Origins and deformation of post-Caledonian sediments on Blomstrandhalvøya and Lovénøyane, northwest Spitsbergen

F. THIEDIG & G. M. MANBY

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Unmetamorphosed, post-Caledonian (Devonian) sediments known from Lovénøyane and eastern Blomstrandhalvøya in the Kongsfjorden area of northwest Spitsbergen have been found to be distributed widely over the latter area. The geometry and composition of the sediments indicate synsedimentary fault activity and the present-day topography is a partially exhumed post-Caledonian (Devonian) landscape. N–S striking deformation structures in the sediments and post-metamorphic brittle structures in the basement marbles are consistent with purely E–W compression. These structures are comparable with similarly oriented folds, thrusts and cleavages in the larger Devonian basin of Northern Svalbard. Their orientation, however, contrasts markedly with the north- to northeast-directed fold and thrust structures developed to the south on Brøggerhalvøya. Although the structures on Blomstrandhalvøya may represent deformation within the foreland of the West Spitsbergen Fold Belt, an earlier Svalbardian origin cannot be ruled out.

F. Thiedig, Geologisch-Paläontologisches Inst, und Museum, Westfalische Wilhelms-Universität, D-4400, Münster, Germany; G. M. Manby, School of Earth Sciences, Thames Polytechnic, Walburgh House, Bigland Street, London E1 2NG, UK.

The discovery of Early Devonian sediments (Gjelsvik 1974; Thiedig 1988) on Blomstrandhalvøya and Lovénøyane in the Kongsfjorden area (Fig. 1) has provided new insight into the development of the Devonian Basin and the response of northwest Svalbard to Svalbardian and/or West Spitsbergen Fold Belt deformation.

The preliminary results of recent detailed mapping (1:10,000) of Blomstrandhalvøya (Kempe 1989; Niehoff 1989) and Lovénøyane are reported here and their significance for the post-Caledonian evolution of the area is discussed.

Geological setting

Blomstrandhalvøya, Lovénøyane and the area northwards from Kongsfjorden consist predominantly of medium to high grade Caledonian marbles, pelitic schists and gneisses, which belong to the Generalfjella and Signefjella formations, respectively (Hjelle 1979). These rocks strike N–S and have been affected by two synmetamorphic, co-linear phases of isoclinal folding, which are refolded by post-metamorphic crenulation to kink-like folds often associated with west-directed thrust faulting and imbrication.

To the north, 10 km along strike from Blomstrandhalvøya, a further narrow strip of red-beds is found, while to the west, on the northern shore of Kongsfjorden (Hjelle 1979), marbles similar to those in the study area are extensively brecciated and red stained. The possible relationships among these scattered outcrops and the extensively developed Devonian basin sediments in the Raudfjorden and Liefdefjorden areas to the north are briefly considered by Manby & Lyberis (this volume).

The area north of Kongsfjorden constitutes the foreland of the West Spitsbergen Fold Belt (Fig. 1). Southwards, across Kongsfjorden to Brøggerhalvøya and Engelskbukta, a sequence of high- to low-grade thrust nappes have ridden over a complex sequence of fold and thrust nappes involving rocks of Late Palaeozoic to Mesozoic age (Fig. 1). These structures belong to the West Spitsbergen Fold Belt, and in the Brøggerhalvøya area they are principally north to northeast directed. This direction of transport contrasts with that found in the main part of the fold belt to the south where folds and thrusts generated during the West Spitsbergen Fold Belt deformation are largely east vergent. The causes of this change in transport direction are discussed briefly below. The timing of and plate motions responsible for the West Spitsbergen Fold Belt are discussed by Lyberis & Manby (this volume).

Post-Caledonian sediments

Detailed mapping (Niehof 1989; Kempe 1989) has brought to light numerous small outcrops of unmetamorphosed sediments across Blomstrandhalvøya and on Lovénøyane. Here we concentrate on the larger sediment bodies indicated in Fig. 2 (localities a–g); the red-beds cropping out on the islands also are described briefly.

