Structural geology around the southern termination of the Lomfjorden Fault Complex, Agardhdalen, east Spitsbergen

ARILD ANDRESEN, PÅL HAREMO, EIVIND SWENSSON & STEFFEN G. BERGH

Andresen, A., Haremo, P., Swensson, E. & Bergh, S. G.: Structural geology around the southern termination of the Lomfjorden Fault Complex, Agardhdalen, east Spitsbergen. *Norsk Geologisk Tidsskrift*, Vol. 72. pp. 83–91. Oslo 1992. ISSN 0029-196X.

Structural observations north and south of Agardhdalen, east central Spitsbergen, demonstrate that the southern termination of the Lomfjorden Fault Complex is characterized by interacting thin-skinned and basement uplifted compressional deformation (up-thrusts). Thin-skinned deformation, characterized by thickening of units due to extensive reverse faulting, is related to at least one and possibly two decollement zones positioned in the Triassic Sassendalen Group (Lower Decollement Zone) and the Upper Jurassic/Lower Cretaceous Janusfjellet Formation (Upper Decollement Zone), respectively. The reverse faulting, often resulting in duplex structures, is particularly well developed in the Triassic Botneheia Member. Formation of a major east-facing anticline (the Eistraryggen Anticline), involving the entire Mesozoic sequence in the area and possibly most of the pre-Mesozoic/post-Caledonian cover rocks, post-dates the thin-skinned deformation. It is argued that the Eistraryggen Anticline is developed above a steep west-dipping basement-rooted reverse fault. All structures observed around Agardhdalen, except for some possible syn- to post-depositional Triassic extensional faults, are inferred to be Tertiary in age and to have developed contemporaneously with the West Spitsbergen Foldbelt. During this event, basin inversion of the Ny Friesland Block, bordered by the Billefjorden Fault Zone and the Lomfjorden Fault Complex, took place.

Arild Andresen, Pål Haremo and Eivind Swensson*, Institutt for Geologi, Universitetet i Oslo, P.O. Box 1047, Blindern 0136 Oslo 3, Norway; Steffen G. Bergh, Institutt for Biologi og Geologi, Universitetet i Tromsø, P.O. Box 3085 Guleng, 9001 Tromsø, Norway.*
**Present address: Norsk Hydro a.s. PO Box 200, 1321 Stabekk, Norway.*

The Lomfjorden Fault Complex is the easternmost of several N–S trending fault zones or fault complexes which subdivide Spitsbergen into large fault-bounded blocks (Fig. 1). Sedimentological and structural observations clearly show that at least one of these fault zones, the Billefjorden Fault Zone, was tectonically active during the Devonian, Early and Middle Carboniferous, Triassic, Late Jurassic and the Tertiary (Orvin 1940; Harland et al. 1974; Mørk et al. 1982; Steel & Worsley 1984). The stress regimes responsible for these separate tectonic events have been debated (Lamar et al. 1986; Haremo et al. 1990; Haremo & Andresen in press). Because of its remoteness, considerably less is known about the tectonic history of the Lomfjorden Fault Complex. It has been referred to as a tectonically active lineament when explaining sedimentary facies variations in the Carboniferous and Tertiary strata (Odell 1927; Orvin 1940; Kellogg 1975; Steel & Worsley 1984). Tectonic structures and regional stress regimes related to these events are not at all well documented, although Andresen et al. (1988) and Nøttvedt et al. (1988a) discussed the Tertiary deformation along both lineaments. The purpose of this report is to present new structural data from Agardhdalen at the southern termination of the Lomfjorden Fault Complex and to discuss the age and kinematic development of these structures within a regional context.

The Lomfjorden Fault Complex

The Lomfjorden Fault Complex (Fig. 1) is composed of a set of N–S to NNW–SSE trending, subparallel, partly curved faults and monoclines/flexures, facing both east and west, in the type area south of Lomfjorden/Lomfjordhalvøya (Fig. 1). Only the westernmost of these faults, called the Vivienberget Fault (Cutbill 1968), has been recognized along the entire length of the fault complex, a distance of approximately 170 km (Cutbill 1968; Harland 1959; Hjelle & Lauritzen 1982). The structural block between the Lomfjorden Fault Complex and Billefjorden Fault Zone is generally referred to as the Ny Friesland Block (Harland et al. 1974) and the 'East Spitsbergen Block' further to the south (see Nøttvedt et al. 1988a, Figs. 1 and 3). No name, formal or informal, exists for the structural block east of Lomfjorden Fault Complex. In the following text we refer to this block as the 'Olav V Land Block'.

The overall displacement across the Lomfjorden Fault Complex is a down-to-the-east movement of the Olav V Land Block relative to the Ny Friesland Block. Because of the regional southwesterly dip of most of the strata on eastern Spitsbergen, successively older rocks are offset across the Lomfjorden Fault Complex as one moves north. A common relationship observed along the northern segment of the Vivienberget Fault is a fault-contact

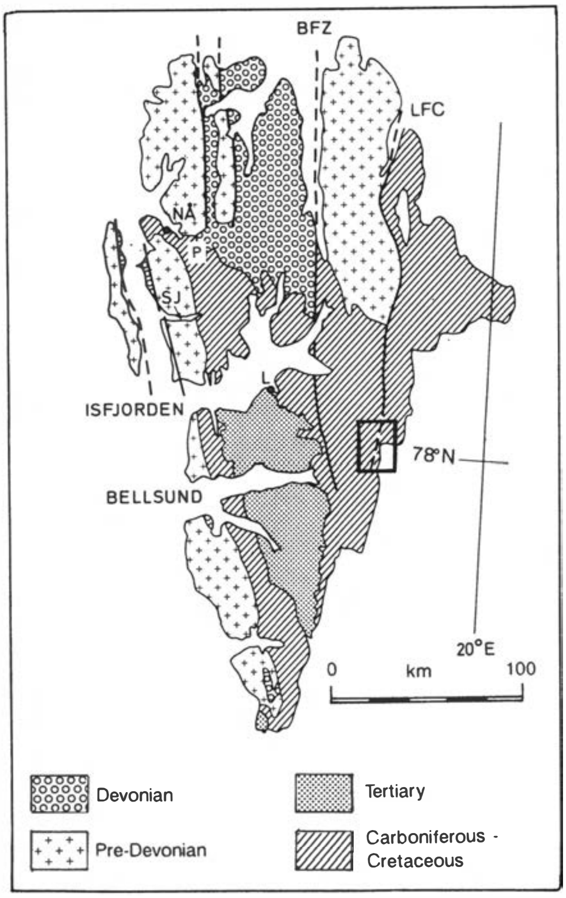

Fig. 1. Simplified geologic map of Spitsbergen showing distribution of the main depositional sequences and the main north–south trending faults subdividing the island into fault bounded blocks. BFZ – Billefjorden Fault Zone; LFC – Lomfjorden Fault Complex; PF – Pretender Fault: L – Longyearbyen; NÅ – Ny Ålesund; SJ – St. Jonsfjorden; P – Pretender. Frame indicates study area (Fig. 3).

