TERTIARY TECTONICS OF SVALBARD

Extended abstracts from Symposium held in
Oslo 26 and 27 April 1988

"The problem of the driving force is still unsolved ..."

Editors: W. K. DALLMANN, Y. OHTA & A. ANDRESEN

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SYMPOSIUM ON TERTIARY TECTONICS OF SVALBARD

Norsk Polarinstitutt / Institutt for geologi, Univ. of Oslo

April 26th and 27th, 1988

PREFACE

The importance of Tertiary tectonics on Svalbard has currently been re-
cognized by many academic and industrial geoscientists. Research on
this topic is going on in many different areas by various groups of
scientists. This symposium is a first attempt to bring together people
interested in these problems and to try to synthesize our present state
of knowledge.

Therefore, in December 1987, we decided to organize an informal sympo-
sium on a national level in order to exchange information and to dis-
cuss future foci of subjects and study areas. As seen from the number
of abstracts, participation was extensive and much greater than expec-
ted. About 60 participants from 22 institutions and companies attended.
Most of them were Norwegian or settled in Norway, but scientists from
Denmark, Germany, England, France and the United States were also pre-
sent.

The talks presented during the symposium included structural descrip-
tions of many areas within southern and central Spitsbergen that were
deformed in Tertiary times. Several seismic sections, both on-land and
off-shore, were also presented. Possible contemporaneous deformation on
northeast Greenland was discussed. Several speakers emphasized their
considerations on the expected strike-slip movement between Svalbard
and Greenland, and the meeting ended up with proposing and discussing
models on the plate-tectonic evolution of the Greenland - Barents Sea
plate boundary, the sequence and timing of events and the nature of the
Spitsbergen thrust-and-fold belt.

Several of the talks dealing with central Spitsbergen emphasized that
Tertiary deformation is more extensive and occurs further east than
hitherto recognized. Much of the thrust displacement is thin-skinned
with major décollement zones localized within incompetent late Carboni-
ferous / early Permian evaporites and Triassic / Jurassic shales. The
overlying Cretaceous and Tertiary strata have moved passively on top
and show relatively little internal deformation. Deformation of the re-
maining upper Paleozoic strata and the Caledonian basement east of the
fold belt is characterized by steeply dipping reverse faults (thick-
skinned tectonics).

The general structural style of the fold belt is very similar that known from marginal thrust-and-fold belts of compressive orogens. At various localities, balanced sections provided estimates of lateral shortening. However, how much of the thin-skinned shortening observed in the incompetent layers is really an expression of crustal shortening, and how much of the thickening is compensated by thinning elsewhere due to migration of material within a more rigidly behaving frame of competent lithologies, has not been studied quantatively yet. The Lomfjorden and Billefjorden Fault Zones have undoubtably been reactivated as steep reverse faults during the Tertiary movements.

There was a general consensus at the conference that the exposed part of the Spitsbergen fold-and-thrust belt cannot be explained as a part of a major flower structure as proposed previously. Folding and thrusting are generally due to convergent east-west movements causing a total shortening of several tens of kilometers. The mechanical problem of the driving forces turning the Tertiary transform movement between Greenland and Svalbard into a dominantly compressive deformation is not yet solved.

A model favoured by some participants explains the early Tertiary tectonics as decoupled strike-slip and compressive processes, where the major strike-slip faults were almost frictionless. The Forland area may represent a transitional zone with alternating extension and compression, although earlier attempts in explaining this history with one persisting stress regime now seem to have failed. Decoupling seems to be little developed along the southwestern Barents Shelf margin, the Hornsund and Knølegga Faults, where Tertiary transform movements mainly reactivated inherited lineaments along older block boundaries. Different stress fields were thus activated in different areas, giving rise to the contemporaneous formation of basins and ridges. Deep seismic sounding confirmed that the mantle-crust boundary was involved in the movements.