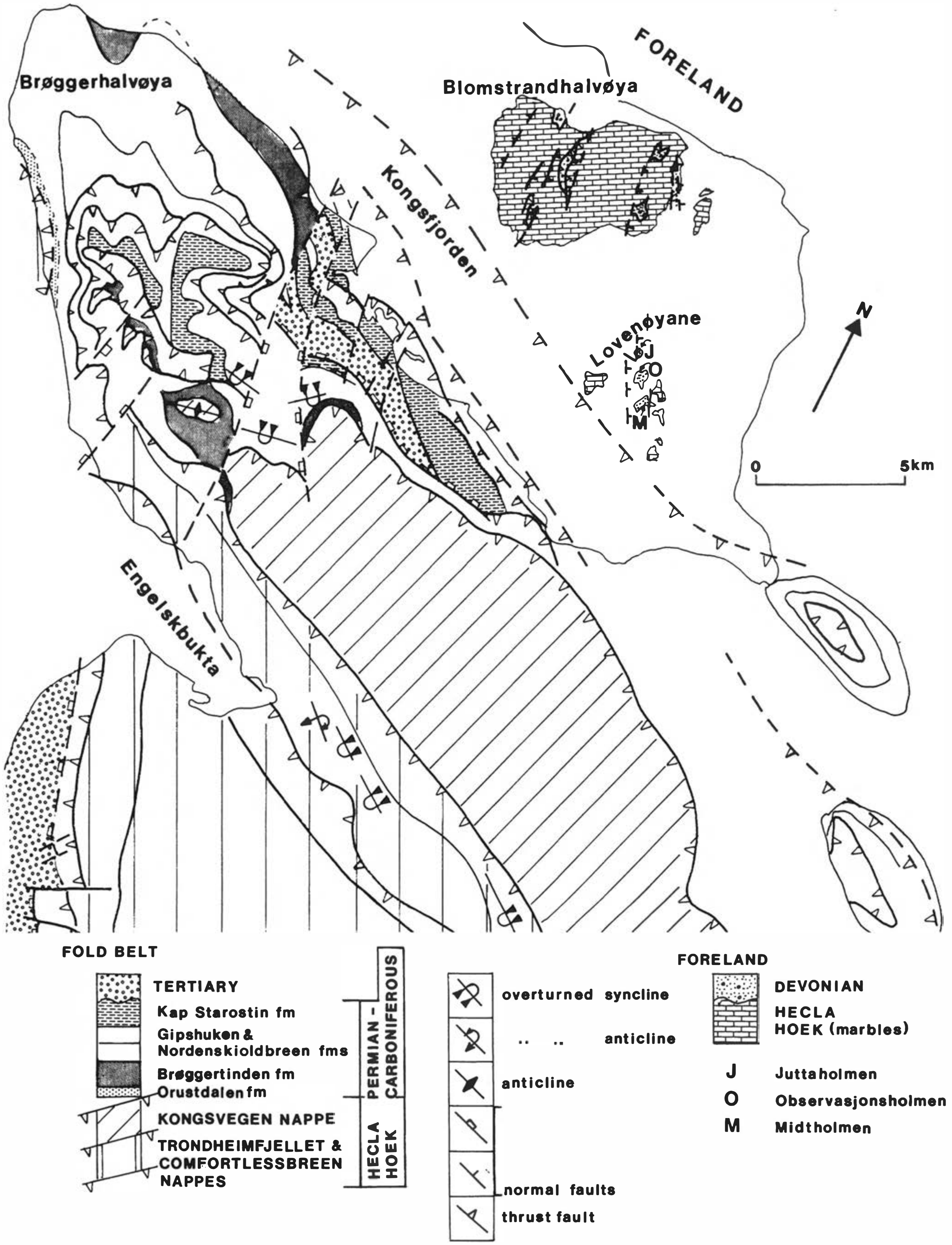

Fig. 1. Geological sketch map of the Kongsfjorden region. Blomstrandhalvøya and Lovénøyane are part of the foreland to the West Spitsbergen Fold Belt, which lies south of the thrust fault (sole thrust) interpreted as running through the fjord.

