoic faulting onshore: indirect evidence

Since there are, as yet, no known absolute datings of fault rock products or mineralisations in onshore Finnmark, we are forced to consider the information available from adjacent areas. Within the area of the Finnmark Platform and adjacent Hammerfest and Nordkapp basins (Fig. 2), there is fairly abundant evidence of Jurassic faulting, principally related to the main rifting event in late Mid to Late Jurassic times. The Hammerfest Basin evolved during this period and into the Cretaceous (Faleide et al. 1993, Doré et al. 1999), and is characterised by mainly E-W-trending faults which swing into a more NE-SW trend close to the bordering, NE-SW-trending Troms-Finnmark Fault Complex (Fig. 2). The NE-SW-trending Nordkapp Basin developed earlier, in Late Devonian-Early Carboniferous time (Gabrielsen et al. 1992, Jensen & Sørensen 1992), but also shows evidence of Mesozoic fault reactivation in the flanking fault zones, such as the Måsøy Fault Complex. Other NE-SW-trending faults occur on the Finnmark Platform, and these are offset by the offshore extension of the NW-SE-trending Trollfjorden-Komagelva Fault Zone (Fig. 2), the trace of which also appears to displace the border fault zone of the Hammerfest Basin (cf. Gabrielsen & Færseth 1989).

Although the NE-SW offshore fault trend is known to have been operative in Devono-Carboniferous time (Bugge et al. 1995) in this southwestern Barents Shelf domain, presumably inheriting and exploiting the Caledonian structural

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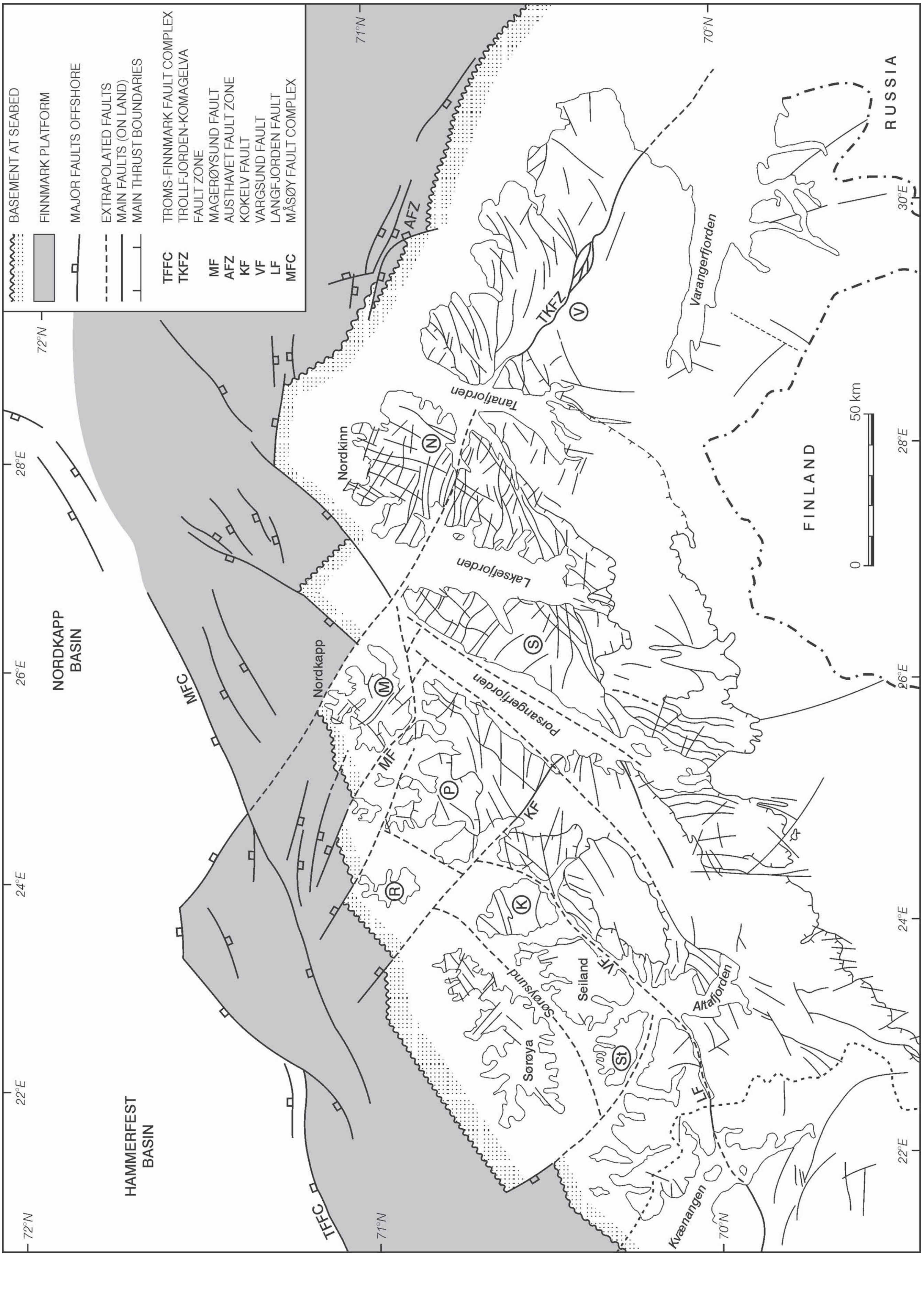
Fig. 2. Map compilation showing the principal mapped faults in the Caledonides of Finnmark and in the immediate offshore area of the Finnmark Platform; modified, updated and, in part, simplified after Lippard & Roberts (1987). K – Kvaløya; M – Magerøya; N – Nordkinnhalvøya; P – Porsangerhalvøya; R – Rolvsøya; S – Sværholthalvøya; St – Stjernøya; V – Varangerhalvøya. Details of the fault patterns within the Hammerfest and Nordkapp Basins are given in Lippard & Roberts (1987, Plate 1) and Samuelsberg et al. (2003).


