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COMPILATION MAP, SUMMARY AND BIBLIOGRAPHY

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Andresen, Arild: Univ. Oslo, Institutt for geologi, Pb. 1047 Blindern, N-0316 Oslo
Bergh, Steffen G.: Univ. Tromsø, Institutt for biologi og geologi, N-9037 Tromsø
Dallmann, Winfried K.: Norsk Polarinstitutt, Pb. 5072 Majorstua, N-0301 Oslo
Maher, Harmon D., Jr.: Univ. Nebraska, Dept. of Geography and Geology, Omaha, USA-Nebraska 68182-0199
Ohta, Yoshihide: Norsk Polarinstitutt, Pb. 5072 Majorstua, N-0301 Oslo

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Cover photo by W.K. Dallmann:
Folded Triassic sandstones and shales within the interior part of the Tertiary fold-and-thrust belt at Curie-Sklodowskafjellet, Wedel Jarlsberg Land, Svalbard.

CONTENTS:

INTRODUCTION

The West-Spitsbergen foldbelt (Svalbard) of Tertiary, possibly in part of Late Cretaceous age, has been addressed in the geological literature since the early part of this century (De Geer 1909, 1912, 1919; Holtedahl 1913; Hoel 1925; Orvin 1934). Frebold (1935) and Orvin (1940) presented the first summaries of the foldbelt structures. A second stage of exploration started after 1960, when Svalbard was rediscovered in light of newly established plate tectonic theory, and the foldbelt was related to relative movements between the Greenland and European (Barents Shelf) plate boundaries. Harland (1969), Harland & Horsfield (1974), Lowell (1972), Birkenmajer (1972a,b) and Kellogg (1975) considered it to be a strike-slip (or transpressive) orogen developed at an intracontinental transform margin. Investigations starting in the 1980s, however, show that most structures within the foldbelt must be ascribed to convergent tectonics, and deformation extends much farther eastward than previously thought (for numerous references see section *Outline of the Tertiary fold-and-thrust belt of Spitsbergen*).

In recent years, the understanding of a multiple phase evolution of the West-Spitsbergen foldbelt has developed. Early observations of local Devonian folding (Vogt 1928; Schenck 1937; Orvin 1940) have been expanded to the recognition of several phases of variable Devonian and Carboniferous deformation, divergent or transcurrent (Birkenmajer 1964, 1981; Harland 1969; Gjelberg & Steel 1981; Steel & Worsley 1984, Dallmann 1992) and convergent (Birkenmajer 1964, 1975; Welbon & Maher 1991; Maher & Welbon 1992; Dallmann 1992; Manby & Lyberis 1992; Chorowicz 1992). One of the critical problems of interpreting the Tertiary structural development is therefore a proper discrimination of Tertiary versus older structures. For the basement part of the foldbelt, the problem of distinguishing Caledonian from younger structures is an additional one.

The term "Tertiary fold-and-thrust belt of Spitsbergen", frequently used in the regional geological literature, is thus that part of the West-Spitsbergen foldbelt that suffered Tertiary overprint or Tertiary first-time deformation. It is congruent with earlier deformed parts in many places, though the zones of maximum deformation seem to have changed their position from one deformation episod to the next.

The challenge of solving the foldbelt structure is to relate convergent structures to the plate tectonic transform boundary which they developed close to, and to solve kinematics and mechanisms that locally transpose transpression into normal-to-boundary convergence. This seems to be a fundamental problem of tectonics, of which Svalbard provides a well-exposed and comparatively well-accessible study area.

The present map is the first complete compilation of the Tertiary fold-and-thrust belt structure at a regional map scale. It covers southern and central Spitsbergen, the area from which known Tertiary deformation is reported. There may be minor Tertiary structures farther north, although documentation describes only folds of Devonian and older age (Vogt 1928; Orvin 1940; Gee & Moody-Stuart 1966; Reed et al. 1987; Manby & Lyberis 1992; Chorowicz 1992). The maps are preliminary. Users of this map and report are encouraged to send us comments, corrections and up-dated maps of areas they are familiar with. New data will be considered for future reports or a possible colour print.

Besides an explanation of the structural elements shown on the map, this map description presents a brief overview of the tectonic setting and age, geometric properties, types of structures, shortening estimates and kinematic interpretations of the Tertiary fold-and-thrust belt. No importance is attached to discussing models, but references to the published literature are extensively made.

MAP DATA AND EXPLANATORY REMARKS

Sources, compilation and accuracy of the geological base map

The Tertiary fold-and-thrust belt map has been compiled from a variety of sources. Norsk Polarinstitutt's bedrock maps, some of which still are under preparation, were used for the majority of map boundaries and the position of most of the tectonic boundaries. The positions of boundaries have been corrected where we had access to new data from field work, mostly by Norsk Polarinstitutt and the Universities of Oslo, Tromsø and Münster (Germany). References to material used which is not included in the references given on the individual regional geological maps of Norsk Polarinstitutt, are given in the descriptive chapter *Outline of the Tertiary fold-and-thrust belt of Spitsbergen*.

The map pattern had to be generalized to match scale reduction from 1:100,000 to 1:200,000 and in order to make the map readable in black-and-white. We have omitted minor occurrences of strata and minor tectonic features which, according to our opinion, are not critical for the overall structural interpretation. Where necessary, we have exaggerated the occurence of critical strata, or emphasized the presence of critical tectonic boundaries. For more exact geographic position, the user is referred to the regional maps listed in the bibliographic part, or is asked to contact Norsk Polarinstitutt for still unpublished map material.

To make the map easier to use in black-and-white, we have connected boundaries across minor glaciers and, partly, fjords. We are aware that this reflects our own interpretations, although we have dashed all uncertain connections, or even added question marks, where we consider other interpretations as possible. We have, however, not tried to calculate the exact positions of boundaries below ice and water. These boundaries are only meant to show clearer the principal structure.

Explanation of map elements

Stratigraphy

$T_1/T_2/T_3$ Tertiary strata consist of alternating sandstones, siltstones, shales and minor conglomerates. Coal seams occur in the lower- and uppermost formations (Firkanten and Aspelintoppen Formations). They have been deposited in several basins, the large Central Tertiary Basin and several smaller basins along the west coast. The base of the Tertiary strata in the Central Tertiary Basin is a regional, low-angle unconformity with a hiatus comprising all of the Late Cretaceous and the Early Paleocene (i.e. an interval of 35-40 Ma.), while it rests nonconformably on Caledonian basement strata in the west coast areas.

We have used an unconventional subdivision of the Tertiary strata. T_1 shows the lower 3 Formations of the Central Tertiary Basin (Paleocene, 600-800 m) that have easterly source areas, while T_2 indicates the 2 overlying formations (Lower Eocene, 260->700 m) with westerly source areas presumably formed during the uprise of the Tertiary fold-and-thrust belt. T_3 is used for Middle/Upper Eocene to possibly Oligocene strata, i.e. the Aspelintoppen Formation (up to 700 m preserved) and probably contemporaneous deposits within smaller basins along the west coast. The T_2/T_3 boundary thus marks the approximate age, where deposition of Tertiary strata in the west coast basins is supposed to have started (Manum & Throndsen 1986).

K includes the Barrêmian to Albian Helvetiafjellet and Carolinefjellet Formations which behave structurally as a comparatively coherent and strong unit, together with the overlying Tertiary strata. The lower formation is dominated by sandstones, while in the upper one sandstones and shales alternate. Thickness: 250 m (outer Isfjorden) to ca. 1200 m (Kvalvågen). The entire Late Cretaceous interval is represented by a hiatus.

dolerite Dolerite intrusions occur mostly as sills. Dykes are observed, but are normally too small for the present map scale (exceptions in the Agardhbukta area and south of Sassenfjorden). They have a (possibly latest Jurassic to) Early Cretaceous age (Burov et al. 1977) and are emplaced within increasingly younger strata to the east.

JK shows the Middle Jurassic to Hauterivian Janusfjellet Formation which mainly consists of shales (black paper shales in the lower part) and siltstones, coarsening to sandstones in the upper part. It is a critical unit for deformation, as it accommodates abundant shear stress by forming thrust flats with associated décollement zones and fold structures. The primary thickness varies probably from 400 to 700 m.

TR(1/2) "Triassic" strata include here deposits of Triassic to Early Jurassic age, the Sassendalen and Kapp Toscana Groups, which are alternating sandstones and shales. The Jurassic part is strongly condensed. Where the scale permits subdivision, this sequence is subdivided at the base of the Bravaisberget Formation or Botneheia Member (upper part of the Sassendalen Group), which consist of bituminous shales and represents a similar zone of low shear strength as the Janusfjellet Formation. Thickness: 200 m (Sørkapp) to 700 m (Sassendalen).

P The Late Permian Kapp Starostin Formation (the only representative of the Tempelfjorden Group on Spitsbergen) constitutes a competent unit of mostly silicified carbonate rocks and cherts. Thickness: 460 m in northern areas, diminishing southward and attenuating to 0-6 m south of Hornsund; ca. 400 m again on Øyrlandet/Sørkappøya.

CP The Gipshuken Group (including the earlier defined Charlesbreen and Campbellryggen Groups) of Middle Carboniferous to Early Permian age is heterogenous and consists of a lower clastic sequence (conglomerates, red beds) and an upper carbonate sequence (limestones and dolomites, often alternating with clastic beds).

Deposits of the Gipshuken Formation (Early Permian) and Ebbadalen Formation (Middle Carboniferous) contain gypsum and anhydrite layers which are critical in controlling deformation. Important occurrences of gypsum are separately marked on the map. The thickness of the group varies strongly due to the configuration of sedimentary basins and attains more than 1600 m in the Billefjorden area. The base is often seen as an angular unconformity, either above tilted or folded Lower Carboniferous, Devonian, or Caledonian basement.

C indicates the Early Carboniferous clastic Billefjorden Group which has been deposited in grabens along the west coast and east of Billefjorden. It consists of quartzitic sandstones and some coaly shales. The maximum thickness exceeds 1000 m (Sørkapp Land).

D Devonian clastic deposits, often multicoloured or red beds, occur in Late Caledonian grabens in the northern part of the map and in the Sørkapp-Hornsund area with strongly varying preserved thicknesses. They are bounded by faults and angular unconformities.

G Caledonian granite intrusions

OS Middle/Late Ordovician and Early Silurian strata form the yougest rocks of the Caledonian basement and occur in the Sørkapp-Hornsund and the St. Jonsfjorden areas. At Hornsund, the clastic/carbonaceous Arkfjellet unit of not well-determined age and thickness is ascribed to this interval. Silurian rocks at St. Jonsfjorden (Bulltinden Formation) constitute 1600 m of coarse clastic sediments, including minor shales and limestones in the upper part.