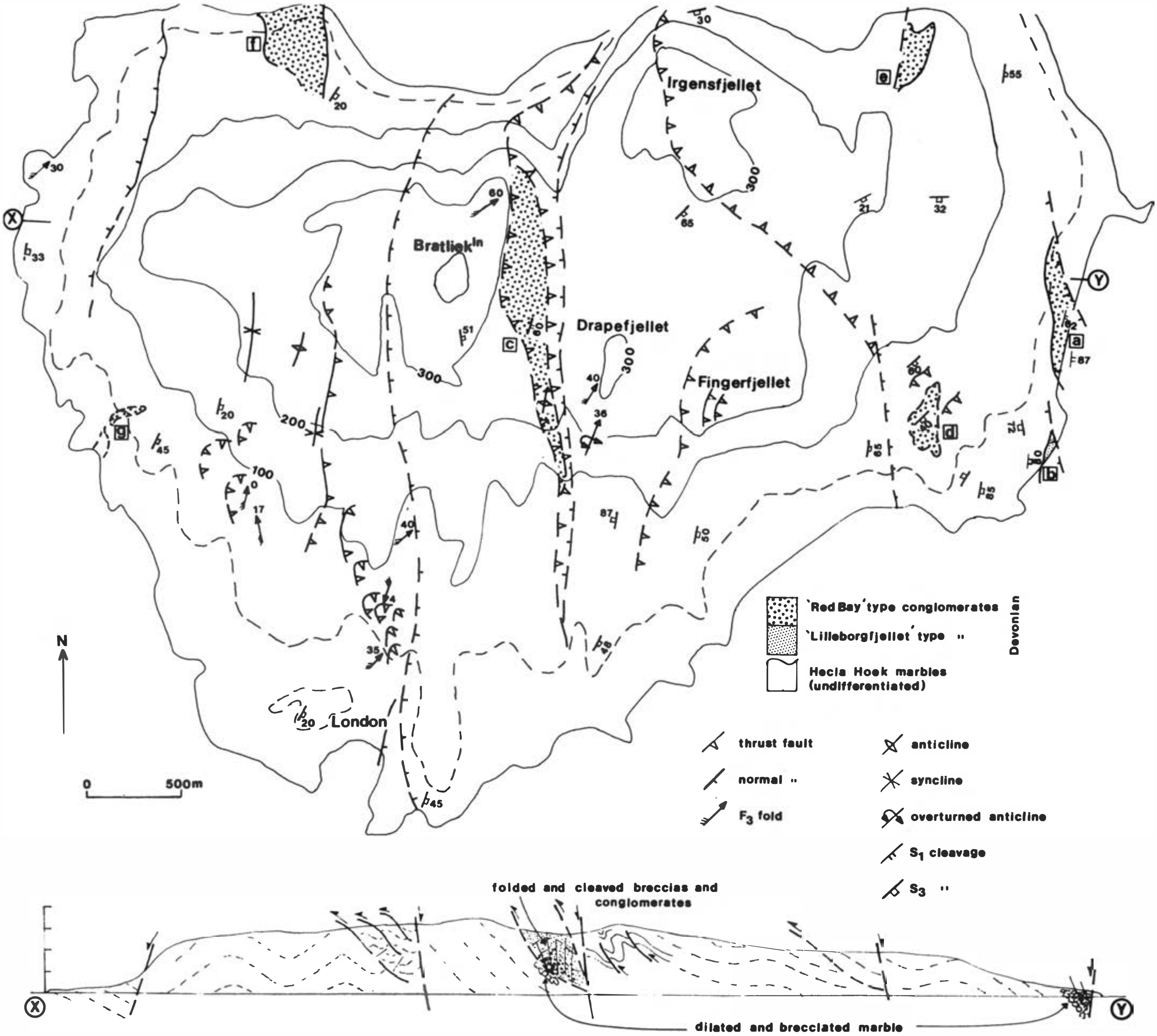

Fig. 2. Geological map of Blomstrandhalvøya showing the location of the principal Devonian rocks cropping out on the peninsula. X–Y = geological cross-section of Blomstrandhalvøya. The Devonian rocks are indicated between Bratliekollen and Drapefjellet and on the eastern margin of the peninsula. The dashed lines indicate the generalized structure of the marbles.

