

# The Supanberget area – basement imbrication and detached foreland thrusting in the Tertiary fold-and-thrust belt, Svalbard

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The Supanberget area, situated in the southern part of the Tertiary Spitsbergen fold-and-thrust belt, occupies a position mainly within the central zone of the belt, characterized by basement-involved thrusting, but includes part of an eastern foreland zone of detached, thin-skinned thrust tectonics. The peculiar feature of Supanberget is the thrust- 'sliced' tectonic style that deforms a previously tightly folded basement-cover contact. Foreland structures indicate the additional presence of a subsurface detachment at a deeper structural level. Contrasts in magnitude and orientation of basement anisotropies may control lateral changes in tectonic style.

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The Tertiary fold-and-thrust belt of Spitsbergen, Svalbard, is situated in an overall dextral transpressive, intracratonic plate regime. Models proposed and established by Harland (1969), Lowell (1972), Birkenmajer (1972), Harland & Horsfield (1974), and Kellogg (1975) have been further constrained by evidence from the seafloor off the Barents Shelf (Myhre et al. 1982; Spencer et al. 1984; Eldholm et al. 1987; Vågnes et al. 1988).

Recent research in the fold-and-thrust belt provides a revised and expanded understanding of its structure. In spite of the overall transpressive regime, detailed investigations in the belt indicate that almost solely convergent motions are responsible for the observed structures (Andresen et al. 1988a, b; Bergh et al. 1988; Dallmann 1988a, b; Maher 1988a, b; Nøttvedt et al. 1988a, b). The eastward extension of the deformed foreland significantly exceeds what previously was believed (Andresen et al. 1988a, b; Haremo et al. 1988; Haremo & Andresen 1988). These results led to the idea of decoupled transform and compressive movements, the transform component being restricted to western offshore areas (Steel et al. 1985; Maher & Craddock 1988; Nøttvedt et al. 1988a, b). A distinct zonation parallel to the trend of the belt has been worked out (Maher 1988a,

b; Dallmann & Maher 1988), dividing it into a western zone of uplift of the Caledonian basement with an uncertain, but varying amount of Tertiary deformation, a central zone of mainly thick-skinned, basement-involved thrusts, and an eastern foreland zone of detached, thin-skinned thrust systems with décollement and ramp-flat geometries.

Lateral changes of tectonic style within these zones are common, and can partly be ascribed to the different structural depths exposed (Dallmann 1988b; Maher 1988a; Dallmann & Maher 1988). The basement-involved thrust zones vary from simpler areas with large-scale folds cut by individual thrusts to complexly imbricated and tightly folded sections. The latter have been described from several places in Oscar II Land (St. Jonsfjorden–Winsnes & Ohta 1988). South of Isfjorden, similar structures have – as far as we know – only been observed in the Supanberget area (Fig. 1). The lack of more frequent observations may be due to the extensive ice cover along the basement-cover contact in Wedel Jarlsberg Land.

In this article, we describe the structure of the Supanberget area, discuss its geometry and origin, and consider a connection between the structural style of the thrust zone and the basement anisotropies.

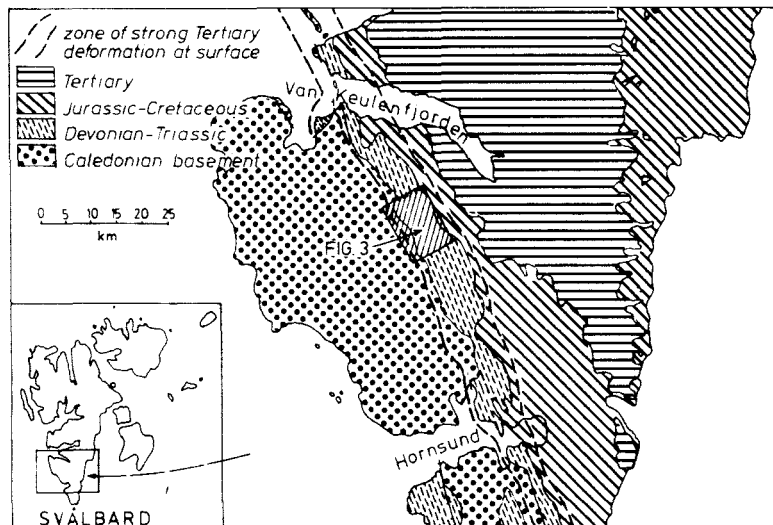


Fig. 1. Location of the Supanberget area and its position within the zone of strong Tertiary deformation in S Spitsbergen.

## Description of the Supanberget area

### *Location, accessibility and exposure*

Supanberget is situated in the interior of Wedel Jarlsberg Land, 20 km S of Van Keulenfjorden, and is part of the central NW-SE trending ridge separating the Caledonian basement in the SW from the post-Caledonian cover strata in the NE (Fig. 1). The area is extensively glaciated. The easiest access by foot is from Van Keulenfjorden along the glacier 'Penckbreen'. Exposures along the mountain sides and ridge crests are mostly excellent, and only a few small areas are covered with moraines or scree. The majority of the ridges can easily be set foot on from the glaciers, but only a minor part of them can be fully surveyed without mountaineering or helicopter support.

### *Stratigraphy and lithology*

**Caledonian basement strata.** – The Caledonian basement of the study area is assigned to the Magnethøgda sequence ('Magnethøgda Group' of Harland (1978)) of Precambrian, possibly Middle Proterozoic age (Flood et al. 1971; Y. Ohta pers. comm. 1988). No detailed descriptions of the lithologies at Supanberget have been published, but similar rocks from the same stratigraphic sequence have been described by Hauser (1982 – 'Antoniabreen Succession'). These strata lie below a major angular unconformity within

the basement rocks, and are part of the 'older sequence' of Bjornerud (1987). In the investigated area, the lithologies can be subdivided into two units. One consists of carbonate rocks, mainly massive grey to yellowish dolomites, with subordinate banded marbles. The other unit consists of dark grey phyllites interlayered with massive quartzite layers up to several meters in thickness. A low angle discordance exists between the lithologic banding of this metaclastic succession and the contact with the carbonate succession. The stratigraphic relationship between the individual units has not been investigated.