CO In the Hornsund-Sørkapp area, the Cambrian Sofiekammen Group and the Ordovician Sørkapp Land Group consist of up to ca. 2300 m carbonate rocks.

PC$_3$ Vendian strata are made up of tilloid diamictites of varying thickness (up to 800? m south of Bellsund), and layers of phyllite. They have mostly attained greenschist facies, but partly sub-greenschist facies metamorphism. The boundary to documented Cambrian deposits is not exposed.

PC$_2$ Pre-Vendian, Late Proterozoic strata (between a Grenvillian unconformity and the Vendian tilloids) consist of mainly greenschist-facies metamorphic rocks of 1-5 km tectonic thickness. They can roughly be divided into a conglomeratic (Slyngfjellet Formation and equivalents), a carbonate-dominated (Höferpynten Formation and equivalents) and a clastic unit (Gåshamna Formation and equivalents) along the west coast of Spitsbergen. Metavolcanites are locally associated with all three different units. On Prins Karls Forland, phyllitic lithologies with quartzites, carbonates and greenschists predominate, and the threefold subdivision is less distinct.

PC$_1$ Pre-Grenvillian strata are not subdivided on the present map. Some units of uncertain age (within the Proterozoic) are included. The rocks consist of different, strongly deformed, but mostly weakly metamorphosed "miogeoclinal" metasediments, mainly schists with intercalated thin, impersistent quartzite and marble layers. The lithostratigraphic order is not established. Fault-bounded units of amphibolite grade metamorphic schists and gneisses occur in places, and there is a distinct unit of basic metavolcanites.

Structure Only structures of Late Mesozoic to Tertiary age are indicated. Older tectonic boundaries without indications of youger reactivation are indicated by the same width lines as rock boundaries.

———— Observed structures of obvious Late Mesozoic/Tertiary age are drawn as lines.

— — — — Suggested structures of Late Mesozoic/Tertiary age are dashed.

—·—·— Observed structures that are of possible Late Mesozoic/Tertiary age are dashed/dotted.

Surfaces

Lines marked as lithological boundaries may be depositional or intrusive contacts, tectonic boundaries older than Late Mesozoic, or less significant tectonic boundaries of Late Mesozoic/Tertiary age that are not indicated as such for reasons of generalization.

500 Structural contour lines (interval 250 m) indicate the approximate depth below sea level of the base of the Tertiary in the Central Tertiary Basin. The lines are mostly based on surface data, though locally accessable bore-hole data have been used. Unpublished seismic data are not considered.

Bedding plane orientations (inclined, horizontal, vertical, overturned), with dip values indicated, represent average orientations for larger areas, not individual measurements. The cross sections are based on more complete data than those given on the map and may help to realize how variable orientations may be in strongly deformed areas. No strikes and dips are indicated in the Caledonian basement and Devonian sediments, because their orientation prior to Tertiary deformation is unknown. Note that orientations in Carboniferous strata may be influenced by both Late Paleozoic and Tertiary tectonics.

Folds

Anticlinal axial trace

Synclinal axial trace

Trace of monocline or structural terrace, curvature convex or concave.

Trace of flexure fold

Trace of overturned anticline / syncline

Dome structure. The symbols are placed approximately on the inflection line. Domes are only indicated in the Central Tertiary Basin where they are thought to be indicators of deformation at lower structural levels.

Intensely folded zone or complex shear zone. These structures are mostly confined to shales and marls, locally with thin sandstone or limestone intercalations that may indicate the internal structure of the zone.

Faults Unless specified differently below, barbs indicate downthrow side of normal faults, whereas teeth point at the overthrust side of reverse faults. In the case of reactivated faults, the youngest suggested movement direction is indicated.

Normal fault

Strike-slip fault. Most observed strike slip displacements are combined with a normal displacement component, i.e. are oblique-slip faults (see below).

Oblique-slip fault. Probable strike-slip faults with a documented normal fault component.

Thrust fault (dip $<45°$)

High-angle reverse fault (dip $>45°$)

Décollement fault

Reactivated older fault. The symbols (barbs, teeth) indicate the type of displacement during reactivation, regardless the original nature of fault. Many ENE-vergent thrusts within the basement strata have little indication of Tertiary reactivation, though it is suggested that many of them have suffered additional offset during the Tertiary.

Fault possibly reactivated during the late Masozoic / Tertiary deformational event.

Fault of uncertain type. In poorly exposed areas, tectonic boundaries may be localized by a disturbed stratigraphical sequence, but the nature of the displacement may be uncertain.

Structure of uncertain type of displacement (normal fault, high-angle reverse fault or flexure) where the downthrow side is recognized (indicated by open squares).

OUTLINE OF THE TERTIARY FOLD-AND-THRUST BELT OF SPITSBERGEN

Tectonic setting

The Tertiary fold-and-thrust belt of Spitsbergen was formed in a dextral, transpressive plate regime, developed along the intracontinental transform margin between the Barents and Greenland Shelves (Fig. 1) during the Paleogene opening of the North Atlantic (Harland 1969; Lowell 1972; Birkenmajer 1972b; Harland & Horsfield 1974; Kellogg 1975). The belt was considered as an example of strike-slip orogen.

This setting was suggested by the necessity of a continental transform off the western margin of Svalbard needed in restoration of the opening of the North Atlantic - Arctic Ocean basin, and the essentially Paleogene age of the foldbelt. On the other hand, the large-scale curved shape of the foldbelt, as then known, seemed to satisfy conditions for wrench tectonics. Lowell (1972) even explained the orogen - without initially using this term - as a large flower structure. He argued that the arrangements of thrusts and en-echelon folds along with a significant involvement of the basement matched structural patterns produced with clay models for transpression and were in contrast with those for convergent orogens.

Talwani & Eldholm's (1977) tracing of fracture zones and magnetic anomalies, several other works based on seismic data (Myhre et al. 1982; Eldholm et al. 1984) and palinspastic plate reconstructions (Srivastava & Tapscott 1986) reliably confirmed the transform setting of the western Svalbard margin during the Paleogene.

Hanisch (1984) considered, as a working hypothesis, a rotational movement of northern Greenland towards the Barents Sea, starting in the Early Cretaceous, to be responsible for some of the foldbelt deformation. The assumption of a rotation pole situated in the Bjørnøya Basin was based on the apparent necessity of a hinge for the Cretaceous opening of the southern and central Atlantic Ocean.

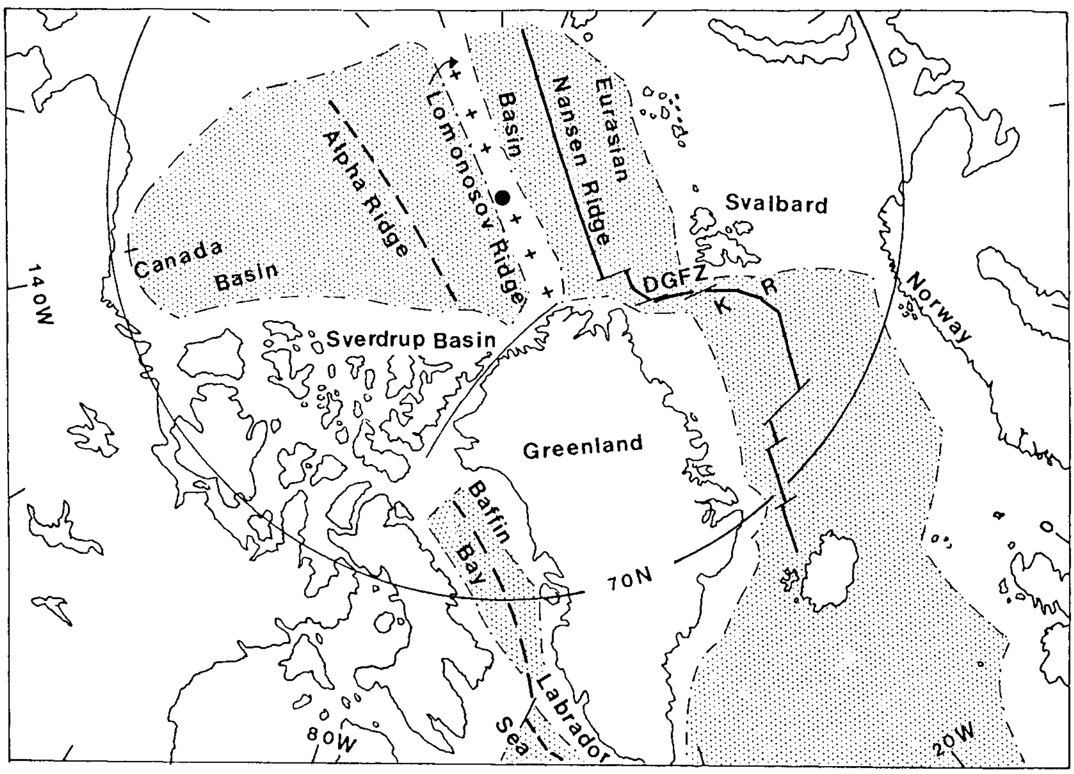

Fig. 1: Map showing the position of Svalbard in relation to the North Atlantic-Arctic Ocean system. Shaded: oceanic crust; thick lines: active spreading ridges; dashed thick lines: extinct spreading ridges; crosses: ridge of continental origin; DGFZ: De Geer Fracture Zone. From Lyberis & Manby (1993b).

This concept has not been developed in the subsequent literature. Still, the presence of thick Cretaceous strata in several basins along the North Norwegian Shelf as far north as to the Tromsø Basin (Eldholm et al. 1979; Hanisch 1984; Spencer et al. 1984) provides evidence for Cretaceous plate-tectonic movements in the Barents Shelf area. Also, another Late Cretaceous event, related to the opening of the Labrador Sea, has been used to explain possible Late Cretaceous deformation of northeastern Greenland in an intracontinental convergent setting (Håkansson & Pedersen 1982). Also Lyberis & Manby (1993a,b) argue for a Late Cretaceous, i.e. pre-transform, age of a great portion of the foldbelt deformation.

Later detailed structural analyses in many areas of Svalbard (e.g. Hauser 1982; Maher 1984; 1988a,b; Dallmann 1988a, 1992; Dallmann & Maher 1989a; Bergh & Andresen 1990; Haremo et al. 1990; Welbon & Maher 1992) suggest that convergent tectonics have been prevailing during much of the fold and thrust development, and general agreement on this was achieved at a symposium on this topic (Dallmann et al. 1988). Yet, there are areas, especially Brøggerhalvøya, where anomalous transport and vergence directions cause difficulties with a simple convergent tectonic model. Earlier interpretations of subsequent convergent and strike-slip events were substituted by a decoupling model, where transpression was partitioned into contemporaneous offshore transform movement and convergent folding, thrusting and uplift of the Svalbard margin (Nøttvedt et al. 1988a,b; Maher & Craddock 1988).