between the Hecla Hoek lithologies of the Ny Friesland Block and the Carboniferous–Permian rocks of the Olav V Land Block (Odell 1927; Orvin 1940; Hjelle & Lauritzen 1982; Andresen et al. 1988; Nøttvedt et al. 1988a, Andresen et al. in progress). The inferred southern continuation of the Vivienberget Fault is developed as a strongly asymmetric east-facing anticline, the Eistraryggen Anticline, involving only Mesozoic starta at the southern termination around Agardhbukta (Gripp 1926; Orvin 1940; Flood et al. 1971; Kellogg 1975; Andresen et al. 1988; Haremo & Andresen in press).

It has not been possible from the existing literature to find conclusive evidence for the geometry and age of the Vivienberget Fault and other structures involved in the Lomfjorden Fault Complex. In light of the transpressional plate boundary that existed between Greenland and Spitsbergen, and the recently described Tertiary deformation along the Billefjorden Fault Zone (Haremo et al. 1990) it is important to learn more about the Lomfjorden Fault Complex, particularly whether it is a strike-slip, contractional or extensional fault complex. Cutbill (1968) concluded, based on sedimentological and stratigraphical obserations, that there is no evidence for movement along the Lomfjorden Fault Complex during the Carboniferous and Permian. Neither is there convincing evidence of tectonic activity during the Mesozoic, although thickness variations within the Triassic strata havė been explained by syn-depositional tectonic movement on older lineaments towards the west (e.g. Billefjorden Fault Zone) (Mørk et al. 1982).

As the youngest strata affected by the Lomfjorden Fault Complex are Early Cretaceous in age, some of the deformation must be Cretaceous or younger. Kellogg (1975), following De Geer (1909), Odell (1927) and Orvin (1940), stated that most of the Cenozoic compression along the west coast of Spitsbergen resulted in block-faulting in the central and eastern areas, and that most of the deformation took the form of folding over reactivated (?) basement faults. He thereby invoked a Tertiary age for some of the movement observed across the Lomfjorden Fault Complex, but presented no new structural or stratigraphical evidence in support of this model.

In the following text we present some new field observations from the Agardhdalen region which demonstrate that many of the deformation structures observed in the area are related to deformation processes other than passive deformation above a reactivated basement fault, as has been previously suggested (Kellogg 1975).

Mesozoic lithostratigraphy in the Agardhbukta area

The Mesozoic sedimentary succession exposed in the Agardhbukta area is composed of terrigenous clastics, predominantly very fine grained, which were deposited in varying offshore marine, marginal marine to fluviodeltaic environments (Mørk et al. 1982; Steel & Worsley 1984). Fig. 2 shows the stratigraphical terminology currently in use for the Mesozoic in this part of Spitsbergen.

The Early to Middle Triassic Sassendalen Group (Mørk et al. 1982) on east Spitsbergen comprises only one formation, the Barentsøya Formation, subdivided into three members. These are the Deltadalen, Sticky Keep and Botneheia Members (Fig. 2). The Deltadalen Member is composed of grey silty shales, siltstones and very fine sandstones and shows gradual transition into the planar laminated shales of the overlying Sticky Keep Member. The depositional contact between the Deltadalen Member and the underlying Permian Kapp Starostin Formation is not exposed in the study area, but is, on the basis of normal stratigraphical thicknesses, interpreted to be located only a few tens of metres below the valley floor south of Roslagenfjellet (Fig. 3). There is a gradational transition from the Sticky Keep Member into the black shales making up the lower part of the overlying Botneheia Member. The upper part of the Botneheia Member is cliff-forming and is characterized by 0.5–1 m thick greyish white, calcite cemented siltstone beds. These siltstone beds are ideal as marker beds for deciphering the internal deformation in the Botneheia Member. A series of syn- to post-depositional faults, to be described in a separate paper,

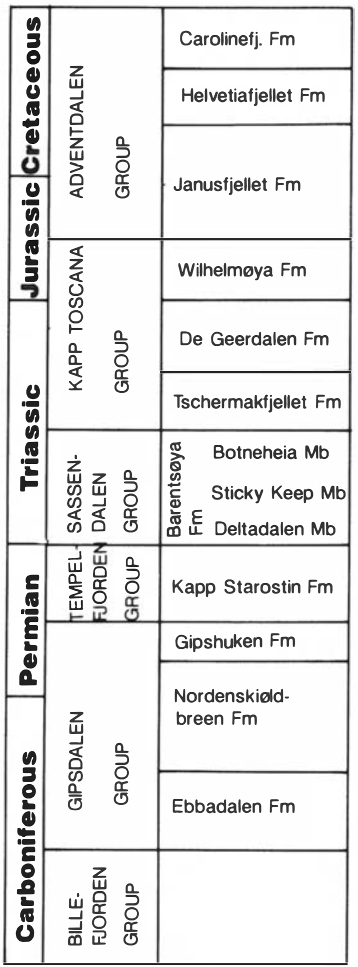

Fig. 2. Summary of lithostratigraphical terminology (simplified) for the Upper Paleozoic and Mesozoic deposits on Spitsbergen used in the text. Based on Mørk et al. (1982) and Steel & Worsley (1984).

occurs in the lower part of the Botneheia Member on the west side of Eistraryggen.

The Kapp Toscana Group (Fig. 2) is a coarsening-upwards sequence starting with the slope-forming Tschermakfjellet Formation, composed of grey shales and siltstones with some characteristically red weathering siderite nodules in its lower part. The overlying cliff-forming DeGeerdalen and Wilhelmøya Formations are dominated by sandstones interbedded with more fine-grained shales and siltstones (Mørk et al. 1982).