**Post-Caledonian cover strata.** – Middle Carboniferous through Lower Jurassic strata of the Supanberget area lie within the larger area in which Różycki (1959) describes the post-Caledonian stratigraphy. However, Cutbill & Chalinor (1965) revised the Carboniferous and Permian stratigraphy, and age relations were again reconsidered by Steel & Worsley (1984). Upper Carboniferous through Permian sections have also been described by Nysæther (1977) from Polakkfjellet, 18 km SE of Supanberget. The stratigraphic column, Fig. 2, is based on these descriptions, but modified by our own observations.

The Carboniferous and Permian stratigraphy is complexly deformed and partly cut by thrusts at Supanberget. In order to decipher the stratigraphy, it is therefore important to observe the undisturbed Zittelberget section to the north. In

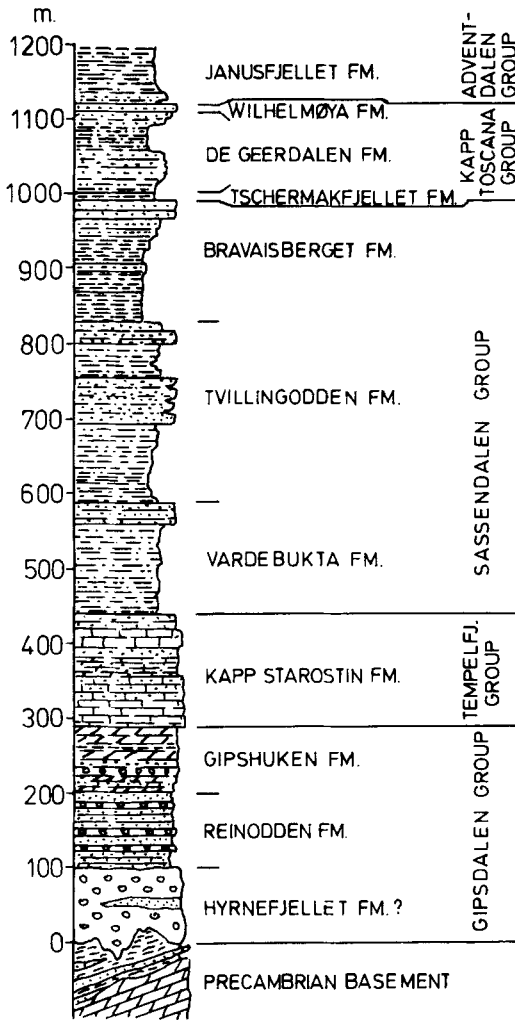


Fig. 2. Stratigraphic column of the post-Caledonian sequence of the Supanberget area. Thicknesses are approximate.

addition, a complicating factor is that the Lower Permian strata (Gipshuken Formation) undergo fairly rapid lateral facies changes towards more clastic dominated deposits to the south.

The lowermost unit is a red, polymict conglomerate succession with intercalated, discontinuous red sandstones of probably Middle (or Upper?) Carboniferous age, and it represents a facies equivalent of the Hyrnefjellet Formation (Birkenmajer 1964) at Hornsund. The rocks vary in thickness from 0 to c. 150 m, and appear to be deposited in Carboniferous graben and half-graben structures (Figs. 3, 4 – section D, and 7).

The overlying, yellow to grey sandstone and conglomerate succession (c. 100 m) can be traced

continuously into the Reinodden Formation at Van Keulenfjorden. It also seems to be an equivalent of the Drevbreen beds at Polakkfjellet (Nysæther 1977) and of the Treskelodden Formation at Hornsund (Birkenmajer 1964). Steel & Worsley (1984) assume that these three Upper Carboniferous to lowermost Permian successions are correlatable. The formation is thinly layered, interbedded with minor dolomites and limestones, and numerous shaly layers as well as clast-supported conglomerate beds with rounded clasts and a porous matrix. These parameters are consistent with a relatively incompetent behaviour.

The overlying Lower Permian Gipshuken Formation (c. 80–100 m) consists mainly of light grey to yellowish weathering dolomitic limestones and dolomites with intercalated cross-bedded sandstones, polymict conglomerates, and shales. The facies of the lower part becomes richer in conglomerates to the south, where the boundary towards the underlying Reinodden Formation is not well defined.

The Upper Permian Kapp Starostin Formation (c. 150 m) is dominated by fossiliferous, partly siliceous limestones. Cherts that are typical for this formation further north are here mostly substituted by shales, silt- and sandstones which occur preferentially in the upper part. The Kapp Starostin Formation still forms the most competent unit of the post-Caledonian succession in this area.

The Lower and Middle Triassic formations of the Sassendalen Group consist of sandstone/shale alternations, representing four main coarsening upward cycles which total approximately 550 m thickness. The upper unit of the group, the Bravaisberget Formation, contains c. 120 m of incompetent, bituminous shales and a c. 40 m thick capping sandstone. The overlying Upper Triassic to Lower Jurassic Kapp Toscana Group is made up of c. 120 m marginal marine sand- and siltstones (Mørk et al. 1982). Clastic sedimentation continues into the Jurassic/Lower Cretaceous Janusfjellet Formation, consisting of highly bituminous siltstones and shales.