From poorly preserved plant remains in the red-beds, Manum (in Gjelsvik 1974) has assigned an Early Devonian age to the sediments on the islands and on the eastern side of Blomstrandhalvøya. The positional relationship between the basement and the additional red-bed exposures discovered, suggests that they are of similar age.

Blomstrandhalvøya

Generally the sediments are found in narrow strips that may be partially fault bounded or occur in distinct fan-like bodies. In most localities the nature of the contact between the unmetamorphosed sediments and the underlying basement marbles can be observed. The contact between the Devonian rocks and the marbles at locality a (Fig. 2) is exposed in stream and cliff sections. The marbles in these sections show, over a few tens of metres, a progressive increase in brecciation accompanied by carbonate-filled extensional veining, which is typically red stained. On the cliff section, large blocks, several metres in size, become detached from the main basement outcrop. These blocks are wrapped by coarse to fine, dark red sandstones and mudstones that contain extremely variable, matrix-supported, marble clasts. Some small-scale synsedimentary folds are found in the finer sediments and in one fold hinge, pipe-like water escape structures have been observed. The sequence dips steeply to the east and clast- to matrix-supported, cobble-sized breccias are the youngest sediments preserved.

Overall, the red-beds at this locality are similar to the megabreccias at the base of the Red Bay Group (Gedinnian) in the Raudfjorden and Liefdefjorden areas (cf. Manby & Lyberis, this volume). Like the examples to the north, the red-beds on eastern Blomstrandhalvøya have much in common with seismically triggered debris flows. The initial fragmentation of the basement marbles may have been fault induced although the extensive red staining is suggestive of some subaerial weathering under arid conditions (cf. Gjelsvik 1974).

Just south of the marble-clast-dominated red-beds (Fig. 2, location b), a poorly exposed, cobble conglomerate with a mica-rich matrix crops out. The clasts are, unlike those in the main exposure, of gneissic composition and are red stained like the matrix. They are in many respects similar to the Lilleborgfjellet conglomerates at the base of the Siktefjellet Group (Early Gedinnian) found in the Raudfjorden–Liefdefjorden area (Gee & Moody-Stuart 1966; Manby & Lyberis, this volume).

The largest area of Devonian rocks on the peninsula lies between Bratliekollen and Drapefjellet (Fig. 2, location c). Here, however, the contact with the basement marbles appears to be thrust faulted. In the extreme southwest, blocks of brecciated marbles occur near the contact and cobble breccias above these are replaced, up sequence (northwards), by more rounded pebble conglomerates and coarse sandstones that weather to a yellow-brown colour.

The sediments in the remaining localities (d–g) are preserved in fan-shaped bodies. They occupy channel cuttings in the marbles which broaden and thicken downslope and generally radiate out from the centre of the peninsula (Fig. 2). While they consist predominantly of angular marble clasts with a wide size range, progressive brecciation of the basement as described for locality a has not been observed. At locality d the sediments weather to a yellow-brown colour and several individual structureless flows, which are south directed, can be recognized within the fan. In this, and at localities e and f, the breccias exhibit small, c. 0.5 m calcite/dolomite filled cavity structures. One of these, at locality d, has a 2–3 cm-thick string of well-rounded vein-quartz pebbles at the base of the infill. At locality g, a narrow channel fill of yellow to red-brown weathered coarse sandstones can be traced downhill to the sea cliff. Seen in cross-section, the basement marbles are penetrated by small (a few tens of centimetres) sandstone-filled tubes.

Fig. 3. Large boulder breccio-conglomerate locality (f, Fig. 2) Blomstrandhalvøya, suturing of clasts defines pressure-solution cleavage surfaces.