BASEMENT AT SEABED
FINNMARK PLATFORM
MAJOR FAULTS OFFSHORE
EXTRAPOLATED FAULTS
MAIN FAULTS (ON LAND)
MAIN THRUST BOUNDARIES
TFFC TROMS-FINNMARK FAULT COMPLEX
TKFZ TROLLFJORDEN-KOMAGELVA FAULT ZONE
MF MAGERØYSUND FAULT
AFZ AUSTHAVET FAULT ZONE
KF KOKELV FAULT
VF VARGSUND FAULT
LF LANGFJORDEN FAULT
MFC MÅSØY FAULT COMPLEX
NORDKAPP BASIN
HAMMERFEST BASIN
Nordkapp
Nordkinn
Tanafjorden
Laksefjorden
Porsangerfjorden
Varangerfjorden
Altafjorden
Sørøysund
Seiland
Sørøya
Kvænangen
FINLAND
RUSSIA
50 km
0
72°N
71°N
70°N
22°E
24°E
26°E
28°E
30°E

grain (e.g., Faleide et al. 1984, Gabrielsen 1984), basin-bordering movements continued through the Permo-Triassic interval and appear to have extended into the Mesozoic. Many such NE-SW-trending faults can be traced onshore, in Finnmark. In a study of the thermotectonic evolution of the mainland region from the Kola Peninsula in Russia to western Finnmark employing apatite fission track data, Hendriks & Andriessen (2002) and Hendriks (2003) have shown that the Kola part of the Barents Sea margin was basically stable, tectonically, after the Triassic. On the contrary, uplift and denudation of at least 2 km of sedimentary cover occurred during and after Triassic times in the western Finnmark domain (Hendriks 2003). Taken as a whole, this points to a westward migration of successive phases of rifting in the southern Barents Sea and immediately onshore region (Doré et al. 1999, Hendriks 2003). Thus, there is a likelihood that existing faults in Finnmark, and especially in western areas, were subjected to successive reactivations in Permo-Triassic and, notably, Jurassic-Early Cretaceous times. Evidence of even younger faulting, in the Late Cretaceous and Tertiary, is more likely to be encountered in the outermost, coastal districts of the county. Some faults on Sørøya, for example, carry loosely consolidated breccias and later gouges which have the appearance of being comparatively young, fault rock products (D.Roberts, unpubl. data). In a reconnaissance study of fault patterns in NE Sørøya, Roberts (1971) speculated that some of the youngest fault movements responsible for production of the friable gouges "may be related to the shear system developed during and subsequent to the opening of the North Atlantic".

Farther southwest, in Troms, and partly in the Lofoten area of Nordland (Fig. 1), onshore, there is documented evidence of both Permian and Jurassic faulting activity associated with regional rifting episodes (Dalland 1975, Bartley 1982, Olesen et al. 1997, Davidsen et al. 2001, Steltenpohl & Andresen 2002, Steltenpohl et al. 2004). There are also Jurassic to Lower Cretaceous sedimentary rocks exposed on the island of Andøya (Dalland 1975). It has been suggested, too, that a linked fault system farther inland, termed the Innermost Boundary Fault system (Fig. 1), marks the approximate, easternmost onshore limit of the Permo-Carboniferous rifted margin (Moser 2000, Moser et al. 2002), located for the most part along the western flanks of major basement windows, reactivating and partly transecting Devonian extensional faults. Many of these linked normal to oblique-slip faults were subsequently rejuvenated in Mesozoic time and, in some areas, notably in the Lofoten region, there is clear evidence of truncation by NE-SW-trending, Mesozoic (possibly Jurassic) faults (Steltenpohl et al. 2004).