## Structure of the Supanberget thrust system

*The basement-involved zone.* – The western, basement-involved zone of the fold-and-thrust

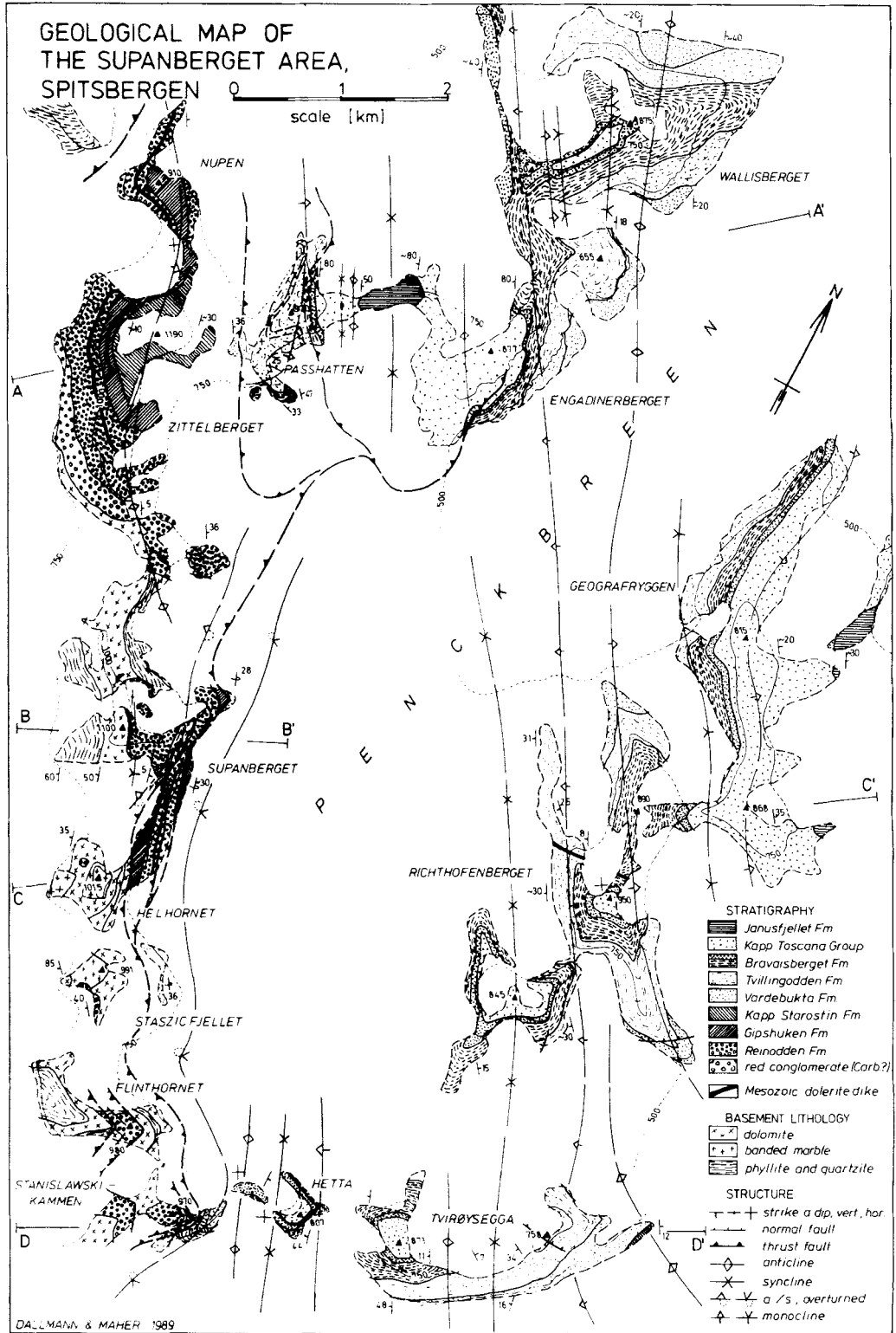


Fig. 3. Geological and structural map of the Supanberget area. Discussion in the text.

belt is exposed in the central ridge, within the mountains Nupen, Zittelberget, Supanberget, Helhornet, Staszicfjellet, Flinthornet, and Stanislawskikammen (Fig. 3). Its lowermost exposed thrust overlies overturned Triassic and Upper Permian strata, and can be traced along the west side of Stanislawskikammen to Supanberget (Figs. 3, 5, 6, and 7), but does not reappear in the mountains to the north. The regional relationship suggests, however, that the incipient thrust ramp at Engadinerberget (Fig. 8) may be related to this thrust system, as indicated in Fig. 4 (section A). Also, the continuity of the structures between Engadinerberget and Richthofenberget argues against the interpretation that the thrust could turn NE and continue beneath the glacier (Penckbreen). Although the map (Fig. 3) would leave room to draw the regional folds with a thrust offset below Penckbreen, the straight-forward continuation of their axial traces does at least not permit a significant offset (compare Figs. 3 and

10). In any case, the thrust offset decreases significantly in the Passhatten-Engadinerberget area (Fig. 3).

On either side of the thrust, sandstones and dolomites are strongly tectonized over a thickness of tens of meters. The overlying carbonate rocks of the lower part of the Gipshuken Formation are overturned and upward bounded by another, obliquely cutting thrust fault at the NE end of Supanberget (Fig. 5). To the south, this fault cuts up the mountain side, but down section into the Reinodden Formation due to an oblique cross-section view from structures more to the east in the northern portions to structures more to the west in the southern portions. A higher thrust splay separates a lower, overturned from an upper, upright slice, each consisting of the Reinodden and basal Gipshuken Formations (Figs. 3, 4 – section B, 5, and 6).