A thin, but very distinctive conglomerate bed (Brentskardhaugen Bed) marks the beginning of the overlying Janusfjellet Formation. The Janusfjellet Formation is a shale-dominated sequence, approximately 400–500 m thick in its undeformed state. The overlying Festningen Sandstone Member, one of the most distinctive and extensive marker beds on Central Spitsbergen, marks the base of the Helvetiafjellet Formation. This formation is the youngest mapped in the area, although the still younger Carolinefjellet Formation is present in the southwesternmost part of the study area (Fig. 3) (Flood et al. 1971).

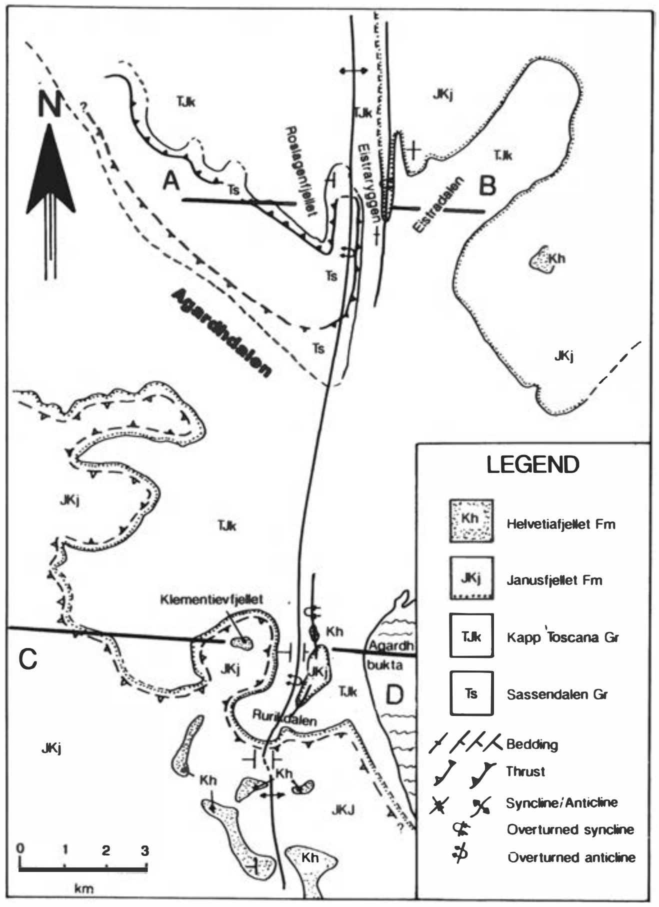

Fig. 3. Simplified structural map of the Agardhdalen area. The heavy lines A–B and C–D represent locations of profile lines presented in Figs. 4 and 5.

Structural geology

The Lomfjorden Fault Complex has degenerated into a single structure in the Agardhbukta area, developed as a strongly asymmetric east-facing anticline, the Eistraryggen Anticline (Figs. 4, 5, 8a). This anticline folds the entire Mesozoic sequence, as seen from the geologic map (Fig. 3) and cross-sections (Figs. 4, 5). It is not clear if

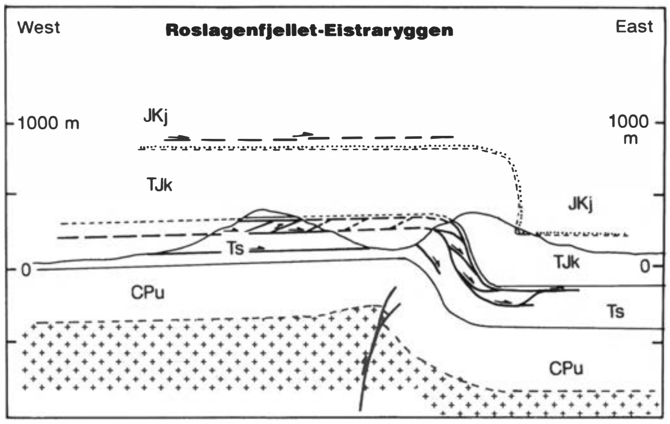

Fig. 4. Simplified structural profile across the Eistraryggen Anticline at Roslagenfjellet–Eistraryggen.

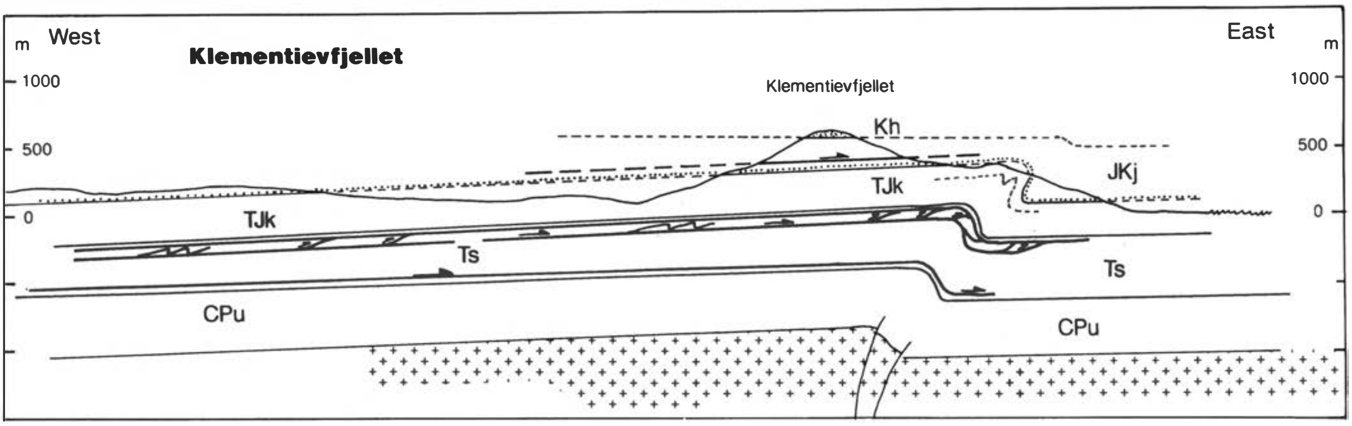

Fig. 5. Simplified structural profile across the Eistraryggen Anticline at Klementievfjellet. Note that the upper thrust in the Janusfjellet Formation (JKj) is not on the map as it is not proven to exist in this area. Based on the thinning of the Janusfjellet Formation in the area, however, it is interpreted as an out-of-sequence thrust cutting down-section in the direction of tectonic transport.

the underlying pre-Mesozoic rocks are affected, as they are not exposed in the area. Based on maps by Cutbill (1968) and Hjelle & Lauritzen (1982) and the recent data from Andresen et al. (1988, in progress) and Nøttvedt et al. (1988b), however, there can be little doubt that the Permian rocks too, are involved in the fold structure, a feature which will be addressed at the end of this discussion.