The most spectacular and best exposed of the post-Caledonian sediment bodies is found at locality f on the northern margin of Blomstrandhalvøya. Here the sediments are distributed in a fan that is truncated on the east side by a later extension fault. The clasts are entirely of marble composition, varying from a maximum size of 2 m (see Fig. 3) and may be subrounded to angular. Within this boulder conglomerate is a thick red sandstone body in contact with the N–S fault. To the west, the boulder beds lie on the basement and no transitional breccias have been found. However, multiphase en echelon tension gashes cut the basement marbles and these are variously filled with red-stained carbonates and sandstone.

Lovénøyane

Gjelsvik (1974) has described the principal features of the Devonian sediments on Lovénøyane and only a few additional points will be noted here. The sediments are extensively developed over three islands (see Fig. 1) which are (from north to south), Juttaholmen, Observasjonsholmen and Midtholmen. The relation between the basement and the Devonian is seen most clearly on the northernmost island (Juttaholmen, Figs. 2, 4a). The fragmented, dilated and sheared basement marbles are in fault contact with boulder-sized conglomerates. At the fault contact, the boulders are strongly sheared over a metre or so and indicate a dominantly reverse sense of movement on the fault. Running N–S through the centre of the island is a block of strongly deformed (cleaved) marble breccias with cobble sized clasts. This is bound to the east by a steep N–S fault on which kinematic indicators show successively superimposed reverse, sinistral and normal senses of slip. The marbles to the east are again intensely fractured and separated from the pebble beds and coarse sandstones, which occupy the easternmost portion of the island, by a steep, west dipping, reverse fault. Observasjonsholmen consists entirely of red-beds affected by a large, N–S striking open fold, which is cut by a spaced west-dipping fracture cleavage (Fig. 4b). On the large island east of Midtholmen the steeply dipping marbles across a wave-cut platform are dissected by a network of sandstone-filled fissures a few centimetres wide.

Deformation structures

The N–S extensional faulting that determined the present-day configuration of the Devonian basin of northern Svalbard paralleled the Tertiary offshore sedimentary basins on the western margin of Svalbard (see