Reinodden strata above these thrusts are locally overturned again. These overturned beds re-

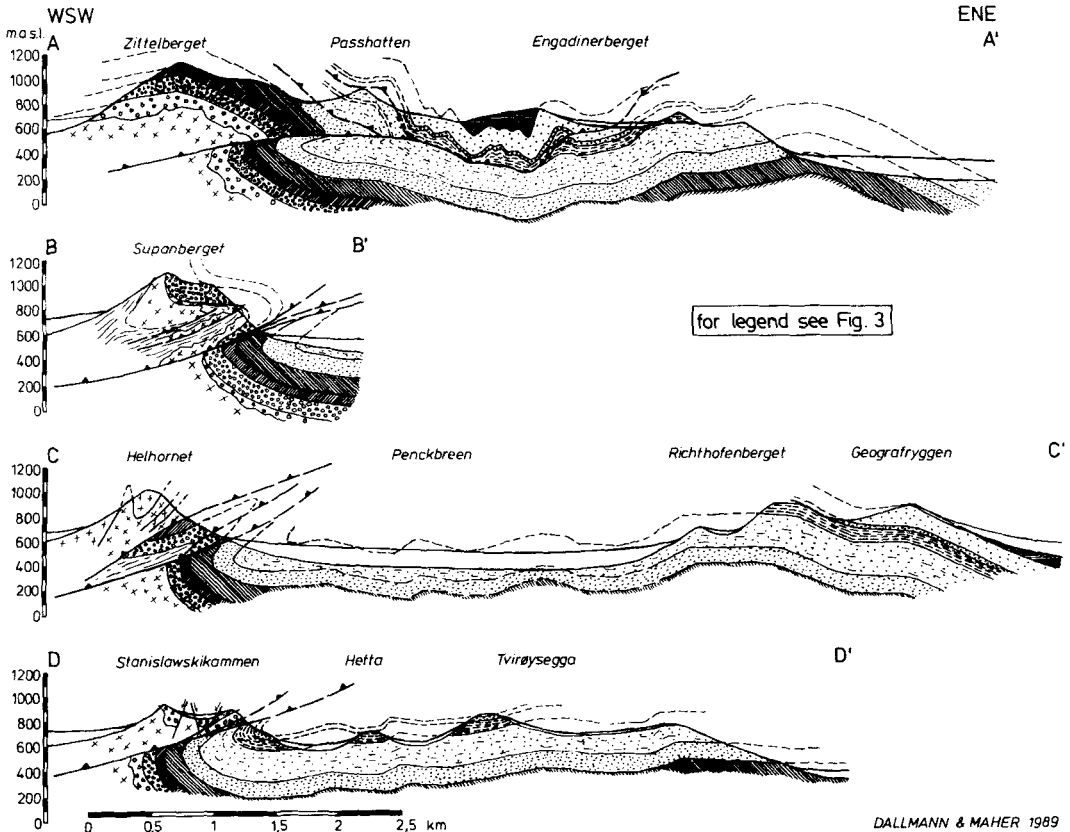


Fig. 4. Geological cross sections through the Supanberget area. Positions indicated in Fig. 3. Discussion in the text.

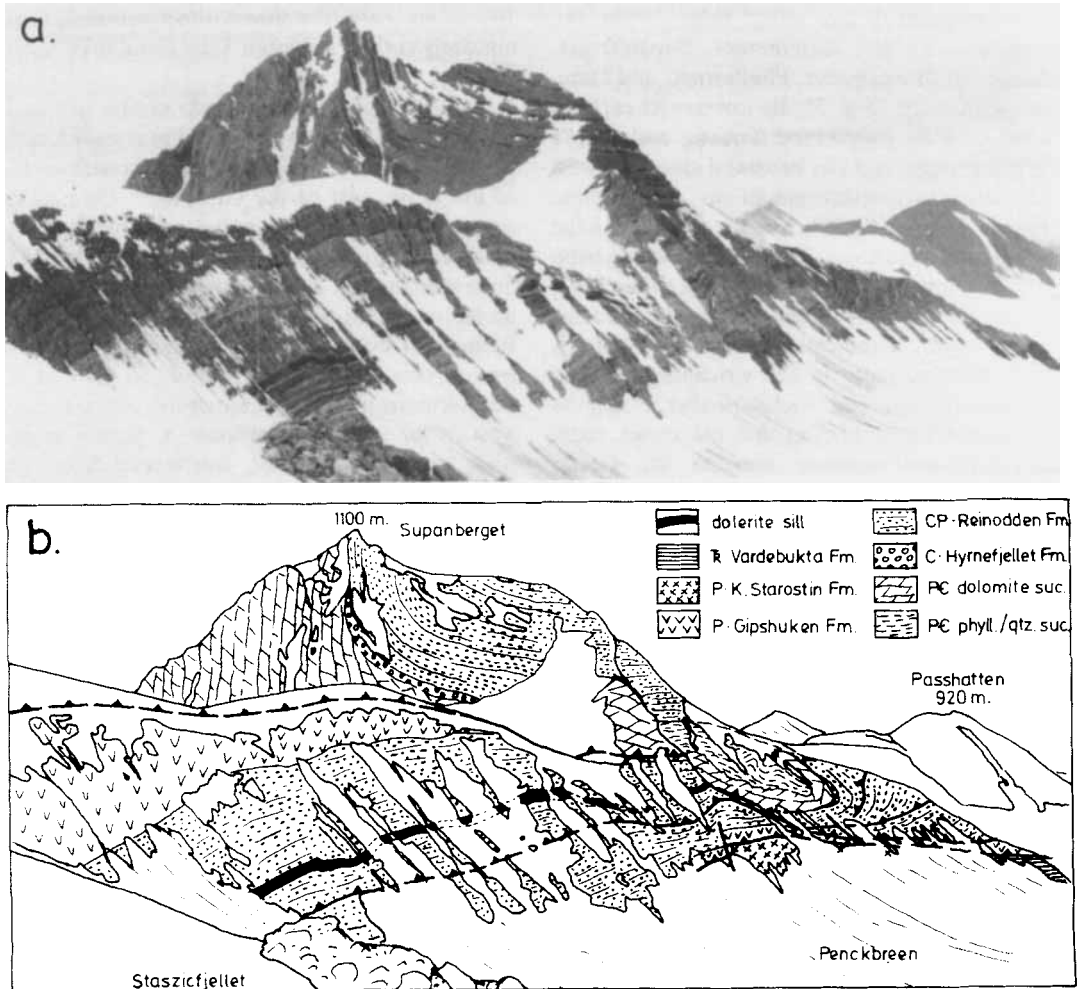


Fig. 5. Oblique view (a) and geological interpretation (b) of Supanberget, seen from the basal thrust in front of Staszicfjellet towards NNW, showing the basement-cored, tight fold with the lower limb dissected by thrust faults.