Stuctural observations along the anticline demonstate considerable variation in deformation style/geometry. Most of this variation is stratigraphically/lithologically controlled and appears to be influenced in particular by the presence of two regionally extensive decollement zones. There are also variations in structural style along the trend of the anticline within the same stratigraphical level. A Lower Decollement Zone is developed in the shale-dominated Sassendalen Group, and shortening structures associasted with this decollement zone are particularly well developed in the Botneheia Member (Haremo & Andresen in press). An Upper Decollement Zone is developed in the shales of the Janusfjellet Subgroup. Our structural observations demonstrate that most of the movement within the Lower Decollement Zone pre-dates the formation of the Eistraryggen Anticline (Haremo & Andresen in press). The mesoscopic structures associated with the Lower and Upper Decollement Zones, as well as the Eistraryggen Anticline are discussed below.

Lower Decollement Zone

Evidence of the Lower Decollement Zone comes from north of Agardhdalen, where various compressional structures are developed in the Barentsøya Formation. These structures are particularly well developed in the small valley between Eistraryggen and Roslagenfjellet (Andresen et al. 1988). The most spectacular reverse faults are developed in the upper part of the Botneheia Member along the western side of Eistraryggen. Here, well-developed reverse faults imbricate the light-coloured calcite-cemented siltstone layers found at this stratigraphical level (Fig. 6). Many of these reverse faults have a flat-ramp geometry and it can be domonstrated in several places that they represent splay faults separating horses in duplex structures. Displacement on individual faults is variable, but may reach several tens of metres. The faults characteristically cut the bedding at an angle of approximately 25–30 degrees.

There is a systematic variation in the dip of these reverse faults across the Eistraryggen Anticline. Reverse faults from the steep eastern limb of the Eistraryggen Anticline have a subhorizontal to easterly dip, whereas those recorded on the flat western limb have a moderate dip towards the west (Fig. 7). This variation suggests that the reverse faults, as well as the duplexes of which they are a part, were formed prior to and later rotated during the development of the Eistraryggen Anticline. A series of small-scale, asymmetric folds, with an average orientation of 171/2, are developed in the Botneheia Member in the hinge zone of the Eistraryggen Anticline (Fig. 7a). The axial surfaces of these folds are subhorizontal to gently east-dipping and are not subparallel to the steeply west-dipping axial surface of the Eistraryggen Anticline. We consider these minor folds to have developed above a local subhorizontal decollement zone somewhere lower down in the Barentsøya Formation, prior to the formation of the Eistraryggen Anticline, with subsequent rotation into their present orientation.

A different style of deformation characterizes the slope-forming lower part of the Barentsøya Formation. When looking westwards from Eistraryggen, a characteristically planar fabric ('cleavage') is seen in the Sticky Keep Member of the Barentsøya Formation in the lower part of Roslagenfjellet. This penetrative fabric element dips 10–15 degrees towards the west, whereas the overall orientation of the bedding dips only a few degrees in the same direction. A closer investigation of this 'cleavage fabric' demonstrates that it is the result of intense small-scale reverse faulting within the shale/siltstone units of the Sticky Keep and Deltadalen Members. Lack of good