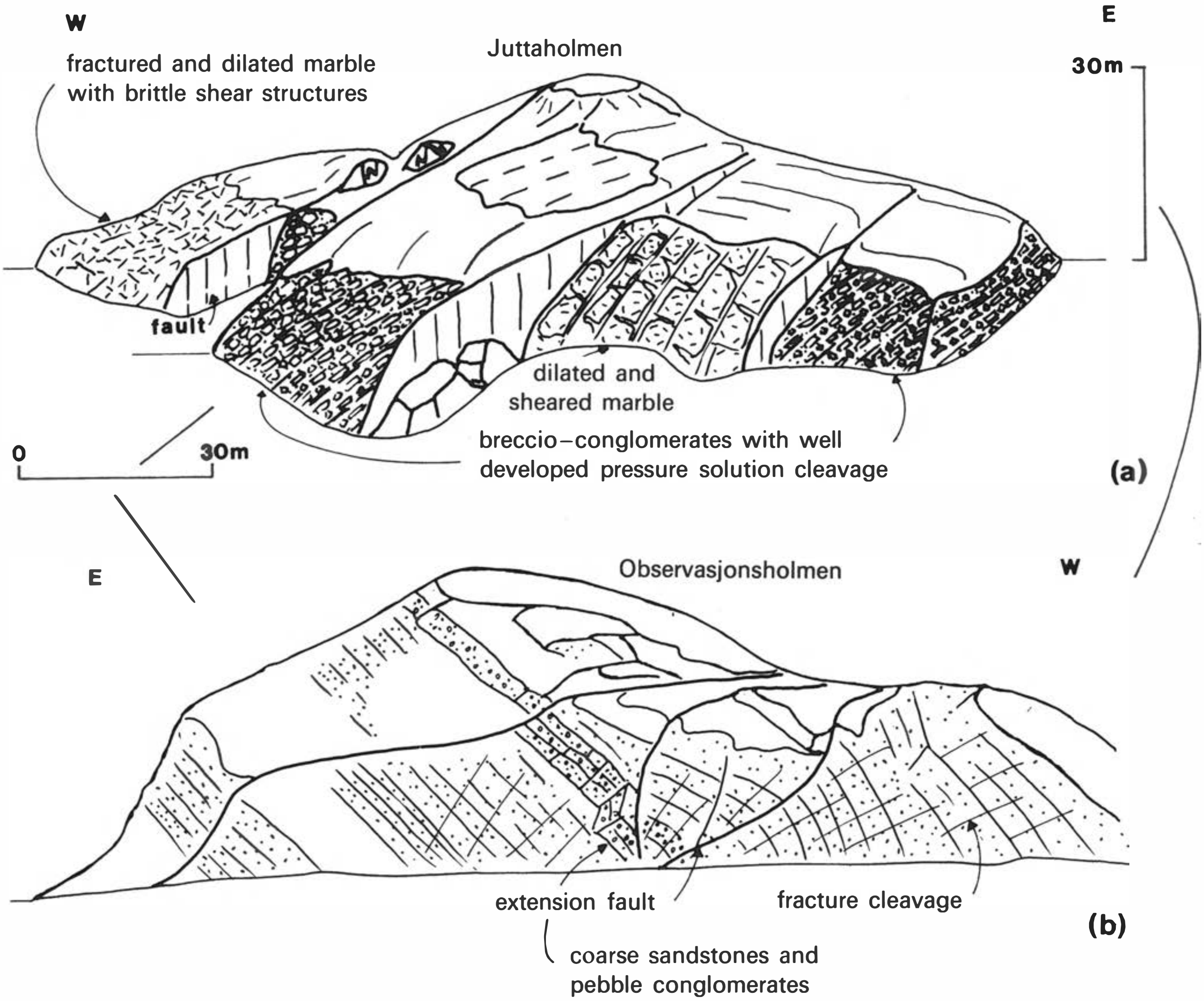

Fig. 4. Field sketches of the Devonian rocks on (a) Juttaholmen and (b) Observasjonsholmen.

Lyberis & Manby and Manby & Lyberis (this volume) for further discussion). The predominant N–S faulting which cuts the Devonian sediments in the study area and has preserved them in down-faulted wedges is probably of the same origin. These faults also cut the earlier contractional structures in the Devonian sediments of the study area.

The gross structure of Blomstrandhalvøya is illustrated in Fig. 2 and the orientations of folds and cleavages in the Devonian and basement rocks are plotted in Fig. 5. Although some scattering of the limited data is evident the pressure-solution cleavages and fold axes in the Devonian rocks have a similar orientation to the post-metamorphic crenulation cleavages and folds in the marbles. In the marbles, the association of crenulation folds with imbricate thrust sequences (Fig. 6) combined with the co-linear relationship with Devonian structures suggests all were formed by the same (Early) post-Devonian deformation event.

At Bratliekollen, locality c (Fig. 2), the red-beds are folded into a tight anticlinal structure verging to the west and incorporating a core of basement marbles. The cleavage penetrates both rock groups alike. The contact with the underlying basement (west) is not exposed but is interpreted as a thrust fault. To the east, the basement marbles clearly override the red-beds on a low-angled thrust (Fig. 7). Although a later extensional fault has displaced the red-beds downwards and projects to cut the overthrust, the fold structures in the overlying marbles below Drapefjellet may be of fault-bend origin (Figs. 2, 7).