present the lower limb of a recumbent fold with a NW-SE trending subhorizontal axis. The core of this fold is made up of basement rocks including both the dolomite and the phyllite/quartzite units, which are deformed by internal thrusts (Figs. 3, 4 – section B, 5, and 6). The basement/cover contact is irregular and depositional, with local paleokarst depressions filled with red conglomerates at the base of the Carboniferous strata. The upper limb of the recumbent fold bends into a vertical position in the upper region of Supanberget (Figs. 4 – section B, and 5).

To the north, at Zittelberget, the Carboniferous/Permian strata form a northeastward dipping monocline (Fig. 4) which is thought to be

the continuation of the fold structure on Supanberget. The basement rocks in these folded, but – at macro-scale – unfaulted parts of the structure belong solely to the dolomite succession.

South of Supanberget, exposures are less continuous. From Helhornet to Stanislawskikammen, only basement rocks along with half-graben structures, filled with Carboniferous red conglomerates, overlie the basal thrust. The discontinuous distribution of Carboniferous red beds and their coarse clastic character in the study area lead us to assume a Carboniferous age of the graben structures. The basement rocks, however, contain one to two more steeply dipping thrust faults, indicating that the imbrication structures

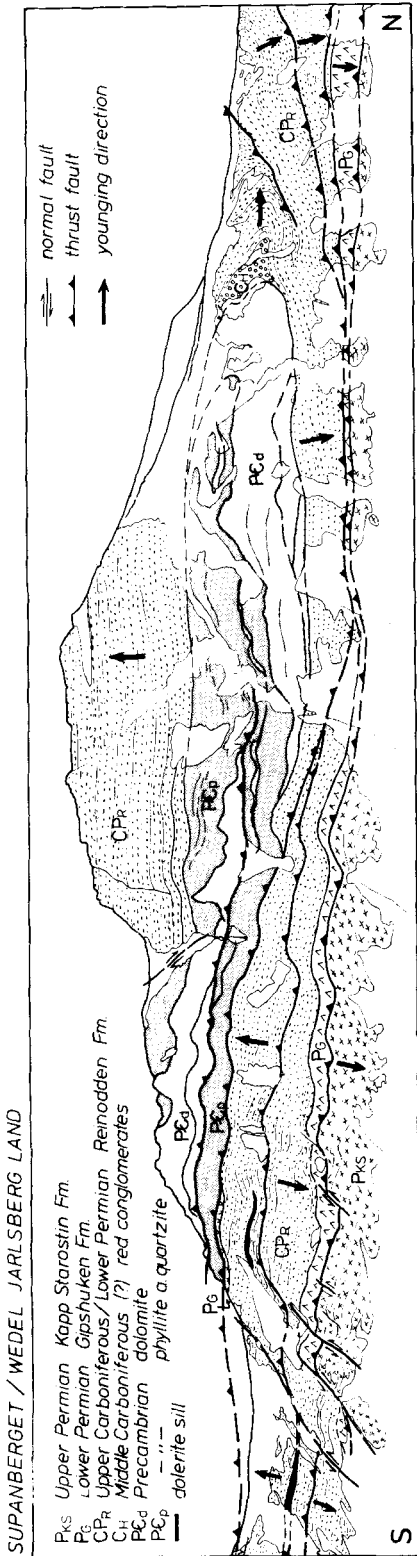


Fig. 6. Geological interpretation of the front view of Supanberget (towards W), indicating imbrication of a basement-cored, tight fold.

of the Supanberget thrust system are continuous to the south (Figs. 3 and 4 – sections C and D). Also, the unconformable contact between the basement rocks and red conglomerates is overturned, suggesting a continuation of the highest overturned fold structure on Supanberget.

*The foreland zone.* – Two ridges surrounded by glaciers extend from the central ridge north-eastward into the foreland zone, where mainly Triassic strata are exposed. The northern ridge is composed of Passhatten, Engadinerberget, and Wallisberget, the southern one of Hetta, Tvirøysegga, Richthofenberget, and Geografryggen. Major fold structures are continuous from one ridge to the other, indicating that no macroscopic thrust fault is hidden beneath the glaciers in between (Fig. 3).

The overturned Triassic strata underlying the basal thrust of the central ridge can be observed to turn back into right-way-up horizontal orientation between Stanislawskikammen and Hetta (Fig. 4 – section D). To the NE along the ridges of Hetta and Tvirøysegga, strata are folded with a sub-horizontal enveloping surface. Folds tend to be monoclinical steps, facing both the NE and SW. At the northeastern tip of Tvirøysegga, the Upper Permian Kapp Starostin Formation just appears in the core of a gently NW dipping antiform (Figs. 3 and 4 – section D).

Similar structures continue through Richthofenberget. The major feature here is a monocline with a SW-down displacement of 200 m in the Triassic strata. To the NE, at Geografryggen, the bedding planes form two further monoclines, the easternmost limb of which represents the western flank of the Tertiary central basin of Spitsbergen (Figs. 3 and 4 – section C).

At Passhatten, the basement-involved thrust is absent and none of the outcropping strata are overturned. Within the Triassic strata of the monoclinical structure of Zittelberget and Passhatten, however, there are décollement-type folds with minor faults. To the east is a tight synclinorium at Engadinerpasset (Fig. 4 – section A). From here to the NE, structures are continuous with the southern ridge. On the major SW dipping monocline at Engadinerberget, a smaller-scale NE directed complex thrust ramp is exposed (Fig. 8) (Różycki 1959). The structural high between this monocline and the NE dipping monoclinical flank of the central basin at Wallisberget is composed of box folds (Fig. 4 – section A).