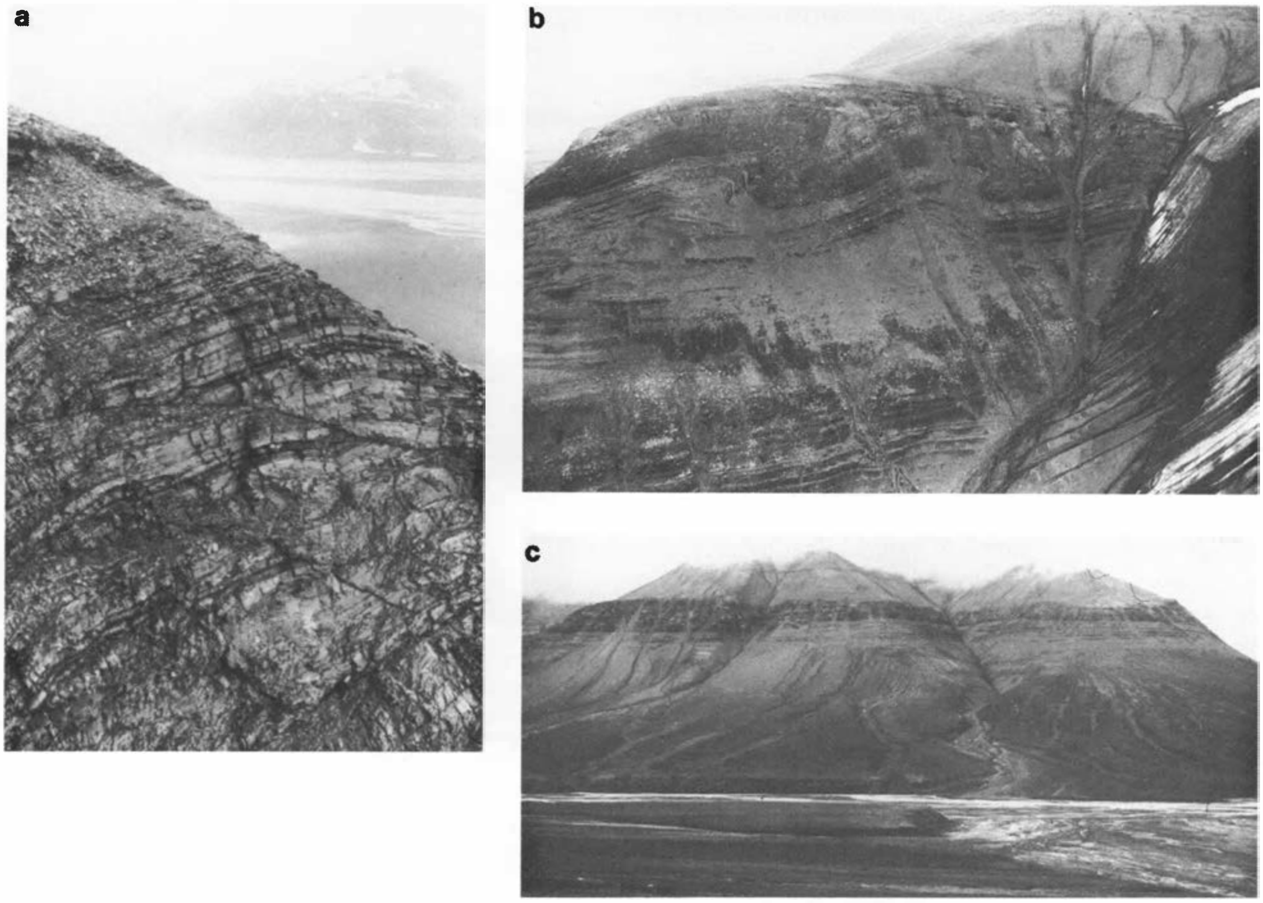

Fig. 6. Shortening structures in the Botneheia Member associated with the Lower Decollement Zone. (a) Duplex structure on the rotated eastern flank of the Eistraryggen Anticline at Eistraryggen. Height of cliff is ca. 15 m. (b) Fold structures in the Botneheia Member of the Sassendalen Group at Fulmardalen. A bedding-parallel thrust ('roof-thrust') separates the folded Botneheia Member from the undeformed Kapp Toscana Group. (c) Unevenly tectonically thickened beds (dark horizon) form the upper part of the Botneheia Member in Vendomdalen. Thickness of thickened unit varies from 25 to 60 m.

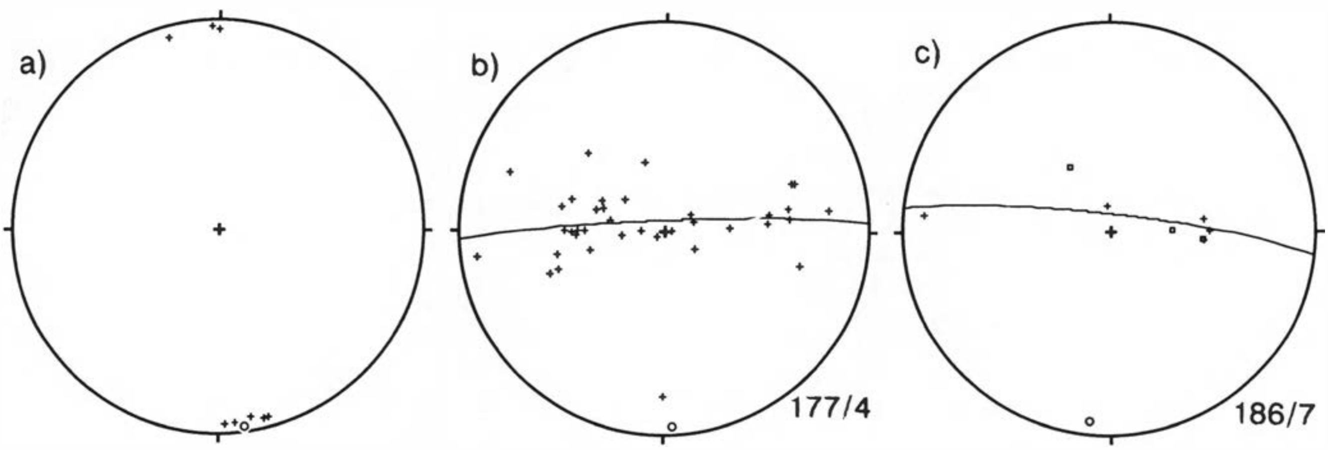

Fig. 7. Structural data from the Roslagenfjellet-Eistraryggen area plotted in equal area stereonets using the lower hemisphere. (a) Measured foldaxes (cross); (b) poles to bedding (cross) and pole to best fit great circle (open circle) 177/4; (c) poles to thrusts (open square) and axial surfaces (cross) to folds associated with the decollement zone in the Botneheia Member. Pole to best fit great circle for the rotated axial surfaces gives a rotational axis of 186/7.

marker lithologies makes it impossible to estimate how much bedding-parallel shortening and associated vertical thickening has taken place at this level.

Neither of the above-described reverse faults appears to continue up into the overlying Kapp Toscana Group, thus indicating that they merge into a major bedding-parallel roof thrust close to the contact between the Sassendalen and Kapp Toscana Groups. This interpretation agrees with structural observations recently made by Haremo & Andresen (in press) further west, and has been incorporated into the geological cross-sections.

Top-to-the-east reverse faults and asymmetrical east-facing folds also occur within the Botneheia Member several places in Agardhdalen towards Sassendalen and are particularly well developed in Fulmardalen and Vendomdalen (Fig. 6a, b).

In conclusion, we therefore prefer to interpret the widespread shortening structures present in the Barentsøya Group as evidence of a major, regional decollement zone in the lower half of the Barentsøya Group. This implies that the overlying, less deformed Kapp Toscana Group, as well as even higher stratigraphical units, has been transported passively eastward several hundred metres, possibly several kilometres, on this decollement zone.

Upper Decollement Zone

Tectonic deformation structures in the shaly Janusfjellet Formation are restricted to a few outcrops just above the Brentskardhaugen Bed on the eastern and southeastern slopes of Klementievfjellet. A commonly observed feature at this stratigraphic level is a rather variable but steep bedding orientation associated with small-scale reverse fautls. Less frequently, minor folds, trending N–S and with a westerly dipping axial surface, are observed. These observations suggest that the decollement zone recognized in the Janusfjellet Formation some tens of kilometres further west by Haremo et al. (1990) may continue eastward to Klementievfjellet.