The general timing of the tectonic regimes in Svalbard and the Barents Sea as stated in the modern literature (transform movement with convergence from late Paleocene through Eocene, transform movement with passive margin formation from Oligocene onward) seems to be well established. The closer timing of individual deformation events, however, is still problematic, and the meeting did not succeed in pointing out distinct trends valid for more than local areas. The timing of events in adjacent parts of Greenland generally of Creataceous age cannot be correlated with the deformation recognized on Spitsbergen at the time being.

One of the important subjects not touched upon at the meeting is the relationship between tectonics and the Tertiary sedimentary record. Detailed facies analyses of the Paleocene to Eocene sedimentary beds in different regions, determination of transport directions and heavy mineral analyses would help in reconstructing the development and migration of positive and negative structures associated with transcurrent movement between Greenland and Svalbard. This point should be stressed in future research and is supposed to be one of the foci of interest at future meetings.

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The extended abstracts of the talks are listed in the order in which they were presented at the meeting. We are grateful to all participants for having enabled the success of the symposium. We thank 'Norsk Polar-institutt' and the Department of Geology of the University of Oslo for sponsering the symposium. The publication of extended abstracts was sponsered by the 'Samarbeidsprosjektet Norsk Hydro/Store Norske Spits-bergen Kulkompani'.

The interest in the subject of Tertiary tectonics on Svalbard documented by the participants of the meeting has encouraged us to envisage a sub-sequent meeting in 1990.

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Oslo, July 1988

The editorial committee:

Winfried Dallmann
(Norsk Polarinstitutt)

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Yoshihide Ohta

BASEMENT OF W-SPITSBERGEN; an outline

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Lufthavn.

The basement of Western Spitsbergen Orogenic belt has two
important traits:
1)   unconformities representing orogenic events, and
2)   possible terrane boundaries formed during the Caledo-
     nian period.

1)   The oldest orogenic event hitherto recognized is of
Grenvillian age, which is marked by the Konglomeratfjella
Conglomerate in Wedel-Jarlsberg Land and the Slingfjella
Conglomerate in the Hornsund area. No radiometric age has
been obtained for this age in W-Spitsbergen, but this event
is constrained by lithostratigraphic correlation with other
parts of Svalbard.   The rocks below the unconformity are
psammo-pelitic clastics and carbonates, varying from low
grade phyllites in the Orvindalen area in the NW to amphi-
bolite facies of Barrovian type in the NW and SE of Horn-
sund.   Judging from the rocks just below the unconformity,
the NW part around Orvindalen was eroded to a shallower
level   than   the   Hornsund area during late Grenvillian
Orogeny. When the unconformity is restored into horizontal
position, the Grenvillian structures are W-verging, over-
turned folds with a ESE strike and very gentle axial
plunge.   Bimodel plutonic rocks in NW Hornsund could be
Grenvillian intrusives, but this is not proved yet.   The
pre-Grenvillian rocks are not exposed in the area north of
Bellsund and south of Kongsfjorden.
     Late Riphean shallow marine clastics and carbonates
overly the unconformity. They are apparantly thinner in
the Hornsund area than in the north of Isfjorden, and are

2-4 km thick in the latter area.   Overlying tilloids of
Vendian age have some basic rocks and green phyllite layers
in them.

   Two unconformities with sub-Cambrian and sub-Ordovician
stratigraphic hiatus, have been stratigraphically recog-
nized in Hornsund. Two K/Ar ages of ca. 550-580 Ma may be
due to the sub-Cambrian event, and the basic rocks in the
tilloids may be related to this event. A late Precambrian
event has been known as the Baikalian Orogeny in the circum
Arctic areas and some U/Pb and Ar $^{40}/^{39}$ ages from NW Spits-
bergen and Rb/Sr ages from Nordaustlandet fall within this
period.   However, the nature and extent of this event is
not yet clear in Svalbard.

   Beside above two, Middle Ordovician, Middle Silurian,
Latest Silurian-Early Devonian and Late Devonian events
have been recognized within the Caledonian period. An
oceanic suture, revealed by the Motalafjella high-pressure
metamorphic complex, south of St. Jonsfjorden, was formed
in the Middle Ordovician event and was overstepped by
flyschoids of Late Ordovician-Early Silurian age. The
Middle Silurian event strongly folded the flyschoids. Most
migmatites and granites in northern Svalbard were emplaced
duringd Middle Silurian and later. The Haakonian (Latest
Silurian-Easrly Devonian) and Svalbardian (Late Devonian)
events are essentially extensional and transcurrent
faulting might also have occurred.