The Tertiary fold-and-thrust belt suffered an overprint of subsequent extensional deformation in connection with the development of a passive continental margin, starting during paleomagnetic anomaly 13 time, after the opening of the Fram Strait between Greenland and Svalbard. This margin is well documented by seismic observations (Myhre et al. 1982; Spencer et al. 1984; Eldholm et al. 1984, 1987; Eiken & Austegard 1986).

Dimensions and directions

The foldbelt is exposed on land for 300 km along strike, from Brøggerhalvøya in the north to Sørkapp in the south. The average trend parallels the continental margin to the west (De Geer Line or Hornsund Fault Zone) and runs $160 \pm 10°$ (NNW-SSE), with a distinct ENE vergence. It is bending to 120° (WNW-ESE) in the northernmost part at Brøggerhalvøya, where the vergence is NNE.

The intensely folded, interior part of the belt with a certain Tertiary deformation age has a maximum exposed width of 30 km in Oscar II Land, while to the south it is only 10-15 km. It attenuates southward in Sørkapp Land, where another fold-thrust zone with similar trend and vergence, the Lidfjellet-Øyrlandsodden zone (Dallmann 1992) occurs 15 km further west and mostly is situated offshore. The entire width of the belt deformed during the Tertiary is up to 175 km, if the following structural domains are included (Fig. 2):

1. The locally redeformed basement high to the west, with an exposed 5-45 km width.
2. Structures in strata of the Tertiary Forlandsundet Graben situated within the western basement high (Gabrielsen et al. 1992; Kleinspehn & Teyssier 1992).
3. The Billefjorden lineament in east-central Spitsbergen, where thrusts generated in the interior zone emerge from below the Central Tertiary Basin and interact with movements along the Billefjorden Fault Zone (Haremo et al. 1990), 40-65 km east of the interior part of foldbelt.
4. The Lomfjorden-Agardhbukta area, where the mechanical connection with the Tertiary fold-and-thrust belt is less documented, though probably present (Andresen et al. 1992a; Miloslavskij et al. 1992a). This zone is situated 25-45 km east of the Billefjorden Fault Zone.

The 55 km wide and 200 km long Central Tertiary Basin, the foreland basin of the foldbelt, is situated between the interior part of foldbelt and the eastern deformed areas 3. and 4., shows only locally traces of Tertiary deformation.

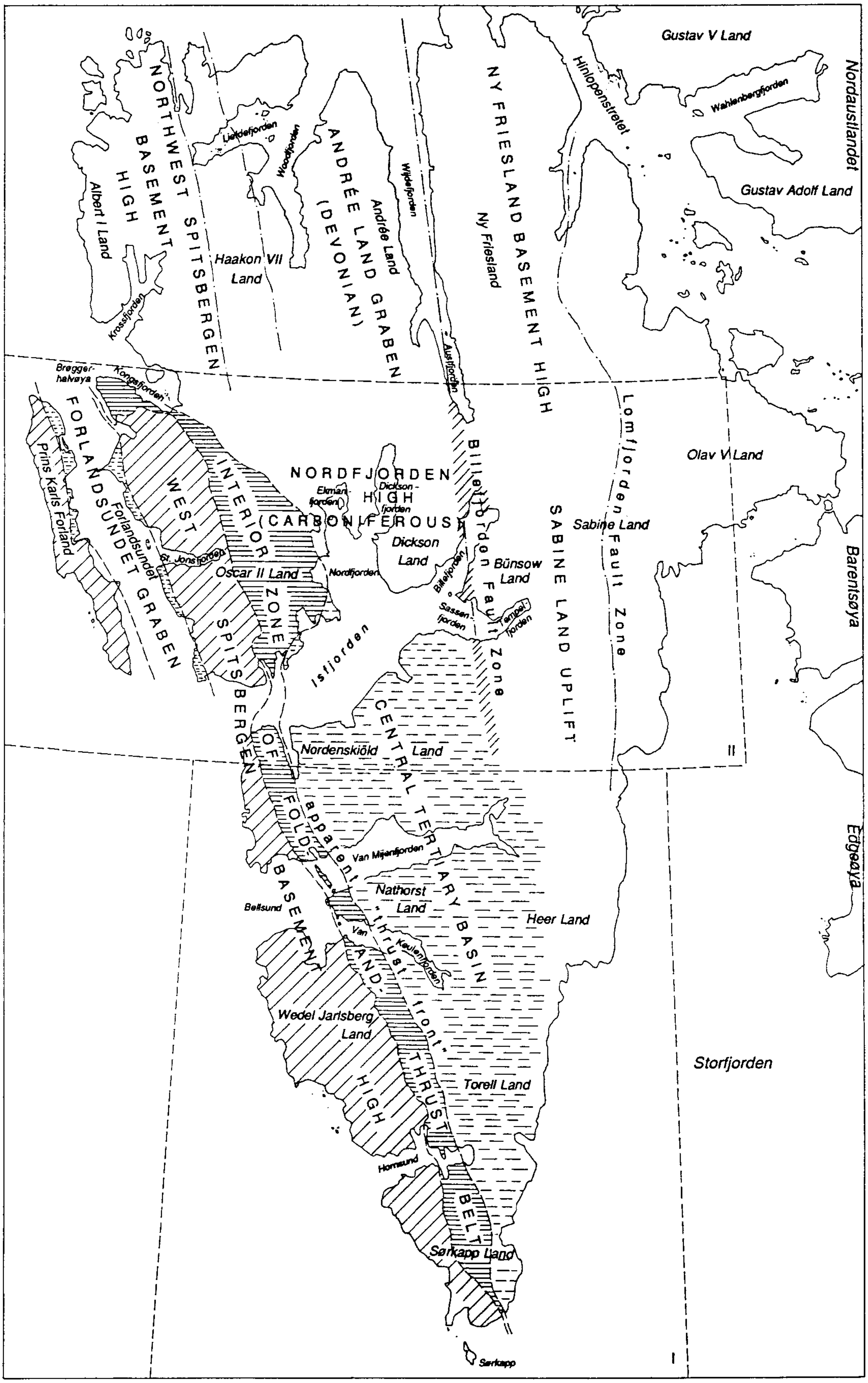

Fig. 2: Geographical extent of the Tertiary fold-and-thrust belt of Spitsbergen and its general structural subdivision. Frames marked I and II show the location of the two map sheets.

Structural subdivision, characteristics and types of structures

Interior part of foldbelt

The interior part of the Tertiary fold-and-thrust belt was developed along older tectonic lineaments defining the eastern boundary of a basement uplift paralleling the western coast of Spitsbergen (Steel & Worsley 1984; Welbon & Maher 1992; Maher & Welbon 1992; Dallmann 1992). Along most of its length, from interior Wedel Jarlsberg Land to northern Oscar II Land, the structures suggest a distinct cross-strike two- or threefold zonation (Maher 1988a; Dallmann & Maher 1988, 1989a,b).

The western zone is characterized by thick-skinned tectonics and consists of several laterally overlapping, basement-involved thrusts with associated folds. Wedge insertion and associated backthrusting occurred frequently and were favoured by the presence of black shale formations with low shear strengths (JK and TR2) (Dallmann 1988a; Dallmann & Maher 1989a; Dallmann 1992).

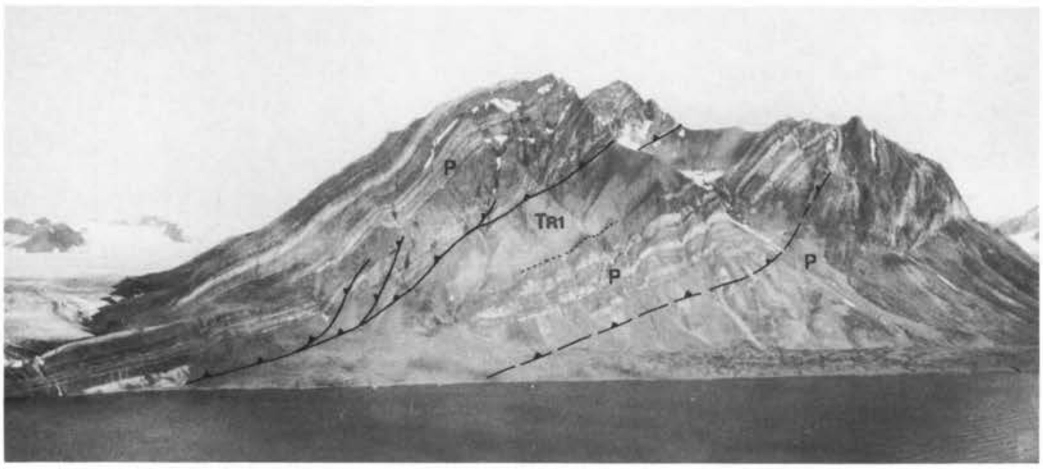

Fig. 3: Deformation in the interior part of the foldbelt: Mediumfjellet in Oscar II Land, viewed from the south. Permian and lower Triassic strata are repeated across a major thrust. At a lower structural level, a blind thrust ends in the core of a fault-propagation fold. From Bergh & Andresen (1990).

The adjacent eastern zone is typically thin-skinned, providing detachments, flat-and-ramp thrust geometries and associated fold types (Figs. 3 and 4; Maher 1988a; Maher et al. 1989; Dallmann & Maher 1989a; Bergh & Andresen 1990; Wennberg 1990; Bergvik 1990; Welbon & Maher 1992, Maher & Welbon 1992; Wennberg et al. 1992). In Oscar II Land, this eastern zone can be subdivided into a proximal one showing folds with subhorizontal enveloping surfaces (probably developed on thrust flats), and a distal one where the thrust system climbs up to higher detachment levels (Maher 1988a; Bergh & Andresen 1990).

As the geometry of the Tertiary basin strata to the east shows, structures on northern Spitsbergen generally plunge to the south, while structures on southern Spitsbergen plunge to the north. The east-west trending axis separating the differing plunge directions runs through southern Nordenskiöld Land and Heer Land. This implies that the most complicated foldbelt structures (Oscar II Land/Brøggerhalvøya and Wedel Jarlsberg Land/Hornsund) are found at structurally deeper levels (Figs. 3 and 4), while the apparently simpler deformation (Nordenskiöld Land) is found at structurally higher levels of the orogen (Fig. 5). Also, the differing lvels of exposure may account for the differing width of the foldbelt structure.

On Brøggerhalvøya, the northern termination of the foldbelt outcrops, the Tertiary fold-and-thrust belt becomes very narrow, lacks a distinct zonation, and deformation is thick-skinned, i.e. characterized by basement-involved thrusts (Manby 1988). Also in the Sørkapp-Hornsund area, the southern termination of the belt, zonation fades out. At Hornsund, the thin-skinned thrust zone disappears. Towards Sørkapp, thick-skinned tectonics also disappear or continue at subsurface, and the interior zone of the foldbelt becomes a single, major flexure (Dallmann 1992).