The Devonian rocks on the eastern margin of Blomstrandhalvøya are cut by intensely developed pressure-solution cleavages that dip steeply to the east (Fig. 8). Here the pressure-solution cleavage anastomoses around the marble clasts, many of which have been deformed in a ductile manner (Fig. 8). Folds do not accompany the cleavages at this locality. While the lack of folds may

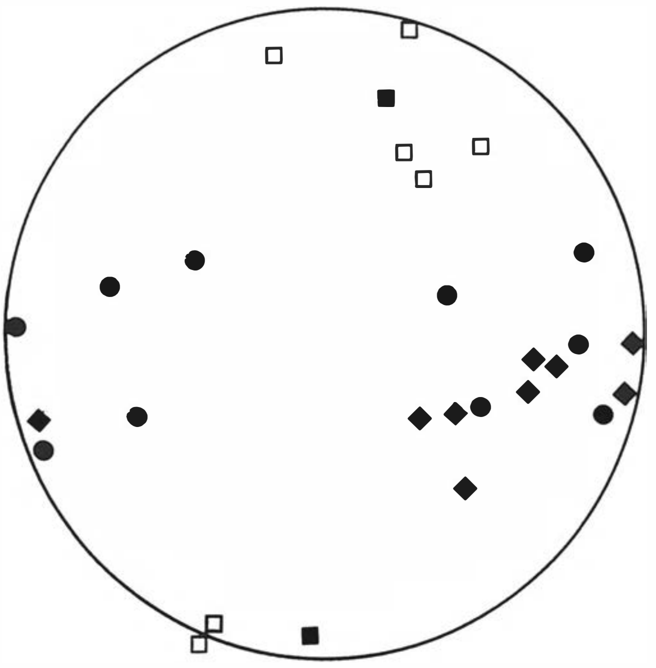

Fig. 5. Stereographic projection of fold and cleavage data from the Devonian and basement rocks on Blomstrandhalvøya. ● pressure solution cleavage in Devonian rocks; ◆ S_3 cleavage in marbles; ■ F_1 folds in Devonian; □ F_3 folds in marbles.

reflect the limited extent of the outcrop it is possible that the cleavage is, alternatively, the expression of the shortening within a thrust slice in which folds did not develop.

The narrow sandstone fan at locality g (Fig. 2) is slightly imbricated with the basement marbles, but strong cleavages and folds are not developed. In contrast the thick, boulder breccio-conglomerate on the northern side of the peninsula (Fig. 2, location f) is strongly cleaved (Fig. 3) and the sandstone channel is folded and internally thrust-faulted. The fan-like bodies at localities d and e are not so strongly deformed and reflect the inhomogeneous distribution of the deformation.

The east-dipping cleavages on Blomstrandhalvøya are replaced by west-dipping cleavages on Lovénøyane.

Fig. 6. Imbricated marbles to the north of London.

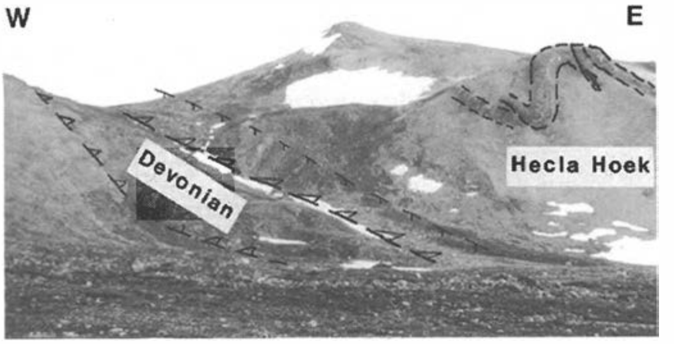

Fig. 7. Folded and overthrust Devonian rocks between Bratliekollen and Drapefjellet (location c, Fig. 2).

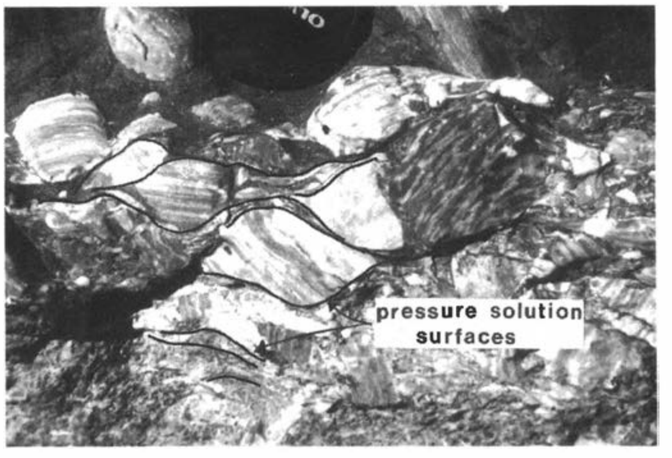

Fig. 8. Marble breccia from eastern Blomstrandhalvøya (location a, Fig. 2). The clasts exhibit clear pressure-solution cleavage effects. Note the ductile deformation of the marble clasts.