Another feature in support of a possible second decollement zone (Upper Decollement Zone) in this area is a marked eastward decrease in thickness of the Janusfjellet Formation. This is well demonstrated in the geological cross-section through Klementievfjellet (Fig. 5). As minimum thickness just east of Klementievfjellet is dramatically reduced compared with the normal undeformed stratigraphical thickness (Flood et al. 1971; Major & Nagy, 1972) a tectonic explanation is favoured. Since minimum thickness is observed close to the hinge zone of the Eistraryggen Anticline the thickness variation could be due to 'flow' of incompetent shaly material away from the hinge zone during the folding process. Another possibility is to explain the thinning by development of a late out-of-sequence fault in the upper part of the Janusfjellet Formation with decapitation of the hinge zone. Such a late out-of-sequence-fault would have to cut stratigraphically downward, causing tectonic thinning, as it propagated eastwards. Structural and stratigraphical observations support such a model for the reduced thickness of the Janusfjellet Formation across Billefjorden Fault Zone in Adventdalen (Haremo et al. 1990). Exposures in the upper part of the Janusfjellet Formation south of Agardhdalen are, however, too poor to demonstate a similar relationship in this area.

Eistraryggen Anticline

The gross asymmetrical geometry of the Eistraryggen Anticline is particularly well displayed in the Roslagenfjellet–Eistraryggen area (Figs. 4, 8a). In this area the anticline is followed eastwards by a syncline with an almost vertical westerly limb and a subhorizontal easterly limb (Fig. 4). The limb linking the anticlinal–synclinal pair is locally overturned. The Brentskardhaugen Bed and the lower part of the Janusfjellet Formation is locally found to have a vertical to slightly overturned orientation in the core of this syncline. Due to lack of exposure, however, it has not been possible to decide whether the vertically oriented Brentskardhaugen Bed is continuous around the fold-hinge or whether it is cut by a west-dipping reverse fault. Units on the subhorizontal western limb of the Eistraryggen Anticline are uplifted approximately 500 m relative to the same beds east of the anticline.

a

b

Fig. 8. (a) The Eistraryggen Anticline viewed from the south across Agardhdalen. The cliff-forming unit in the middle of the slope represents the upper part of the Botneheia Member. (b) Large-scale chevron-like folds in the sandstone dominated De Geerdalen Formation.

The Eistraryggen Anticline is traced southward across Agardhdalen to the eastern slopes of Klementievfjellet (Fig. 5), where the upper part of the Kapp Toscana Group and the lower part of Janusfjellet Formation, including the distinctive Brentskardhaugen Bed, and the Helvetiafjellet Formation are involved in the deformation (Fig. 4). There is an overall change in fold geometry from a rather simple overturned anticline at Rurikdalen to a more complex anticlinorium, composed of at least two anticlines and a syncline, northward towards Agardhdalen. Because of the oblique erosional surface relative to the trend of the fold hinges, a somewhat complex map pattern is developed (Fig. 3).

The mesoscopic deformation structures in the sandstone-dominated upper part of the Kapp Toscana Group are typically asymmetric folds (Fig. 8b) with sharp hinges and straight limbs (chevron folds). The axial surfaces dip 60–70 degrees towards the west. Parasitic, minor folds and reverse faults are commonly found in the core of larger structures. Most of the minor folds

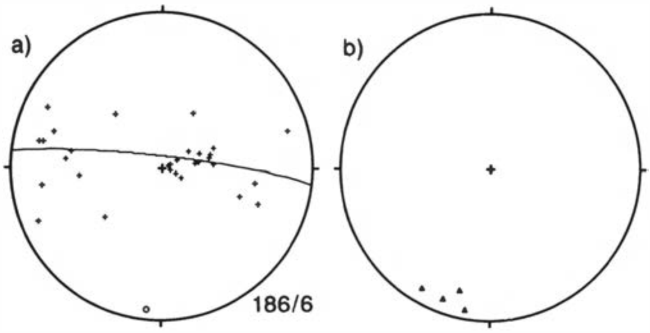

Fig. 9. Structural data from the Klementievfjellet area. (a) Poles to bedding (cross) define a foldaxis (open circle) with orientation 186/6. (b) Measured foldaxes (open triangle) in the De Geerdalen Formation. The data are plotted in equal area net using the lower hemisphere.

have axial surfaces that are subparallel to the axial surface of the large overturned anticline, and are accordingly interpreted as parasitic structures on the Eistraryggen Anticline, and not as compressional structures developed above the Lower Decollement Zone. The folds in the area are oriented approximately 190–200 with a plunge of 10–15 degrees towards the south (Fig. 9). This is clearly different from the orientation of the small-scale structures recorded in the Eistraryggen–Roslagenfjellet area, and supports the proposed different origin for each of these two sets of folds.

The amplitude of the Eistraryggen Anticline at the stratigraphic level of the Festningen Sandstone Member diminishes and dies out southward towards the area east of Ingelfieldbukta. A down-to-the-east offset of ca. 100 m of the Festningen Sandstone is observed on the ridge just south of Rurikdalen. This offset is reduced to only 20–30 m at the next ridge approximatley 3 km further south, and no offset is observed in the Ingelfieldbukta area. It is not clear whether this offset is related to a west-dipping reverse fault splaying off from the Upper Decollement Zone, or whether it represents the eroded hinge zone of the Eistraryggen Anticline. There is, however, no evidence of a vertical fault cutting through the entire stratigraphy, as indicated in previous publications (Flood et al. 1971). On the map (Fig. 3), the observed offset of the Festningen Sandstone is marked as a fold-hinge zone rather than a fault.

Discussion

The field observations reported above, compiled into a simplified map and two cross-sections, demonstrate that the southern termination of the Lomfjorden Fault Complex is a highly asymmetrical, monoclinal-like east-facing anticline, the Eistraryggen Anticline. The amplitude of this anticline diminishes southward and it apparently disappears as a prominent structural feature 10–15 km south of Rurikdalen. It is at present not clear to what extent this change in amplitude is controlled by variable N–S offset across a basement-involved fault (see below) or whether it is stratigraphically controlled with diminishing offset upwards in the stratigraphy.