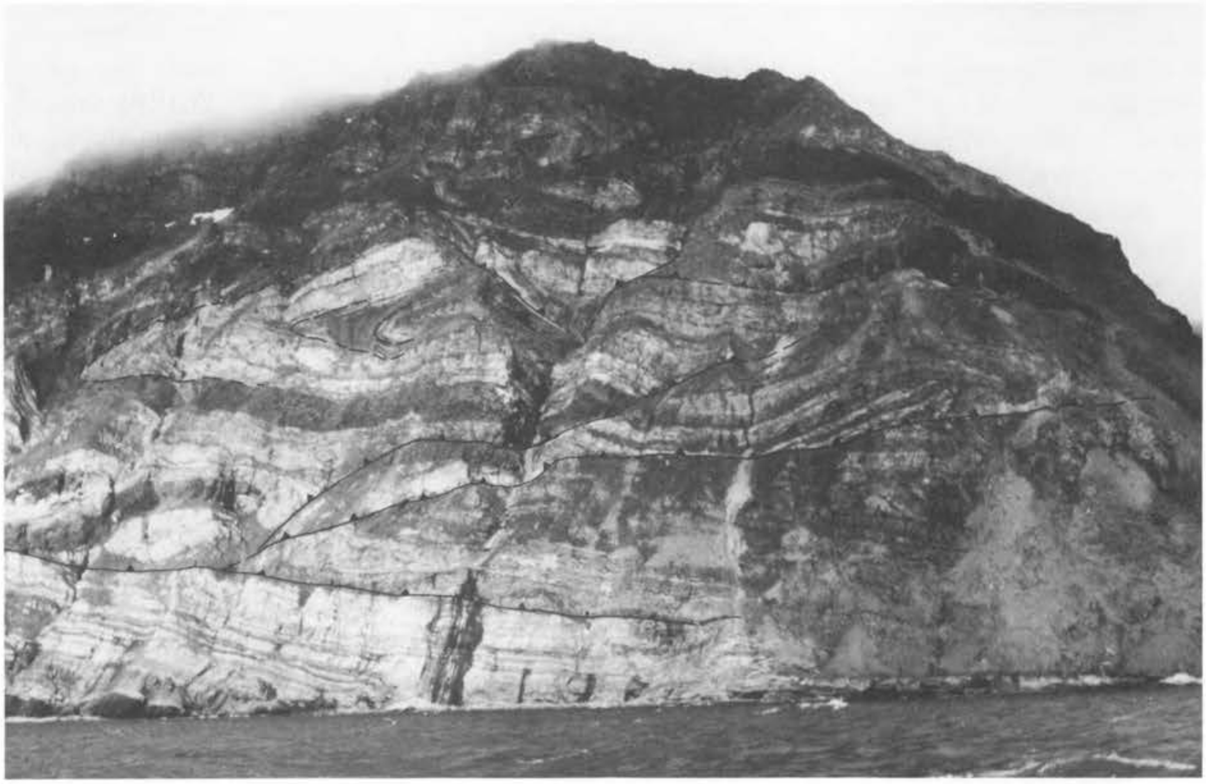

Fig. 4: Deformation in the interior part of the foldbelt: Isoclinal folds and imbricate thrusts in Late Paleozoic strata at Midterhuken, Bellsund. From Dallmann et al. (1990).

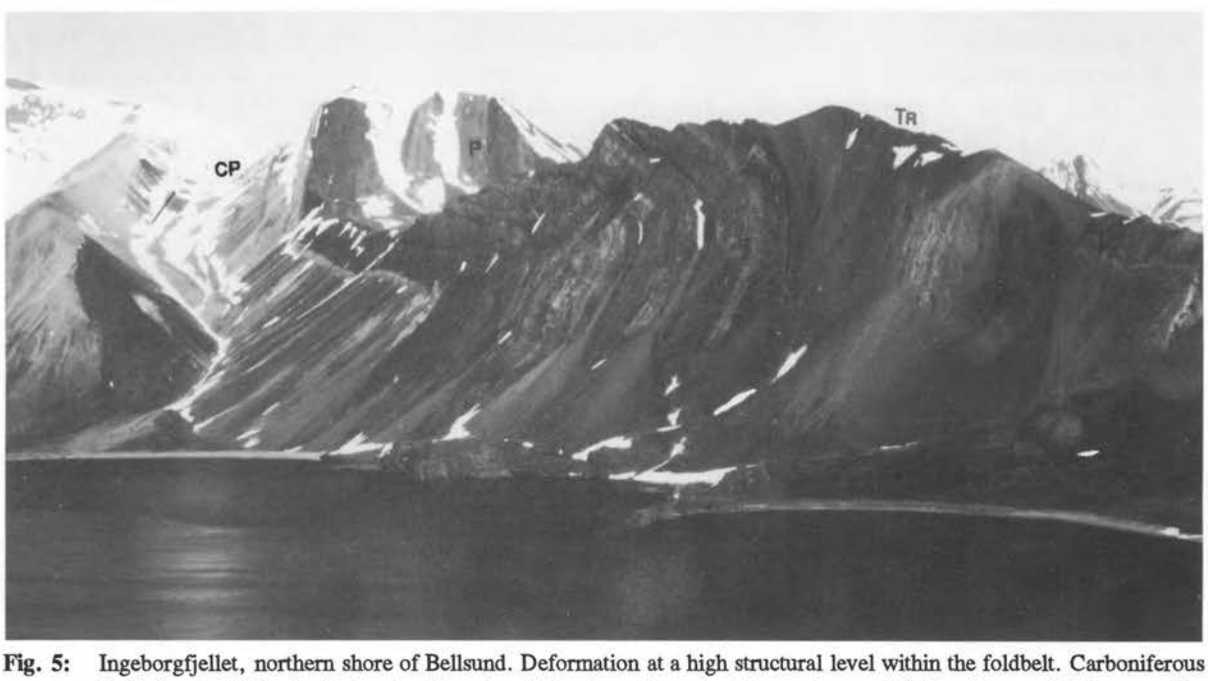

Fig. 5: Ingeborgfjellet, northern shore of Bellsund. Deformation at a high structural level within the foldbelt. Carboniferous (left) through Triassic strata, steeply eastward dipping with a step-like, east-vergent fold pattern probably caused by slip in the underlying strata.

Western Basement High

Compessional basement uplift along western Spitsbergen was associated with folding and thrusting along the margin of the basement high, though it is certain that the high has developed since the Caledonian. It formed the western margin of the Devonian Andrée Land Graben of northern Spitsbergen (Orvin 1940), the margins of the Lower Carboniferous grabens (Orvin 1940; Steel & Worsley 1984; Mann & Townsend 1989) and the Middle/Upper Carboniferous St. Jonsfjorden Graben (Steel & Worsley 1984; Welbon & Maher 1992). Two preferred structural highs during the Upper Paleozoic, the Nordfjorden High and the Sørkapp-Hornsund High, have been documented stratigraphically and sedimentologically (Gjelberg & Steel 1981; Steel & Worsley 1984). Strata of different ages (Devonian, Carboniferous, Triassic, Tertiary) unconformably overly the basement in different areas and thus indicate its long uplift history, though it is suggested to have been a depositional area from the Triassic to the Early Cretaceous (Steel & Worsley 1984).

Tertiary uplift occurred in combination with convergent movements with a WSW-ENE transport direction, with the exception of Brøggerhalvøya. The degree of Tertiary, compressive deformation in the basement is not easy to determine, as Tertiary structural directions are mostly congruent with and difficult to distinguish from earlier, Carboniferous and Caledonian ones.

South of Hornsund, subhorizontal to moderately tilted strata of mainly Carboniferous and Triassic age unconformably overlying the basement indicate that very little post-Carboniferous compression has affected the basement high there (Flood et al. 1971; Winsnes et al. 1992; Dallmann 1992). North of Hornsund, Mesozoic dolerite dykes cut the basement in E-W direction without being thrusted or folded, except where they approach the interior part of the foldbelt (Birkenmajer 1986; Ohta & Dallmann 1991). In both areas, however, normal faulting, likely related to the Late Eocene-Oligocene passive margin development, is clearly seen.

In Bellsund, however, a downfaulted block with Carboniferous to Cretaceous strata at Reinodden shows that cover strata overlying the basement is folded and forms part of the foldbelt (Dallmann et al. 1990). Carboniferous strata overlying the basement in Nordenskiöld Land are only tilted (Hjelle et al. 1986; Hjelle 1988). In western Oscar II Land, Carboniferous slivers between basement rocks (locally containing uppermost Carboniferous strata) are intensely folded and thrusted (Ohta et al. 1991/1992).

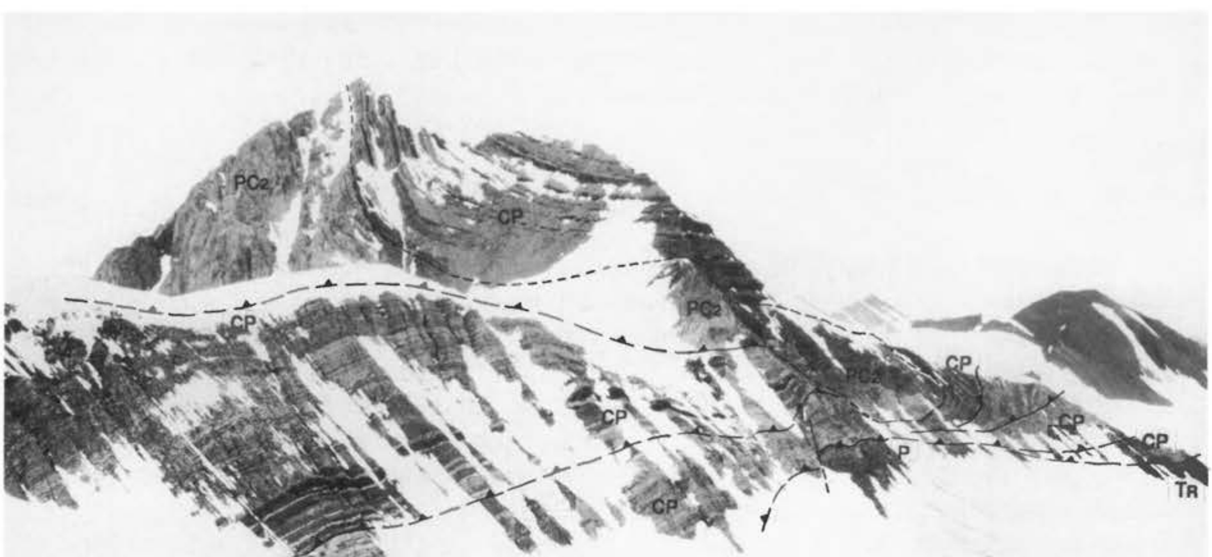

Fig. 6: Supanberget in Wedel Jarlsberg Land, viewed along-strike towards NNW. The photo shows a complex basement-cover contact: a basement-cored, tight, northeast-vergent fold with its lower limb dissected by thrust faults. From Dallmann & Maher (1989a).