## Discussion

### *Thrust geometry*

The basement-involved part of the described structure is an imbricate fan developed within the core of a tight fold. The thrust system is blind or almost blind to the north and east, whereas its southern continuation is not known due to the extensive glacial cover (it may continue all the way to Hornsund, c. 35 km). The basal thrust, at which basement rocks are thrust over Paleozoic and Triassic strata, is continuous across the study area, whereas the imbricate splays cannot be traced laterally (Fig. 3). Along the southern half of the Supanberget eastern face, the middle one of the three exposed thrusts probably forms a splay between the two others, with the upper branch line exposed (middle part of Fig. 6). Alternatively, the thrusts at Supanberget may be part of a duplex structure with two horses exposed (terminology after Boyer & Elliott (1982)).

Structures at Passhatten and the western part of Engadinerberget overlie the Supanberget thrust system (Fig. 4). Here, Triassic and Jurassic strata are folded at a short wavelength, suggesting a décollement zone at a low depth, i.e. within shaly parts of the Sassendalen Group. Elsewhere in the fold belt, comparable structures were recognized above décollement zones (Maher et al. 1986; Dallmann 1988a). The décollement may – as the most simple model – be the subsurface continuation of the Supanberget thrust system. The ramp structure at Engadinerberget (Fig. 8), where minor thrusts ascent from the Bravaisberget Formation shales through the overlying sandstone sequence into the Tschermakfjellet Formation shales, has likely a ramp-flat geometry associated with the décollement. This interpretation (Fig. 4 – section A) easily explains the observed surface structures. Possible alternative interpretations (that we consider less likely and do not address further) would be that the Supanberget thrust system terminates at a tip line further west, and that the detachment zone beneath Passhatten-Engadinerberget is the surface continuation of some deeper rooted structure.

A minimum estimate of shortening within the Zittelberget-Engadinerberget area can be made by measuring the shortening accommodated by the fold structures overlying the thrust, which is about 500–750 m (sinuous-bed estimate). (This amount must equal the sum of the transport along

the thrusts and the shortening by drag folds beneath the thrust.) A possible larger thrust displacement would imply that there have to be further, not observed surface structures in the foreland, e.g. bedding parallel thrusts, or backthrusts in the Passhatten area (compare Fig. 4 – section A). Both types of structure have been observed further north in the fold-and-thrust belt (Dallmann 1988), and their possible existence must also be considered here, because it could greatly increase the amount of shortening related to the thrust system.

Further south, in the area between Supanberget and Stanislawskikammen, it is possible to estimate a minimum amount of shortening by matching stratigraphic units across the thrust. It is greatest at Stanislawskikammen (Fig. 4 – section D), where thrust displacement is at least 1 km. An additional amount is accommodated by drag folding.

Structures at the southern ridges between Hetta and Geografryggen (Figs. 3 and 4 – sections C and D) and their northerly continuation at the eastern part of Engadinerberget and Wallisberget (Figs. 3 and 4 – section A) are clearly situated at a structural level lower than the Supanberget thrust system. Here, the Triassic strata are folded at km-scale wavelengths. Folds tend to be composed of monoclines, box folds, etc. The geometry is very similar to a fold pattern resulting from subsurface detachments with ramp-flat geometries as discussed by Gretener (1972) and Suppe (1983) (Fig. 9). A possible detachment zone would, however, be situated at a greater depth, as many of the Permian strata are involved in the folding (Fig. 4 – section D). This is clear from mapping in adjacent areas to the south (Rózycki 1959; Birkenmajer 1964).

It is, however, not easy to find lithologies beneath the Permian strata suited to accommodate the long flats of such a detached thrust fault. While detachments in the northern part of the fold-and-thrust belt often are developed within gypsum layers of the Giphshuken Formation (Harland & Horsfield 1974; Maher 1988a), gypsum or anhydrite seems almost to be absent in the present area. The shaly layers in the Carboniferous to Lower Permian succession observed at Zittelberget and Supanberget are quite thin and not continuous. On the other hand, attenuating shaly beds could be the reason for the relatively frequent ramping of the thrust fault as constructed in Fig. 9.