One such major, linked fault in the Nordland-Troms region is the NE-SW-trending Vestfjorden-Vanna fault complex (VVFC) (Forslund 1988, Olesen et al. 1997) (Fig. 1) which carries evidence of initial Permian, sinistral-slip to dip-slip movements, as well as several younger structures. The VVFC has been shown to extend northeastwards into Finnmark via diverse linked faults and splays, entering the county as the Langfjorden Fault (Olesen et al. 1990) (Figs. 1 and 2). The same fault, when traced farther northeast across Altafjorden, is the Vargsund Fault (Worthing 1984, Lippard & Roberts 1987), which has a marked downthrow to the northwest (Zwaan & Roberts 1978, Olesen et al. 1990). This fault is also included by Moser et al. (2002) as the northernmost part of the Innermost Boundary Fault system.

The ***Vargsund Fault***, estimated on geophysical evidence to dip at 45-60° to the northwest (Olesen et al. 1990), preserves the plutonic rocks of the Seiland Igneous Province in its hangingwall. The fault continues to the northeast, east of Kvaløya, and is inferred to be offset by the NW-SE-trending Kokelv Fault (Lippard & Roberts 1987); it then most likely continues north-northeastwards through Rolvsøysundet (Fig. 2). A study of fracture patterns on eastern Seiland (Worthing 1984) pointed to a component of dextral strike-slip or oblique-slip along the Vargsund Fault, but the age of these movements is not known. Similar evidence for oblique-slip on minor faults in the hangingwall on Kvaløya has been recorded by Ø. Jansen (pers. comm.1987). In the adjacent footwall, Scandian-age thrusts and mylonites above the Svecokarelian rocks of the Repparfjord-Komagfjord window are transacted by numerous, small, NE-SW-trending, fairly steep faults paralleling the Vargsund Fault, all with consistent downthrows to the northwest (Jansen 1976).

Although precise age constraints are lacking, it is suggested that the normal to dextral oblique-slip components of movement along the Vargsund Fault relate to later reactivation of a major fault that probably initiated during either Devono-Carboniferous or Permo-Carboniferous rifting. By analogy with the situation farther south along the Lofoten to Mid Norway passive margin, where Jurassic successions are preserved in half-grabens in near-shore areas or fjords (Dalland 1975, Bøe & Bjerkli 1989, Davidsen et al. 2001, Sommaruga & Bøe 2002), it is suggested that the composite Vargsund-Langfjorden fault may conceivably preserve a concealed half-grabenal succession in its hangingwall beneath outer Altafjorden. Likewise, based on geophysical data (Olesen et al. 1990), possible Mesozoic successions may lie concealed adjacent to the prolongation of the Vargsund Fault beneath the sea area between Kvaløya and Rolvsøya. This notion will provide a challenge to further shallow reflection-seismic surveying in near-shore/in-shore parts of northern Norway. In this regard, another potential location for concealed Mesozoic deposits might be in the southwestern part of Sørøysund (Fig. 2), along which a NE-SW-trending fault has been inferred (Lippard & Roberts 1987).

The long, NE-SW-trending fjords of Porsangerfjorden, Laksefjorden and Tanafjorden (Fig. 2) also hold some potential for possible concealment of limited thicknesses of fault-controlled, post-Caledonian sediments (cf. Bugge et al. 1995, fig.8). As these fjords, however, are situated in the central and eastern areas of Finnmark, and landward of the outer limit of 'basement at seabed' (Fig. 2), any possible sedimentary successions are more likely to be of Late Palaeozoic age rather than Mesozoic.

Conclusions

A compilation of the post-Caledonian fault system in Finnmark made over 15 years ago has been reassessed in the light of our more recent knowledge of the general geology onshore, well data and seismic-reflection profiling in offshore areas, and evidence of multiphase faulting farther south in the counties of Troms and Nordland. Although age determinations on fault rock products are still lacking in Finnmark, the character and trends of faults both on-land, to the south, and offshore in the southern Barents Sea domain, allow deductions to be made regarding the likely ages and reactivation histories of certain major faults.

Taking the specific example of the NE-SW-trending Vargsund-Langfjorden Fault, a component of Mesozoic reactivation is inferred and it is suggested that Mesozoic sedimentary rocks may lie concealed beneath Altafjorden in a half-grabenal structure in the hangingwall of this major fault.

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