The involvement of the Caledonian basement under the Tertiary folding and thrusting can be studied best close to the boundary with the strata of the interior foldbelt (Fig. 6). Observations suggest that the basement rather was deformed by slip along cleavages than by folding, and that deformation diminishes - at least locally - towards the interior of the basement high (Dallmann & Maher 1989a; Welbon & Maher 1992; Maher & Welbon 1992). A peculiar feature is that several thrusts in the thick-skinned foldbelt zone "root in the air" and must return into the basement farther west (Maher 1984; Ohta et al. 1991/1992; Welbon & Maher 1992). Previously existing thrusts within the basement may have been reactivated during the Tertiary, where they had a favourable orientation related to the stress field, as suggested by many authors (e.g. Birkenmajer 1972b).

Forlandsundet Graben

A graben structure paralleling the foldbelt trend occurs within the western basement uplift between Oscar II Land and Prins Karls Forland. Only its margins are exposed, while most of it is situated below the strait of Forlandsundet. Its width is 12 to 18 km. The western margin on Prins Karls Forland is exposed over a distance of 45 km, while the eastern one only shows local exposures on Sarsøyra and Kaffiøyra (Hjelle & Lauritzen 1982). Carboniferous strata are preserved within a marginal fault zone in southwestern Oscar II Land that may represent the eastern margin continuation (Ohta et al. 1991/1992). Seismic survey has revealed the continuation of this or related graben structures southward to Bellsund, and similar features offshore from Hornsund (Eiken & Austegard 1987).

The age of the clastic sediment fill is Late Eocene to Oligocene (Livšic 1967, 1974; Vakulenko & Livšic 1971), i.e. the sedimentary basin is thought to be initiated during the extensional event of passive margin formation. The basin was larger than the area presently situated between the boundary faults of the graben, and a depositional contact with the basement is locally observed (Kleinspehn & Teyssier 1992). The stratigraphy and sedimentary environment is described by Livšic (1967, 1974), Atkinson (1962, 1963), and Rye Larsen (1982). A composite stratigraphical column suggests ca. 3000 m preserved stratigraphic thickness (Prins Karls Forland; Livšic 1974), while results from vitrinite reflectance in lower parts of the strata indicate a burial temperature of 250° suggesting a considerable higher primary thickness, even taking into account a possible higher thermal gradient during the Oligocene (Kleinspehn & Teyssier 1992).

The complex deformation history reflects mainly a transtensional environment with an initial (Lepvrier & Geyssant 1984, 1985) or intermediate (Gabrielsen et al. 1992) period of minor transpression as shown by many small convergent structures.

Central Tertiary Basin

The foreland basin of the Tertiary fold-and-thrust belt extends from the inner Isfjorden to the Sørkapp area and forms a 60-70 km wide synclinorium with minor interior basin and dome structures (Nordenskiöld Land) and open fold sets paralleling the foldbelt. The western limb, close to the foldbelt, dips at angles from 5-25°, the eastern limb at 1-10° (average on seismic sections 2-3°). Occasional ENE-directed thrust faults dissect the strata and indicate that foldbelt deformation continues eastward at depth. Numerous thrust splays at depth are recorded on seismic profiles (R. Gabrielsen, pers. comm. 1990). The fold sets in the Sørkapp-Hornsund area indicate the presence of décollement zones below the basin strata (Dallmann 1992).

The basin contains clastic strata of Paleocene to Eocene age (Manum & Throndsen 1986), or possibly up to Oligocene age (Vakulenko & Livšic 1971; Livšic 1965, 1974). During the Late Paleocene, the source area changed from east to west, reflecting the uplift and contemporaneous erosion of the Tertiary fold-and-thrust belt to the west (Livšic 1973, 1974; Steel et al. 1981). The preserved thickness of the sedimentary sequence in the central part of the basin is ca. 1900 m (Dallmann et al. 1990), or 2300 m in a composite section (Harland et al. 1976). An additional 1500-2000 m indicated by vitrinite reflectance data was removed by erosion (Manum & Throndsen 1978).

The relatively steep western flank (locally up to 25°) is ascribed to crustal thickening by wedge insertion within the Mesozoic and Late Paleozoic strata at depth (Dallmann 1988a, 1992; Dallmann & Maher 1989a).

Billefjorden Fault Zone

The Billefjorden Fault Zone (exposed from Austfjorden to Kjellstrømdalen) is a north-south trending tectonic lineament that dates back at least to the Devonian and that has been reactivated several times with different kinematic responses to the varying stress fields. Harland et al. (1974) provide a summary of data from the zone known until then, and also refer to reactivation related to the Tertiary fold-and-thrust belt.

Recent work (Ringset 1988; Ringset & Andresen 1988a,b; Haremo & Andresen 1988; Haremo et al. 1988, 1990; Dallmann 1993) underlines the significance of Tertiary reactivation by giving evidence for ENE-ward thrusting within Mesozoic strata under coeval down-to-west movement along the Billefjorden Fault Zone south of Isfjorden. A bedding-parallel thrust sheet arriving from the west cuts down-section into uplifted strata to the east of it. Associated structures are thrust duplexes, monoclines, flexure folds and thrust splays in the sediments overlying the fault (Haremo et al. 1990). The subsurface structure of the fault zone has recently been studied by seismics and aeromagnetics (Skilbrei et al. 1993).

Lomfjorden Fault Zone

The Lomfjorden Fault Zone, exposed from Lomfjorden to Agardhbukta, is a second north-south trending tectonic lineament, situated 25-45 km east of the Billefjorden Fault Zone. The exposed structure affects strata of up to Early Cretaceous age and may thus be of Tertiary origin (Andresen et al. 1992a,b; Miloslavskij et al. 1992a,b, in press). However, the tectonic block pattern and the distribution of Middle Carboniferous sedimentary facies between Sassenfjorden and Negribreen, suggests that the Lomfjorden Fault Zone is distinctly related to the Carboniferous history of the Billefjorden Fault Zone (Miloslavskij et al. 1992b) and is, therefore, thought to be a similar reactivated lineament. South of Negribreen, it even parallels faults of Caledonian age.

Tertiary structures are generally ENE-vergent reverse faults with associated splays and fault-propagation folds. These interact with thin-skinned thrusts within Mesozoic strata (Andresen et al. 1992a).

Structural descriptions (including explanation of cross sections)

Sørkapp-Hornsund area (cross sections J, K and L)

The western basement high in the Sørkapp-Hornsund area consists of several structural elements. Imbricate and partly refolded, east-vergent Caledonian thrusts cause a complicated basement structure (Birkenmajer 1972b). To the east of it, the Samarinbreen Syncline, filled with Devonian and Early Carboniferous strata, was formed during the Adriabukta Phase of Early or Mid-Carboniferous age (Birkenmajer 1964; Dallmann 1992). These structures were partly eroded. On the Early Carboniferous peneplain other Early Carboniferous and - after a renewed uplift - Mesozoic sediments were deposited. These elements form the so-called Sørkapp-Hornsund High which has been a positive structure throughout most of the Late Paleozoic since the Middle Carboniferous (Gjelberg & Steel 1981). It also shows condensed thicknesses of Triassic and Jurassic strata (Winsnes et al. 1992).

Unfolded Mesozoic dykes cross-cutting the basement north of Hornsund indicate that the Tertiary fold phase did not considerably affect these parts of the basement; only the thrusts beneath Luciakammen and Sofiekammen are thought to have been reactivated to an unknown extent (Birkenmajer 1972b, 1986; Ohta & Dallmann 1991; Dallmann 1992). A set of 2 to 4 late normal faults cross-cut the high, with a cumulative down-to-west displacement of at least 1500 m. The different amount of offset of Carboniferous and Triassic strata, respectively, along one fault at Höferpynten indicates that these faults also are of pre-Triassic age, and inherited from the Late Paleozoic. In places, compressive structures are related to these normal faults, suggesting that they formed zones of weakness during the Tertiary folding event.

The interior part of the Tertiary foldbelt shows a complex, multiphase structure at Hornsund. It has been explained by late normal reactivation of early thrust faults (Birkenmajer 1964, 1972b), though recent observations suggest early wedge insertion and backthrusting overprinted by younger thrusting with associated refolding (Fig. 7; Dallmann 1992; Winsnes et al. 1992). The structure becomes more simple towards the south and terminates in one single monocline at Keilhaufjellet. Tertiary thrusts are thought to have developed within zones of weakness that are inherited from Caledonian and Carboniferous times (Dallmann 1992).

Fig. 7: Complex thrust-and-fold system north of Hornsund, looking north from the eastern top of Hyrnefjellet. The mountain Condevintoppen (left) with inverted Triassic strata at its face, is dissected by an inverted thrust fault overlain by Jurassic shales. The mountain Strykjernet (right) shows the core of the overturned to recumbent fold, defined by Cretaceous sandstones. The entire area is thought to form the footwall of a major east-vergent thrust exposed farther west.

The foreland basin to the east exposes Cretaceous and Tertiary strata that show gentle folds, possibly due to some deeper-seated décollement zone. The western flank of the basin is overturned (Cretaceous strata) at Hornsund, and moderately to gently dipping farther south (Birkenmajer et al. 1992, Winsnes et al. 1992).

A second fold zone, the Lidfjellet-Øyrlandsodden Fold Zone, parallels the interior foldbelt, but is mostly situated offshore to the west. It is exposed on Øyrlandsodden/Sørkappøya, where Permian and Triassic strata form locally overturned folds, and on Lidfjellet/Sergeijevfjellet (near Hornsundneset), where ENE-vergent thrusts have emplaced Triassic on top of Jurassic and Cretaceous strata (Winsnes et al. 1992; Dallmann 1992).

To the east of this fold zone at Øyrlandet, the Øyrlandet Graben shows Tertiary strata at the surface. Its eastern boundary fault has an offset exceeding 3000 m and probably belongs to the set of late normal faults developed in relation to the passive margin formation.

Shortening estimates (Dallmann 1992) indicate a distinct decrease in minimum shortening across the interior part of the foldbelt from north to south, from minimum 8 km (probably 10-12) at Hornsund to 0.2-0.3 km at Keilhaufjellet. Additional shortening within the basement block is considered to be very small, while the Lidfjellet-Øyrlandsodden Fold Zone suggests a minimum shortening of 1800 m at Lidfjellet.

Interior Wedel Jarlsberg Land/Torell Land - Bellsund (cross sections H <west> and I)

In this area, the Western Basement High constitutes an intensely imbricated structure of Caledonian age, involving Precambrian to Ordovician strata. Tertiary reactivation of individual structures is not documented, though Tertiary thrusts forming the interior part of the foldbelt obviously root in the basement.