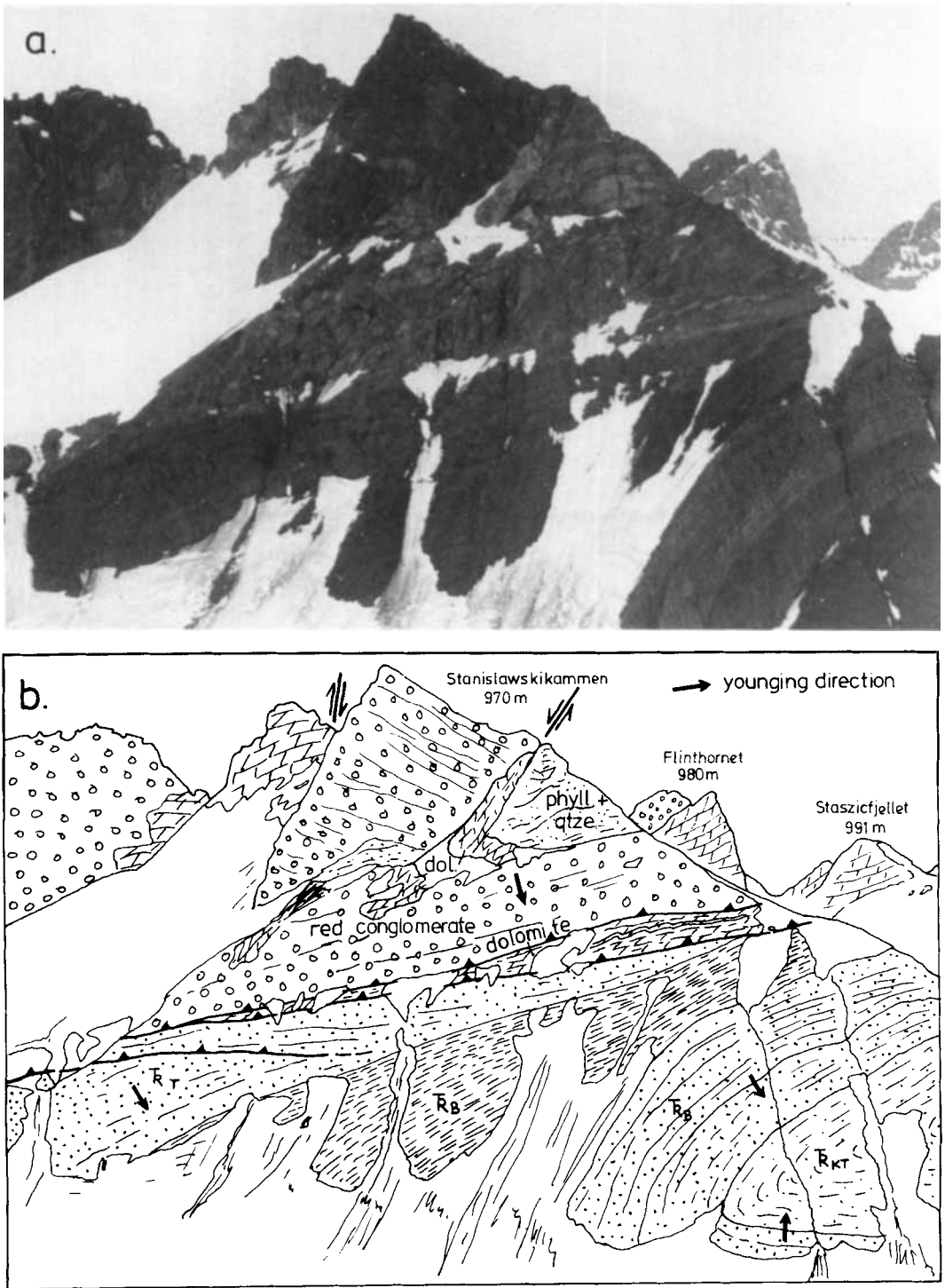


Fig. 7. Side view (a) and geological interpretation (b) of Stanislawskikammen, seen from helicopter towards NW. The structure represents basement-involved imbrication and drag folding below the basal thrust fault.

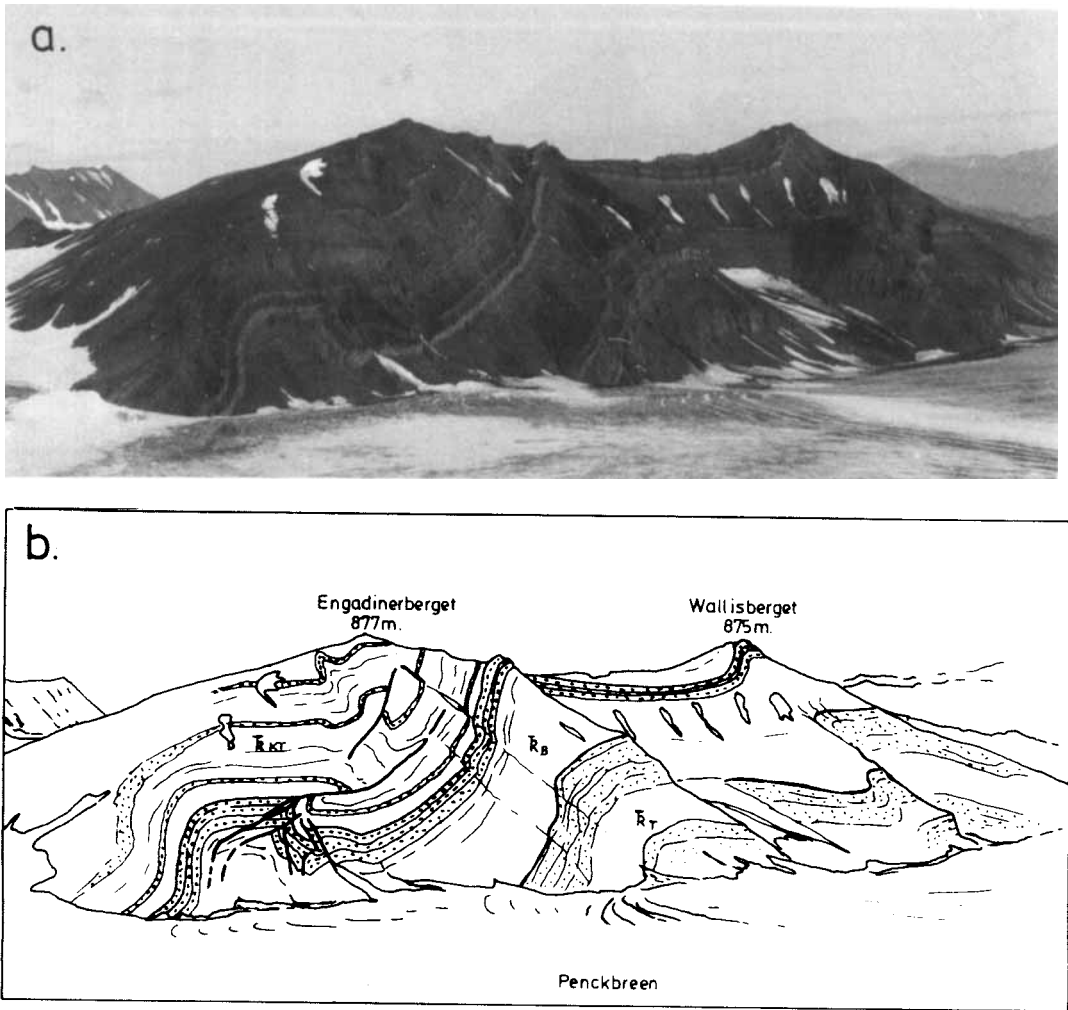


Fig. 8. Oblique view (a) and geological interpretation (b) of Engadinerberget, seen from helicopter towards NNW. The structure represents an incipient thrust system with a ramp-flat geometry, and is probably part of the foreland continuation of the Supanberget thrust system.