Conclusions

The small red-bed sequences cropping out on Blomstrandhalvøya and Lovénøyane appear to represent the eroded remnants of a previously more widespread blanket of Devonian sediments. Although subsequent deformation and erosion have combined to mask the original geometry of the Devonian rocks, they are either preserved in elongate and asymmetric wedges or else in distinct fan-shaped bodies. The almost radial distribution of the fans suggests that the central part of Blomstrandhalvøya was emergent at the time of deposition. Over a large part of Blomstrandhalvøya the basement marbles exhibit dense networks of extensional veining that are either filled with red-weathered carbonate or occasionally with red sandstone. These two observations suggest that much of the present landsurface of Blomstrandhalvøya was at or near the surface as the red-beds were accumulating.

At some localities the composition and character of the sediments, combined with the extensive hydraulic fracturing and dilation of the basement marbles, suggests that the red-beds were generated by active faulting. The breccias on the eastern margin of Blomstrandhalvøya and on Juttaholmen are very similar to the megabreccias at the base of the Red Bay Group of the main Devonian

Basin in the Raudfjorden and Liefdefjorden area to the north. It appears from these observations that the Devonian Basin of northern Svalbard was much more extensive than the present outcrop to the north suggests. The distribution of the fault breccias indicates that if the red-beds of the study area are part of the wider Devonian basin, it must have been characterized by several small fault-controlled asymmetric, sub-basins.

The similarity in orientation of the folds and cleavages in the Devonian rocks with the post-metamorphic crenulation folds and cleavages in the basement suggest a common E–W compressional origin. Similarly oriented, but larger scale structures affect the whole of the main Devonian basin to the north. While some of this deformation can be attributed to Late Devonian, Svalbardian E–W compression, there is a case for the suggestion that some, if not most, is related to the formation of the West Spitsbergen Fold Belt (see Manby & Lyberis, this volume). There is nevertheless a clear contrast between the E–W compressional structures in the foreland and the north to northeast transport of nappes to the south on Brøggerhalvøya (Fig. 1). The E–W compression on the foreland to the north of Kongsfjorden is displayed, however, by the larger part of the West Spitsbergen Fold Belt south of Engelskbukta. The progressive change in transport of the nappes northwards on to Brøggerhalvøya may be explained simply by pinning of the sole thrust to the northwest of Kongsfjorden as the nappes were driving eastwards. The effect has been to allow the nappes to the south to travel farther east, forcing, at the same time, the nappes near the pinned termination to move in a more northerly direction. The north-directed nappe transport in the Brøggerhalvøya district therefore could be a localized variation of the regional E–W contractional event which produced the predominantly N–S striking deformation structures in the fold belt and the foreland.

It is not clear to what extent the Devonian basin-forming faults have been reactivated. However, on the few exposed fault surfaces that are found, slickenside lineations indicating earlier reverse motions are superimposed by lineations indicating later strike-slip and normal displacements. Evidence for strike-slip is of interest as it may reflect transfer faulting in the foreland that propagates ahead of the advancing nappes or above a blind floor thrust. Normal motions on faults, however, are dominant and reflect the latest E–W extension of the western margin of Svalbard, after magnetic anomaly 13.

It is apparent that the foreland to the West Spitsbergen Fold Belt north of Kongsfjorden has not behaved as a passive block since Caledonian time but that inhomogeneously distributed E–W compressional structures are common. Sedimentary and structural evidence suggests that some of this deformation focused on N–S faults which were established towards the close of the Caledonian orogeny and that have repeatedly influenced the subsequent evolution of the Svalbard archipelago.

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