In addition to the Eistraryggen Anticline, extensive layer-parallel shortening has taken place along and above two stratigraphically and structurally different levels (Upper and Lower Decollement Zones). The layer-parallel shortening strutures found in the Barentsøy Formation are geometrically not related to the Eistraryggen Anticline, nor are they restricted to the Eistraryggen Anticline. Furthermore, there is ample evidence, in the form of rotated reverse faults and duplexes, to suggest that the internal deformation recorded in the Barentsøya Formation preceded the formation of the Eistraryggen Anticline. Observation of similar layer-parallel shortening structures at the same stratigraphic level several places further west as well as within the West Spitsbergen Foldbelt (Maher et al. 1986, 1989; Mann & Townsend 1989; Nøttvedt et al. 1988a, b; Bergh & Andresen 1990), suggests that the Lower Decollement Zone extends from the outer Isfjorden region across Spitsbergen to Storfjorden. This interpretation is also supported by seismic sections from Isfjorden and Van Mijenfjorden (Faleide et al. 1988; Nøttvedt & Rasmussen 1988). Based on this correlation and the assumption that movement along the entire length of the Lower Decollement Zone was more or less contemporaneous throughout, a Paleocene to Eocene age seems likely (Andresen et al. 1988).

Our observations demonstrate, furthermore, that stratigraphic thickness variations observed within the Barentsøya Formation/Sassendalen Group should be used with great care when making statements about syn-depositional Triassic basin configurations (Mørk & Bjorøy 1984; Mørk et al. 1982). Most of these thickness variations appear to be attributable to post-depositional Tertiary tectonic processes. The structural observations and thickness variations within the Janusfjellet Formation, combined with similar observations of the same unit in the inner part of Adventdalen (Andresen et al. 1988; Haremo & Andresen 1988), suggest that a second major decollement zone, possibly developed as two or more bedding parallel thrusts, is present in this unit. Of particular interest is the reduced thickness of the Janusfjellet Formation in the hinge area of the Eistraryggen Anticline. A similar relationship observed along the Billefjorden Fault Zone has been explained by out-of-sequence thrusting, related to decapitation or omissional faulting of an already formed west-facing monoclinal structure (Andresen et al. 1988; Haremo & Andresen 1988). It is tempting to use a similar model to explain the thickness variation within the Janusfjellet Formation in the Klementievfjellet region, and this has been indicated in our structural interpretation shown in Fig. 5. However, the conclusive data for such a kinematic model are still lacking.

Assuming an early Tertiary age for the layer-parallel deformation in the Sassendalen Group, the superimposed Eistraryggen Anticline must also be Early Tertiary or younger in age. The geometry as well as the kinematic model for the anticline at depth, however, are unclear. One possible explanation would be that the Eistraryggen Anticline developed as a forced- or drape-fold above a steep-west-dipping reverse fault in the underlying more competent pre-Mesozoic units as indicated by Haremo et al. (1988) and Nøttvedt et al. (1988a). The geometry of this fault at depth, however, is highly uncertain. One possible explanation is that the fault soles out westwards in one of the Carboniferous or Permian evaporite sequences. Such a model would be in agreement with observations from Isfjorden, where Ringset & Andresen (1988) have argued that the Gipshuken Fault and Anservika Anticline are caused by splay faults linked together by a sole-thrust in the evaporites in the Ebbadalen Formation. A major problem with this model, however, is the fact that most sedimentological models (Steel & Worsley 1984) suggest that the evaporites of the Ebbadalen Formation thin out and disappear somewhere west of Agardhdalen.

The most reasonable explanation for the Eistraryggen Anticline, and the one favoured here, is to relate formation of the anticline to reactivation of an old, steep west-dipping basement (Hecla Hoek) fault. This model is supported by available data from further north along the Lomfjorden Fault Complex. From the geological map of Spitsbergen presented by Flood et al. (1971), one can observe that the Eistraryggen Anticline aligns with a major N–S trending fault, the Vivienberget Fault, along which the western side is uplifted realtive to the eastern side. From this map, the stratigraphical information given by Cutbill & Challinor (1965) and the recent observations by Andresen et al. (in progress), vertical offset across this fault appears to be roughly 500–700 m. Data from further north along the lineament (Andresen et al. 1988, in progress) suggest that the Vivienberget Fault is a steep west-dipping reverse fault or up-thrust. Both the geometry and compressional features associated with the Eistraryggen Anticline are thus consistent with a model in which the Vivienberget Fault continues southward to Agardhdalen and there controls the development of the Eistraryggen Anticline.

The relative age-relationship between thin-skinned and basement-involved deformation observed along the Lomfjorden Fault Complex in Agardhdalen is opposite to what has been described from the Billefjorden Fault Zone. In the latter area it is now well documented (Andresen et al. 1988; Haremo & Andresen 1988) that a phase of compression caused uplift of the Ny Friesland Block relative to the Nordfjorden Block prior to thin-skinned thrusting. The overall geometry of the Billefjorden Fault Zone and the Lomfjorden Fault Complex, furthermore, demonstrate uplift or basin inversion of the Ny Friesland Block, as proposed by Nøttvedt et al. (1988a).

Conclusions

Structural data from the southern termination of the Lomfjorden Fault Complex in the Agardhdalen area demonstrate the interaction of thin-skinned and basement-involved Tertiary compressional deformation. The thin-skinned deformation, localized to a major decollement zone in the Sassendalen Group, clearly preceded movement across a steeply dipping basement fault, controlling development of the east-facing Eistraryggen Anticline in this region. The link between this decollement zone and the West Spitsbergen Foldbelt is interpreted as evidence of an Early Tertiary (Paleocene/Eocene) age for both the thin-skinned deformation and the basement up-thrust. A less well documented decollement zone, the Upper Decollement Zone, is inferred to be present in the Janusfjellet Formation. Movement on this fault zone most probably post-dates the formation of the Eistraryggen Anticline.

Acknowledgements. – This research was made possible through financial support from NAVF (Grant 440.89/002 to A.A.), Samarbeidsprosjektet Norsk Hydro/SNSK and a Research Fellowship from Nordisk Ministerråd (to PH). Statoil is thanked for helicopter transportation and use of their camp in Agardhdalen. The manuscript has benefited from critical comments made by Arvid Nøttvedt and Bjørn Larsen.

Manuscript received April 1991

References

Andresen, A., Bergh, S. G., Hansen, H., Kløvjan, O., Kristensen, S. E., Lifbjerg, F., Lund, T., Mair, B. F., Midbøe, P. & Nøttvedt, A. 1988: Geometry and structural development of the Billefjorden and Lomfjorden fault zones in the Isfjorden–Sabine Land area, Spitsbergen. Abstract, Nordiske Geologiske Vintermøte, Copenhagen, 1988, 33–34.