On Reinodden, as previously stated, folded and locally overturned Carboniferous through Cretaceous strata are exposed in a down-faulted block indicating that foldbelt tectonics have also affected the strata originally overlying the basement to the west of the present foldbelt. On Calypsostranda, Late Eocene to Oligocene strata (Head 1984), i.e. younger than the foldbelt, depositionally overlie the basement within a down-faulted block (Thiedig et al. 1979; Dallmann 1989).

Fig. 8: Midterhukfjellet, northern shore of Midterhuken, Bellsund. A décollement zone within Triassic dark shales has caused a major flexure fold within overlying sandstone formations, as well as parasitic folds and minor thrusts within the shales and intercalated thin sandstone and limestone beds.

In the Midterhuken and Reinodden areas, Early Carboniferous Billefjorden Group strata occur only in the highest thrust sheets, i.e. those derived from most westerly locations. In the shorter transported, lower thrust sheets, these strata is lacking. This suggests that a Carboniferous graben-like basin was situated in the present basement area prior to the Tertiary thrusting event (Steel & Worsley 1984; Dallmann et al. 1990; Maher & Welbon 1992). Thus, there are abundant potential zones of weakness that may have been regenerated during the deformational event.

The principle structural framework of the Tertiary fold-and-thrust belt in this area reveals four basement-involved, ENE-vergent thrusts which laterally overlap (Dallmann et al. 1990), from south to north with decreasing structural level; these are the Supanberget Thrust System (Fig. 6; Dallmann & Maher 1989a), the Saussureberget Thrust, the Berzeliustinden Thrust (Sun 1980; Hauser 1982; Dallmann 1988a) and the Bravaisknatten Thrust (Maher 1984; Maher et al. 1986). From south to north, one goes from lower to higher structural levels, where thrusts are progressively rotated eastward, the uppermost one (Bravaisknatten Thrust) being rotated into an easterly dip (Dallmann 1988b). A common characteristic of these thrusts are that they tend to bend into parallelism with the cover strata, mostly within Mesozoic shale formations (preferentially the Triassic Bravaisberget Formation, Fig. 8, and the Mid Jurassic-Early Cretaceous Janusfjellet Formation).

One portion of the thrust displacement is accommodated by WSW-vergent backthrusts (partly forming décollement zones), while the other portion may be transferred eastward by a thin-skinned thrust system, below the Central Tertiary Basin, according to observations from farther northeast (see below). Basin-and-dome structures to the east of the exposed thrusts, as well as flexure, chevron and box folds as well as minor thrusts within the exposed Mesozoic strata (Fig. 9; Dallmann & Maher 1989a; Dallmann et al. 1990) and seismic surveys along the fjords at the west coast (Faleide et al. 1988, 1990) support the assumption of décollements at depth. This results in considerable crustal thickening of the sedimentary strata below the western flank of the Central Tertiary Basin, which explains its marginal uplift and inclination of up to 25°ENE.

The Central Tertiary Basin in Nathorst Land and Torell Land in general shows two synclinal axes with a very gentle anticline in between. Between Nathorstbreen and Kvalvågen, a series of gentle synclines and anticlines occurs. In addition, a down-to-SW oriented flexure occurs in Cretaceous strata at Morsjnevbreen, near Kvalvågen. Seismic data explaining the specific cause of these structures have not been released.

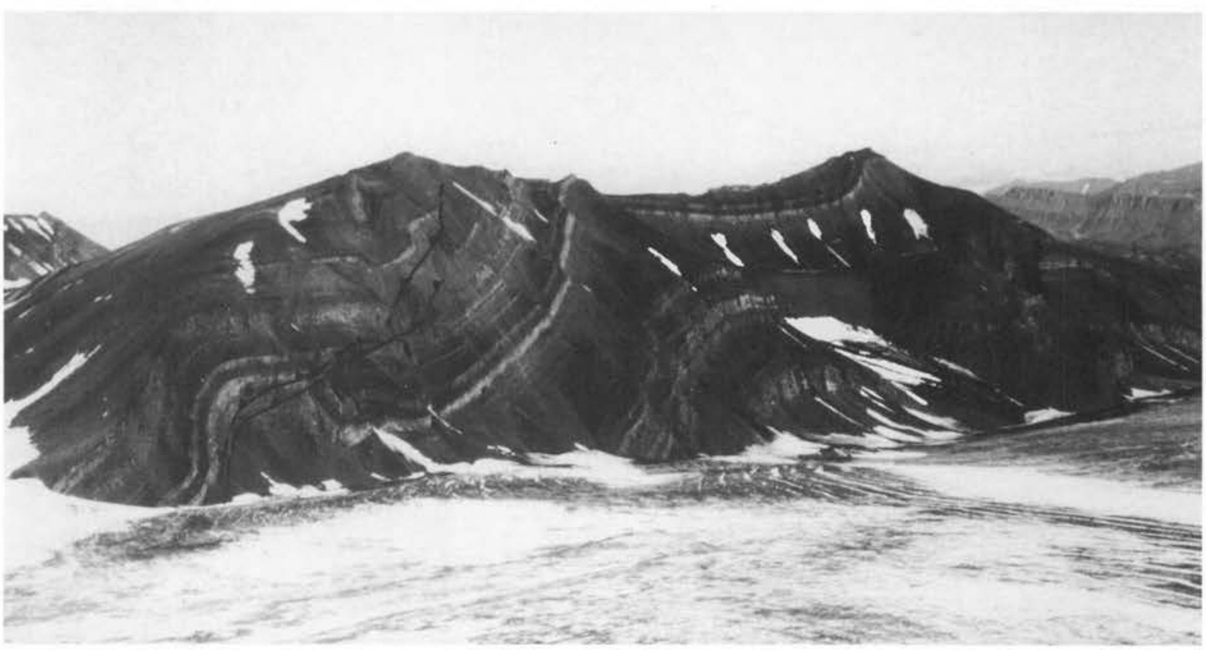

Fig. 9: Engadinerberget, Wedel Jarlsberg Land. The zone of thin-skinned thrusting: A fold-propagation fold is developed at the end of a blind thrust within Triassic strata.

Minimum estimates of Tertiary shortening across individual thrust systems are ca. 2 km at Supanberget (Dallmann & Maher 1989a), ca. 2 km at Berzeliustinden (Dallmann 1988a) and 4-8 km on Midterhuken (dependent on the applied model; Maher 1988b). The real shortening may be considerably higher. Also, the existence of additional, underlying thrusts is suggested by the rotation of the exposed ones.

Western and Central Nordenskiöld Land (cross sections E and F)

Only a narrow part of the Western Basement High is exposed in Nordenskiöld Land, reflecting mainly a continuation of the situation from south of Bellsund (Hjelle 1969, 1988; Hjelle et al. 1986). An additional feature is the presence of down-to-west normal faults, possibly correlatable with the Tertiary, post-foldbelt extensional event, and partly with local extension during thrusting (Ohta et al. 1991/1992). Some of these fault blocks contain Lower Carboniferous strata, but no significant folding was within the latter.

Fig. 10: The Fuglefjellet Thrust at Grumantbyen, southern shore of Isfjorden, within Tertiary basin strata. It represents one of very few thrusts that dissect the Central Tertiary Basin strata up to the present surface.

The Bravaisknatten Thrust exposed on Midterhuken (Maher 1984) is suggested to continue eastward within the subsurface strata below Nordenskiöld Land. Structurally overlying fold sets, locally complicated by minor, associated thrusts and décollements, deform the cover strata within the foldbelt to the east (Maher et al. 1989; Ohta et al. 1991/1992). Contrary to Maher et al. (1989), another basement-involved thrust, probably at a lower structural level than the Bravaisknatten Thrust, has recently been mapped, the Kleivdalen Thrust. It emerges from the basement into the Lower Carboniferous, where it is tilted eastward. Together with associated splay faults and an overlying décollemnt in the Triassic strata, it provides a foreland-dipping duplex system (Braathen et al., in prep.).

The uplift of the Central Tertiary Basin flank, a dome-and-basin pattern within the Tertiary strata (Livšic 1973, 1974), a thrust (splay?) fault dissecting the basin strata at Grumantbyen (Fig. 10; Major & Nagy 1972), and the fact that a ENE-vergent thrust system appears in the Mesozoic strata east of the basin (Haremo et al. 1990) suggest that significant foldbelt tectonics are present at sub-surface in western Nordenskiöld Land. This is also supported by an interpretation of a seismic survey in Isfjorden by the Geophysical Department at the University of Oslo (Ohta 1988), showing considerable crustal thickening off the Isfjorden coast.

Oscar II Land (cross sections B <west>, C and D <west>)

In Oscar II Land, north of Isfjorden, an almost 50 km wide zone of intensely deformed Late Paleozoic and Mesozoic strata, and even basement strata in the west, is exposed. It signifcantly narrows towards Brøggerhalvøya to the north. The reason for the considerable width of this outcrop, compared with Nordenskiöld Land to the south, is thought to be due to exposure of different structural levels, i.e. below and above the roof thrust, respectively. The threefold zonation of the foldbelt is distinct (western basement-involved, central thin-skinned and eastern thrust-front zone; Maher 1988; Bergh et al. 1988a,b; Bergh & Andresen 1990).

A typical feature of western Oscar II Land is the high degree of involvement of the rocks of the Western Basement High in the folding and thrusting. Here, the entire outcrop area of the basement high seems to be involved in Tertiary thrusting or thrust reactivation. This is controlled by highly deformed slivers of Lower to Upper Carboniferous strata along the west coast and within the basement block (Ohta et al. 1991/1992; Bergh et al. 1993; Hjelle et al. 1994).

Fig. 11: Bydalsfjellet, northern Jämtlandryggen, Oscar II Land, viewed along-strike towards northwest. Upper Permian strata is repeated by a thin-skinned thrust with a hangingwall cut-off.

The boundary of the basement block with the cover strata is deformed in a similar way as in Wedel Jarlsberg Land with basement-cored folds, e.g. at Trygghamna (Ingebrigtsen et al. 1988) or thick-skinned thrust-fold complexes, e.g. at St. Jonsfjorden (Maher & Welbon 1992; Welbon & Maher 1992). A décollement zone can be traced across a large distance within the Middle to Upper Carboniferous strata. Due to the extensive glacial cover, direct links between the areas of different styles of deformation cannot be made. The basement-cover contact shows a step-wise configuration at map view, probably due to the soutward plunge of the foldbelt in combination with oblique lateral

Fig. 12: Tight, overturned fold in Permian strata at Mediumfjellet, seen from the north. The exposure is situated between thin-skinned thrusts within the eastern "thrust front" zone of the foldbelt.