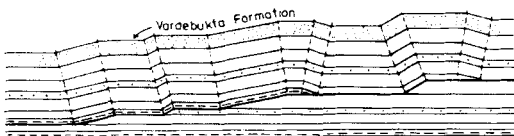


Fig. 9. The structural contour of the Triassic Vardebukta Formation at Hetta and Tvirøysegga (Fig. 4 - section D), explained by an underlying detachment with a ramp-flat geometry. The indicated bedding units are extrapolated from the geometry of the surface fault-bend folds, and are not meant to show the real stratigraphy, which is uncertain because of the lateral inconsistency of the Late Paleozoic strata. The depth of the detachment is schematic.

Other possible candidates for a subsurface detachment are shaly layers of the Lower Carboniferous Billefjorden Group, or even phyl-lites of the Vendian Gåshamna Formation (basement), both common stratigraphical units in the area north of Hornsund (Birkenmajer 1964, 1978).

The orientation of the shortening direction and the regional fold axis is documented in Fig. 10. The horizontal fold axes oriented parallel to the trend of the 300 km long fold belt and the thin-skinned style are most easily explained by for-

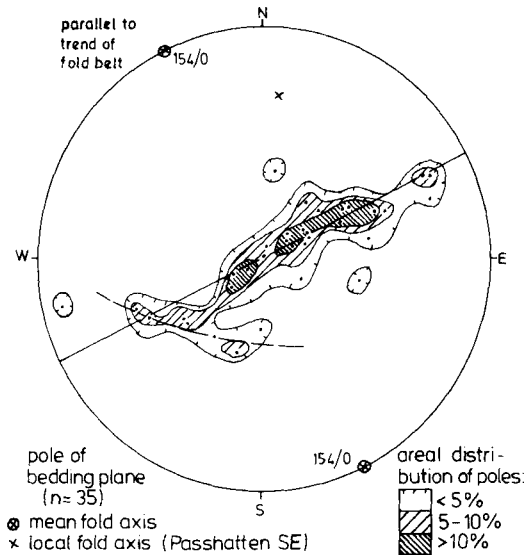


Fig. 10. Stereographic equal area projection of poles to bedding planes in the cover strata of the Supanberget area (Fig. 3), indicating deformation by convergent tectonics. The mean regional fold axis is horizontal and parallel to the trend of the fold belt. The deviating poles in the SW are measured along one local fold at Passhatten (SE ridge), which probably has developed by differential movement along the over- and underlying detachments.

mation in a convergent regime. Evidence for block rotation required by other regimes (e.g. dextral transpression) is lacking in this area.

#### Nature of basement involvement

A striking phenomenon is that the lithologic layering in the metamorphic basement apparently is not folded in the same way as in the cover strata. Folds observed in the basement rocks are of different style and orientation, and are therefore supposed to be older, probably of Caledonian age. In one case (N face of Supanberget), folds within the basement are clearly truncated by the Caledonian unconformity. Similar relations can be observed elsewhere (e.g. Handley 1983).

We therefore suggest that the basement rocks were dominantly deformed by fracturing, slip along foliation, and faulting during the Tertiary deformation episode.

In the massive dolomites of the basement, the fracture pattern is quite complex, and a statistical analysis has not yet been done. However, there is an obvious relation between the character of anisotropy of the basement rocks and the style of

deformation of the adjacent cover rocks. Where massive dolomites underlie the unconformity, the latter are folded gently or form huge, open flexures, and may be dissected by a single, brittle thrust fault (Fig. 4 – sections A and B). This style of deformation has also been described from a place further north in Wedel Jarlsberg Land (Berzeliustinden–Dallmann 1988a).

Where the banded phyllite/quartzite sequence underlies the unconformity, their foliation controls the thrust direction (or is rotated into the thrust direction), and folds of the overlying strata are tight and overturned (Fig. 4 – sections B and C). Internal thrust faults within the basement rocks can be observed (Figs. 4 – section B, and 6). In areas where the Supanberget imbricate thrust system can be observed to dissect the unconformity down into the basement, phyllites always form part of the basement lithology (Figs. 3 and 4 – section D).

As one would expect, contrast in the degree of basement anisotropy development (phyllite/quartzite versus dolomite) and a favourable orientation control the deformation style in the immediately overlying cover strata. Areas with strongly developed basement anisotropies (phyllite/quartzite successions) are therefore expected to show more complex deformation in the cover strata.

## Conclusions

The Supanberget area is one of the few areas in Wedel Jarlsberg Land where the structural style of the basement-involved zone of the Tertiary fold-and-thrust belt and the transition to the foreland structures can be continuously observed, although the ice cover is extensive. Our structural analysis shows that, as elsewhere on Spitsbergen, structures are of compressive origin, and are similar to those of other marginal fold-and-thrust belts.

The Supanberget thrust system is a basement-involved, laterally discontinuous, imbricate system cutting folded, mostly overturned strata. It turns most likely into a detachment zone with a ramp-flat geometry in the overlying cover strata to the northeast. The minimum shortening associated with this structure exceeds 1 km, but may be considerably greater. Foreland structures indicate at least one further detachment at a greater depth, through which deformation is translated north-

eastward down below the western flank of the Tertiary central basin.

Basement composition and anisotropies clearly influence the structural style as the thrusts emerge from the basement into the cover. A well-developed anisotropy is thought to give rise to a more complex thrust system within the adjacent cover strata. In that way, basement anisotropies may locally control lateral structural changes in the fold-and-thrust belt.

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