Bergh, S. G. & Andrsen, A. 1990: Structural development of the Tertiary fold-and-thrust belt in east Oscar II Land, Spitsbergen. *Polar Research 8*, 217–236.

Cutbill, J. L. 1968: Carboniferous and Permian stratigraphy of Ny Friesland, Spitsbergen. *Norsk Polarinstitutt Årbok 1966*, 12–24.

Cutbill, J. L. & Challinor, A. 1965: Revision of the stratigraphical scheme for the Carboniferous and Permian rocks of Spitsbergen and Bjørnøya. *Geological Magazine 102*, 418–439.

De Geer, G. 1909: Some leading lines of dislocation in Spitsbergen. *Geologiska Föreningens i Stockholm Förhandlinger 31*, 199–208.

Faleide, J. I., Gudlaugsson, S., Eiken, O. & Hanken, N. M. 1988: Seismic structure of Spitsbergen: implication for Tertiary deformation. *Norsk Polarinstitutt Rapportserie 46*, 47–50.

Flood, B., Nagy, J. & Winsnes, T. S. 1971: Geological map of Svalbard 1:500 000, Sheet 1G, Spitsbergen southern part. *Norsk Polarinstitutt Skrifter 154 A*.

Gripp, K. 1926: Beiträge zur Geologie von Spitzbergen. *Abhandlungen Naturwissenschaft, Hambugr, B. 21*, 1–38.

Haremo, P. & Andresen, A. 1988: Tertiary movements along the Billefjorden Fault Zone and its relation to the Vest-Spitsbergen orogenic belt. *Norsk Polarinstitutt Rapportserie 46*, 71–74.

Haremo, P. & Andresen, A. in press: Tertiary decollement thrusting and inversion structures along Billefjorden and Lomfjorden Fault Zones, East Central Spitsbergen. Norwegian Petroleum Society conference volume on *Structural and tectonic modelling and its application to petroleum geology* (Stavanger 1989).

Haremo, P., Andresen, A., Dypvik, H., Nagy, J., Elverhøi, A., Eikelend, T. A. & Johansen, H. 1990: Structural development along the Billefjorden Fault Zone in the area between Kjellstrømdalen and Adventdalen/Sassendalen, Central Spitsbergen. *Polar Research 8*, 195–216.

Hardland, W. B., 1959: The Caledonian Sequence in Ny Friesland, Spitsbergen, *Quarterly Journal of the Geological Society of London 114*, 307–342.

Harland, W. B., Cutbill, J. L., Friend, P. F., Gobbet, D. J., Holliday, D. W., Maton, P. I., Parker, J. R. & Wallis, R. H. 1974: The Billefjorden Fault Zone, Spitsbergen – the long history of a major tectonic lineament. *Norsk Polarinstitutt Skrifter 161*, 1–77.

Hjelle, A. & Lauritzen, Ø. 1982: Geological map of Svalbard 1:500 000, Sheet 3G, Spitsbergen northern part. *Norsk Polarinstitutt Skrifter 154 C*, 1–15.

Kellogg, H. E. 1975: Tertiary stratigraphy and tectonism in Svalbard and continental drift. *American Association of Petroleum Geologists Bulletin 59*, 465–485.

Lamar, D. L., Reed, W. E. & Douglass, D. N. 1986: Billefjorden Fault Zone, Spitsbergen: is it part of a major Late Devonian transform? *Geological Society of America Bulletin 97*, 1083–1088.

Maher, H. D., Craddock, C. & Maher, K. 1986: Kinematics of Tertiary structures in upper Paleozoic and Mesozoic strata on Midterhuken, West Spitsbergen. *Geological Society of America Bulletin 97*, 1411–1421.

Maher, H. D. Jr., Ringset, N. & Dallmann, W. K. 1989: Tertiary structures in the platform cover strata of Nordenskiöld Land, Svalbard. *Polar Reserach 7*, 83–93.

Major, H. & Nagy, J. 1972: Geology of the Adventdalen map area. *Norsk Polarinstitutt Skrifter 138*, 1–58.

Mann, A. & Townsend, C. 1989: The post-Devonian tectonic evolution of southern Spitsbergen illustrated by structural cross-sections through Bellsund and Hornsund. *Geological Magazine 126*, 549–566.

Mørk, A. & Bjorøy, M. 1984: Mesozoic source rocks on Svalbard. *In* Spencer, A. M. (ed.): *Petroleum Geology of the North European Margin*, 371–382. Norwegian Petroleum Society, Graham and Trotman, London.

Mørk, A., Knarud, R. & Worsley, D. 1982: Depositional and diagenetic environments of the Triassic and Lower Jurassic succession of Svalbard. *In* Embry, A. F. & Balkwill, H. R. (eds.): *Arctic Geology and Geophysics*, 371–398.

Nøttvedt, A. & Rasmussen, E. 1988: Tertiary deformation in Central-West Spitsbergen. *Abstract, Nordiske Geologiske Vintermøte, Copenhagen, 1988.*

Nøttvedt, A., Livbjerg, F. & Midbøe, P. S. 1988a: Tertiary deformation of Svalbard – various models and recent advances. *Norsk Polarinstitutt Rapportserie 46*, 79–84.

Nøttvedt, A., Livbjerg, F., Midbøe, P. S., Eide, J. R., Kristensen, S. E., Rasmussen, E., Andresen, A. & Bergh, S. G. 1988b: Tertiary deformation in East-Central Spitsbergen. *Abstract, Nordiske Geologiske Vintermøte, Copenhagen, 1988.*

Odell, N. E. 1927: Preliminary notes on the geology of the eastern parts of central Spitsbergen, with special reference to the problem of the Hecla Hoek Formation. *Quarterly Journal of the Geological Society 83*, 147–162.

Orvin, A. K. 1940: Outline of the geological history of Spitsbergen. *Skrifter om Svalbard og Ishavet 78*, 1–57.

Ringset, N. & Andresen, A. 1988: The Gipshuken Fault System – evidence for Tertiary thrusting along the Billefjorden Fault Zone. *Norsk Polarinstitutt Rapportserie 46*, 67–70.

Steel, R. J. & Worsley, D. 1984: Svalbards post-Caledonian strata – an atlas of sedimentational patterns and paleographic evolution. *In* Spencer, A. M. (ed.): *Petroleum Geology of the North European Margin*, 109–135. Norwegian Petroleum Society, Graham and Trotman, London.