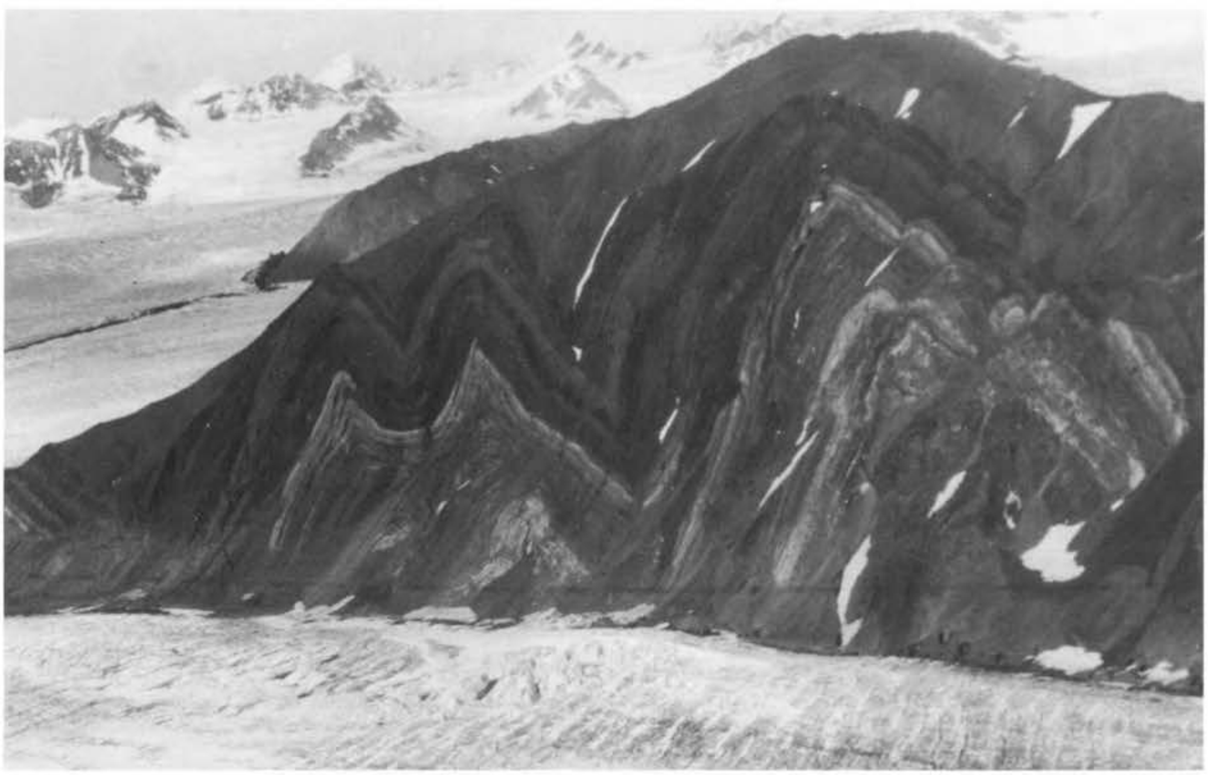

Fig. 13: Upright fold set at Klampen, east of St. Jonsfjorden, in the middle zone of the foldbelt; décollement-type deformation in Upper Permian and Triassic strata.

thrusts or apparent SW-NE oriented transverse faults. An excellent example of the latter is the Ymerbukta Fault (Ohta et al. 1991/1992), also known as the "Isfjorden Fault" (Harland & Horsfield 1974) between Nordfjorden and Isfjorden.

To the east, this zone is succeeded by the wide central zone of thin-skinned thrusting and décollement folding, with generally upright, tight, disharmonic, locally ENE- or WSW-ward overturned folds (Figs. 11, 12 and 13). The few thrusts that dissect the surface commonly end blind in anticline cores. The basal décollement is expected to be situated in Permian anhydrite/gypsum layers at shallow depth, i.e. in a higher stratigraphic level than in the western zone (Bergh & Andresen 1990).

The eastern zone defines the apparent thrust front, the location where the décollement faults underlying the central zone ramp to the surface. It consists of at least six separate, imbricate thrust sheets with bounding thrusts with flat-ramp geometries and associated hangingwall folds (Bergh & Andresen 1990; Bergh et al. 1993). The lowermost thrust is observed within the evaporites of the Lower Permian Gipshuken Formation which are disharmonically folded and tectonically thickened (Bergh & Andresen 1990; Wennberg 1990; Hansen 1991; Wennberg et al. 1993). The entire structure displays a complex, hinterland-dipping duplex with a sole thrust in the Permian evaporites and a roof thrust in Triassic shales.

Shortening estimates based on bed-length estimates of the relatively competent Upper Permian strata and on a seismic record of the basement-cover contact indicate a shortening of ca. 20 km (ca. 50%) for the area between Trygghamna and the eastern thrust front, i.e. to the east of the Western Basement High (Bergh et al., in prep.).

Just east of the thrust front, monoclines within Mesozoic strata indicate the presence of N-S striking faults that terminate in the subsurface. The exposed Blomesletta Fault, between Ekmanfjorden and Dicksonfjorden, a west-vergent, high-angle reverse fault, may be a representative of this fault set. Another N-S striking fault with a subvertical orientation and a down-to east displacement occurs even farther east in Dickson Land. These faults provide the structural transition from the foldbelt tectonic regime to that of the Billefjorden Fault Zone.

Brøggerhalvøya (cross section A <east>)

On Brøggerhalvøya, the northernmost exposure of the Tertiary fold-and-thrust belt, the structural trend changes abruptly to almost east-west (Barbaroux 1966, Challinor 1967, Manby 1988). The foldbelt probably was forced to change direction by a buttress, the basement high of northwestern Spitsbergen.

Apart from the directions, the style of deformation on Brøggerhalvøya seems in many ways to resemble that one of the Hornsund area. Structures appear very narrow: Overturned fold nappes and backthrusts occur. The basement rocks are fully involved in folding and thrusting. Thrusts are locally out-of-sequence and cut each other giving rise to a complex stacked thrust nappe structure that shows N- to NNE-directed transport and accommodates a crustal shortening of at least 18 km, probably 20-30 km across the foldbelt (Manby 1988; F. Thiedig, pers. comm. 1988).

Billefjorden - Eastern Nordenskiöld Land (cross sections B <east>, D <middle> and F)

This area is structurally controlled by the Billefjorden Fault Zone of which three segments are exposed, from N to S: 1. between Austfjorden and Billefjorden; 2. Gipshuken; 3. between Isfjorden and Reindalen. The fault zone cuts through different stratigraphic intervals in each of these segments, younging from north to south. Also, the structural features differ from place to place.

The northern segment shows a pattern of 4-6 subparallel and branching, east-dipping faults cutting through basement, Devonian and Carboniferous strata (Harland et al. 1974; Dallmann et al. 1994;

McCann, in prep.). West of the fault zone, thick Devonian graben sediments are preserved, while no Devonian rocks occur to the east of it. East of the fault zone, Carboniferous sediments are thickly developed. This implies opposite faulting directions in Devonian and Carboniferous times, when the Billefjorden Fault Zone acted as a marginal fault of the Devonian Andrée Land Trough and the Carboniferous Billefjorden Trough, respectively. Differential movements of the individual faults with different offsets at different times during the Devonian and Carboniferous can also be observed directly on the exposures. A horst within the fault zone exposes Precambrian basement.

Harland & Gayer (1972), Harland et al. (1974) and Harland (1978) argue for considerable Late Devonian sinistral strike-slip movement along the Billefjorden Fault Zone, while Lamar et al. (1986) argues against this and for post-Devonian, west-vergent reverse-slip. Structures of certain Tertiary age displaying a compressionally deformed half-graben with at least 1000 m Tertiary vertical offset are observed in the southern part of this area at Petuniabukta (Fig. 14; Dallmann 1993).

In the middle exposed segment, Gipshuken, the fault zone consists of two exposed fault planes dissecting Middle Carboniferous through Permian strata (Fig. 15). Post-Permian, ca. 350 m west-vergent reverse slip has been reported and ascribed to Tertiary compression (Ringset 1988; Ringset & Andresen 1989a,b). The faults are clearly aligned with the Devonian and Lower Carboniferous graben margin faults at the northern end of Billefjorden. Also here, the Tertiary reverse offset is most likely an overprint on inherited structures.

In the southern segment, the fault zone dissects Late Permian through Cretaceous strata (Major & Nagy 1964/1972, Major et al. 1992). Only one fault plane is present which shows ca. 300 m west-vergent reverse offset. West-vergent high-angle reverse faulting is overlapped with ENE-directed décollement thrusting within Triassic and Jurassic shales. On the uplifted block east of the Billefjorden Fault Zone, 300 m of Middle Triassic through Middle Jurassic strata have been cut out by the décollement. Detachment tectonics were associated with the formation of thrust duplexes and thrust ramps. Simultaneous minor movements along the main reverse fault created several flexure folds, monoclines, reverse and normal faults within the thrusted hangingwall strata (Haremo et al. 1990; Haremo 1992).

Agardhbukta - Negribreen (cross sections D <east>, G and H <east>)

The Lomfjorden Fault Zone is the most prominent structural feature within this area (Andresen et al. 1992a,b; Miloslavskij et al. 1992a,b, in press). The main fault plane is an east-vergent, high-angle reverse fault which involves Precambrian to Early Cretaceous strata (Fig. 16). Within the exposed part, the vertical offset of the strata (including drag flexures) increases from ca. 100 m at Rurikfjellet in the south to ca. 450 m at Eistraryggen (though almost no offset is documented at Nordmannsfonna), ca. 800 m at Hayesbreen to ca. 1500 m at Akademikerbreen.

At Agardhbukta (Klementievfjellet and Eistraryggen), most of the offset is accommodated by a sharply bending flexure with an overturned limb. It is uncertain, if the additional offset by faulting is significant. At Klementievfjellet, several reverse splay faults are observed that are each related to overturned parasitic folds (Andresen et al. 1992a).

Mesozoic strata are thought to have been thrust eastward along bedding-parallel thrusts within the Triassic Botneheia shales, where duplexes locally are exposed (Vendomdalen, Fulmardalen, Eistraryggen). These thrusts possibly interacted with movements along the Lomfjorden Fault, though this is less prominent here than in the Billefjorden Fault Zone (Andresen et al. 1992a, Miloslavskij et al. in press). The Janusfjellet Formation shows a considerable decrease in thickness at Klementievfjellet (Agardhbukta) from 400 m to 250 m, which has been explained by a similar normal fault/thrust interaction (Andresen et al. 1992a). Subsequent field work in the area seems to reveal that no specific stratigraphic section within the Janusfjellet Formation is cut out, and instead all horizons attenuate proportionally (Miloslavskij et al. in press). This may suggest syn-depositional (Jurassic-Early Cretaceous) uplift of the block to the west of the Lomfjorden Fault in this area.

Fig. 14: Middle Carboniferous strata at Løvehovden, Petuniabukta, within the Billefjorden Fault Zone. West-vergent high-angle reverse faults turn over into flexures. From Dallmann (1993).

Fig. 15: Billefjorden Fault Zone in Billefjorden, near Gipshuken, seen from the north. A west-vergent, high-angle reverse fault dissects Permian strata. An associated monocline is seen in the footwall to the right.

From Nordmannsfonna to the north, the fault zone splits up. A system of down-to-west displacing structures affects all exposed strata of up to Triassic age. The structures are mainly situated below glaciers and may be either normal faults or flexures. At Glyntnosa (near Rabotbreen), a combined flexure and subvertical fault is exposed, across which the stratigraphy is dislocated 450 m down to west. Farther north, at Von Postbreen, the offset is only ca. 100 m. This zone of down-to-west displacement is connected along-strike with the main reverse fault by minor flexure zones which show an en-echelon arrangement (Andresen et al. 1992b).

Farther north, at Akademikerbreen, the reverse fault offset attains a ca. 1500 m (Miloslavskij et al. in prep.). At Lomfjorden, to the north of the map area, no reference horizons are exposed. The minimum displacement is 500 m and high-angle reverse faulting was acompanied by obliquely oriented folding and faulting suggestive of an additional sinistral strike-slip component (Bergh & Braathen, in prep.).

Fig. 16: The Lomfjorden Fault Zone at Vivienberget, south of Akademikerbreen. It constitutes a high-angle reverse fault with associated faults in the hangingwall that may be reactivated Carboniferous or older structures.

BIBLIOGRAPHY

This bibliography is subdivided into topics. It presents an overview of published literature and theses on the foldbelt tectonics. It is supposed to present most of the work related to the Tertiary thrust-and-fold belt of Spitsbergen, though it does not claim to be complete.

Maps and map descriptions

Scale 1:1,000,000

Winsnes, T.S. 1988: Bedrock map of Svalbard and Jan Mayen 1:1,000,000. *Norsk Polarinstitutt Temakart No. 3.* (with short description)

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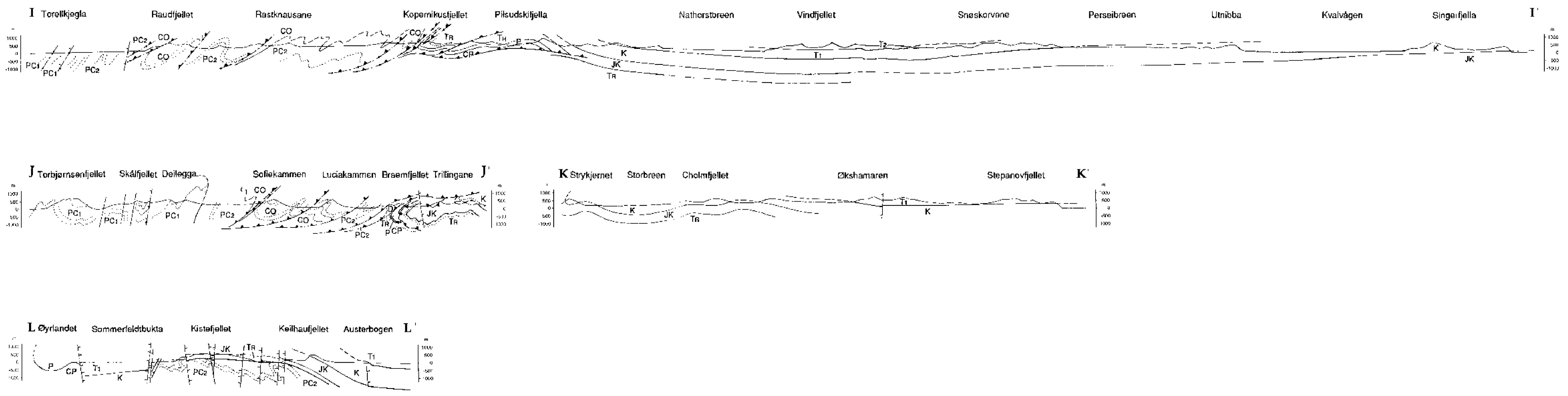

TECTONIC MAP

TERTIARY FOLD-AND-THRUST BELT OF SPITSBERGEN

CROSS SECTIONS

Dallmann, W.K., Andresen, A., Bergh, S.G., Maher, H.D. & Ohta, Y.

SCALE 1:200,000

0 5 10 15 20 km

For legend see maps.

TECTONIC MAP

TERTIARY FOLD-AND-THRUST BELT OF SPITSBERGEN

SHEET I - SOUTH

Dallmann, W.K., Andresen, A., Bergh, S.G., Maher, H.D. & Ohta, Y.

SCALE 1:200,000

0 5 10 15 20 km

contour interval 50 m

LIST OF CONTRIBUTORS

The map contains data from published and unpublished work by:

A. Andresen	T. Gjelsvik	Ju.Ja. Livšic	S.Z. Różycki
S. Bergh	M.J. Hambrey	H.D. Maher	S. Siedlecki
A. Bergvik	S. Hansen	H. Major	S.N. Šlënskij
A.S. Birjukov	P. Haremo	A.A. Makarev	A.M. Teben'kov
K. Birkenmajer	W.B. Harland	A. McCann	F. Thiedig
M.G. Bjornerud	E.C. Hauser	M.Ju. Miloslavskij	P. Waddams
A. Braathen	A. Hjelle	A.P. Morris	A. Welbon
V.V. Chajlov	E.P. Karnoušenko	J. Nagy	M. Wendorff
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LEGEND

For detailed explanations of map elements see text book

STRATIGRAPHY

T3 Aspelintoppen Formation of the Central Tertiary Basin (up to 700 m preserved) and probably contemporaneous deposits within smaller basins along the west coast (Middle/Upper Eocene to possibly Oligocene); sandstones and shales

T2 Hollendardalen through Battfjellet Formation of the Central Tertiary Basin (Lower Eocene, 260->700 m) that have westerly source areas; sandstones and shales

T1 Firkanten through Grumantbyen Formation of the Central Tertiary Basin (Paleocene, 600-800 m) that have easterly source areas; sandstones and shales, locally coals

K Helvetiafjellet and Carolinefjellet Formations (Barrêmian to Albian); sandstones and shales; 250 m (outer Isfjorden) to ca. 1200 m (Kvalvågen).

Dolerite intrusions; mostly sills (Latest Jurassic to Early Cretaceous)

JK Janusfjellet Formation (Middle Jurassic through Hauterivian); shales (black paper shales in the lower part) and siltstones; 400 to 700 m

TR Sassendalen and Kapp Toscana Groups (Triassic and Lower Jurassic); sandstones and shales; 200 m (Sørkapp) to 700 m (Sassendalen); where possible subdivided:

TR2 Upper Triassic to Lower Jurassic, often black shales at base (Bravaisberget Formation and equivalents)

TR1 Lower to Middle Triassic formations

P Kapp Starostin Formation (Upper Permian); silicified carbonate rocks and cherts; 460 m in N, attenuating to 0-6 m S of Hornsund; ca. 400 m at Sørkapp

CP Gipshuken Group (Middle Carboniferous to Early Permian); conglomerates and red beds in lower part, carbonate rocks in upper parts; gypsum at two levels in N; up to 1600 m thick

C Billefjorden Group (Lower Carboniferous); quartzitic sandstones, shales, locally coals; thickness exceeds 1000 m (Sørkapp Land); locally deformed during Late Paleozoic

D Devonian deposits; multicoloured or red clastics; strongly varying thickness; locally deformed during Late Paleozoic

Basement rocks with penetrative Caledonian and/or older deformation:

G Caledonian granite intrusions

OS Arkfjellet and Bulltinden Formations, within age interval Middle Ordovician to Early Silurian; mostly carbonate rocks, also clastics in N; up to 1600 m

CO Sofiekammen Group (Cambrian) and Sørkapp Land Group (Ordovician); carbonate rocks; up to 2300 m

PC3 Vendian strata; tilloid diamictites and phyllites; varying thickness (up to ?800 m, Bellsund); weak Caledonian metamorphism (sub-greenschist to greenschist facies)

PC2 Pre-Vendian, Late Proterozoic strata (between the Grenvillian unconformity and the Vendian tilloids; mainly greenschist-facies metamorphic supracrustal rocks; 1-5 km tectonic thickness.

PC1 Pre-Grenvillian strata; some units of uncertain age (within the Proterozoic) included; strongly deformed, metamorphosed supracrustal rocks (mostly greenschist, locally amphibolite facies)

STRUCTURE

Only structures of Late Mesozoic to Tertiary age are indicated.

Observed structures of obvious Late Mesozoic/Tertiary age
Suggested structures of Late Mesozoic/Tertiary age
Structures of possible Late Mesozoic/Tertiary age

Surfaces

Lithological boundary or other boundary that is not a Late Mesozoic/Tertiary tectonic boundary

500 Structural contour lines (interval 250 m), base of Tertiary strata in the Central Tertiary Basin.

25 25 Bedding plane orientations (inclined, horizontal, vertical, overturned) representing average orientations for larger areas; no bed orientations are indicated in the Devonian and older strata, because their orientation prior to Tertiary deformation is unknown

Folds

Anticlinal axial trace

Synclinal axial trace

Trace of monocline or structural terrace, curvature convex or concave

Trace of flexure

Trace of overturned anticline/syncline

Dome structure; symbols placed approximately on the inflection line; only indicated in the Central Tertiary Basin where they are thought to be indicators of deformation at lower structural levels

Intensely folded zone or complex shear zone

Faults

Unless specified differently below, barbs indicate downthrow side of normal faults, whereas teeth point at the overthrust side of reverse faults. In the case of reactivated faults, the youngest suggested movement direction is indicated.

Normal fault

Strike-slip fault. Most observed strike-slip displacements are combined with a normal displacement component (see below)

Oblique-slip fault

Thrust fault (dip <45°)

High-angle reverse fault (dip >45°)

Décollement fault

Reactivated older fault. The symbols (barbs, teeth) indicate the type of displacement during reactivation, regardless the original nature of fault

Fault possibly reactivated during the Late Mesozoic / Tertiary deformational event

Fault of uncertain type

Structure of uncertain type of displacement (normal, reverse, flexure?) where the downthrow side is recognized (indicated by open squares)

TECTONIC MAP

TERTIARY FOLD-AND-THRUST BELT OF SPITSBERGEN

SHEET II - NORTH

Dallmann, W.K., Andresen, A., Bergh, S.G., Maher, H.D. & Ohta, Y.

SCALE 1:200,000

0 5 10 15 20 km

contour interval 50 m

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