   A N-S structural trend is common all over the Svalbard
Caledonies, and a E-W compressive stress is inferred.   A
conjugate set of faults, NE-SW and NW-SE in strike and
steep dips, were developed in a later stage.   These two
directions of faults and longitudinal faults are the
essential fractures in the Caledonian terranes along the
northern side of Svalbard.

2)   The Late Caledonian event of Middle Silurian time is
recognizable over the whole Svalbard, but the Early Caledo-
nian event is of different age in W and NW Spitsbergen. The
later area had a metamorphic event to form eclogite around
550-500 Ma ago, while the former area had a high-pressure
metamorphism to form blueschists around 480-470 Ma ago.
This infer that the amalgamation of these two areas is
Middle Ordovician in time.

   The oceanic rock assemblage and blueschist-eclogite
metamorphism in the Motalafjella, reveal a narrow oceanic
suture zone which may separate two terranes on either side
of the zone. This suture is tracable as discontinuous

serpentinite bodies along the eastern boundary fault of the Forlandsundet graben for about 50 km to the north of St-Jonsfjorden in a NNW direction, while the southern extension is not clear.

The zone occurs as a thrust slice with a gentle W-dip and form a part of a probable accretionary prism developed during Middle Ordovician time. The thrust imbricated structures, each thrust unit is 1-3 km in thickness, extend over the whole area from Isfjorden to Engelskbukta. It seems that there is no newly formed thrust in this area and all Tertiary stresses are accommodated by the reactivation of these Caledonian structures at varying scale, from large thrust to individual cleavage slips, in manners of non-affine displacement.

Similar thrust imbrication structures exist in the N-Wedel-Jarlsberg Land, while the Caledonian structures in the W Nordenskiold Land and Hornsund-Sørkapp areas are mainly steep in dip. These differences in the basement structure are reflected in the deformation of platform sediments of post-Devonian age; large thrust and complex overturned fold structures developed in the E Oscar II Land and E Wedel Jarlsberg Land, while relatively simple, large fault-propagation folds were formed in the W Nordenskiold Land and middle Sørkapp Land. Some Upper Paleozoic-Mesozoic beds overly the steep structured basement in the latter two areas. These younger beds do not show strong folding, but instead, are flat or weakly tilted by block faulting.

A typical thrust imbricated structure develops along Kongsfjorden with a NW-SE strike, and a large structural break has hitherto been inferred along the fjord. Recent field work shows that the Caledonian rocks show a gradational change from a high to low grade across the fjord. The axial plunge of Caledonian rocks in NW Spitsbergen is gently to the south and low-grade rocks can thus be expected on the southern side. Slivers of mylonitic granites and sillimanite-bearing gneisses in the southern side of the fjord indicate that high grade rocks similar to the northern side, underly in the Brøggerhalvøya area. The NW trend along Kongsfjorden appeared in the Late Paleozoic time as a boundary of sedimentary facies change and might have been accentuated during the Middle Cretaceous uplift of N Spitsbergen, to form a hinge of tilting along the fjord. This hinge zone developed as the Brøggerhalvøya thrust zone during the Tertiary deformation period.

Devonian extensional faulting occured subparallel to the

Caledonian axial trend, in a N-S direction, and controlled the positions of Late Paleozoic sedminetary basins. The western boundary faults of the Devonian graben extend to the south to control the positition of the present boundary between the basement and platform cover strata in Oscar II Land.

post-Devonian platform cover

Devonian molasse

Caledonian granite

Up.Ordovician-
  Lower Silurian flysch

Cambro-Ordovician

Vendian-
Up. Riphean

Mid Riphean

Oceanic sutur;
  bluesch.eclogite etc.

Caledonian migmatite
  Up. Mid.Riphean mixed
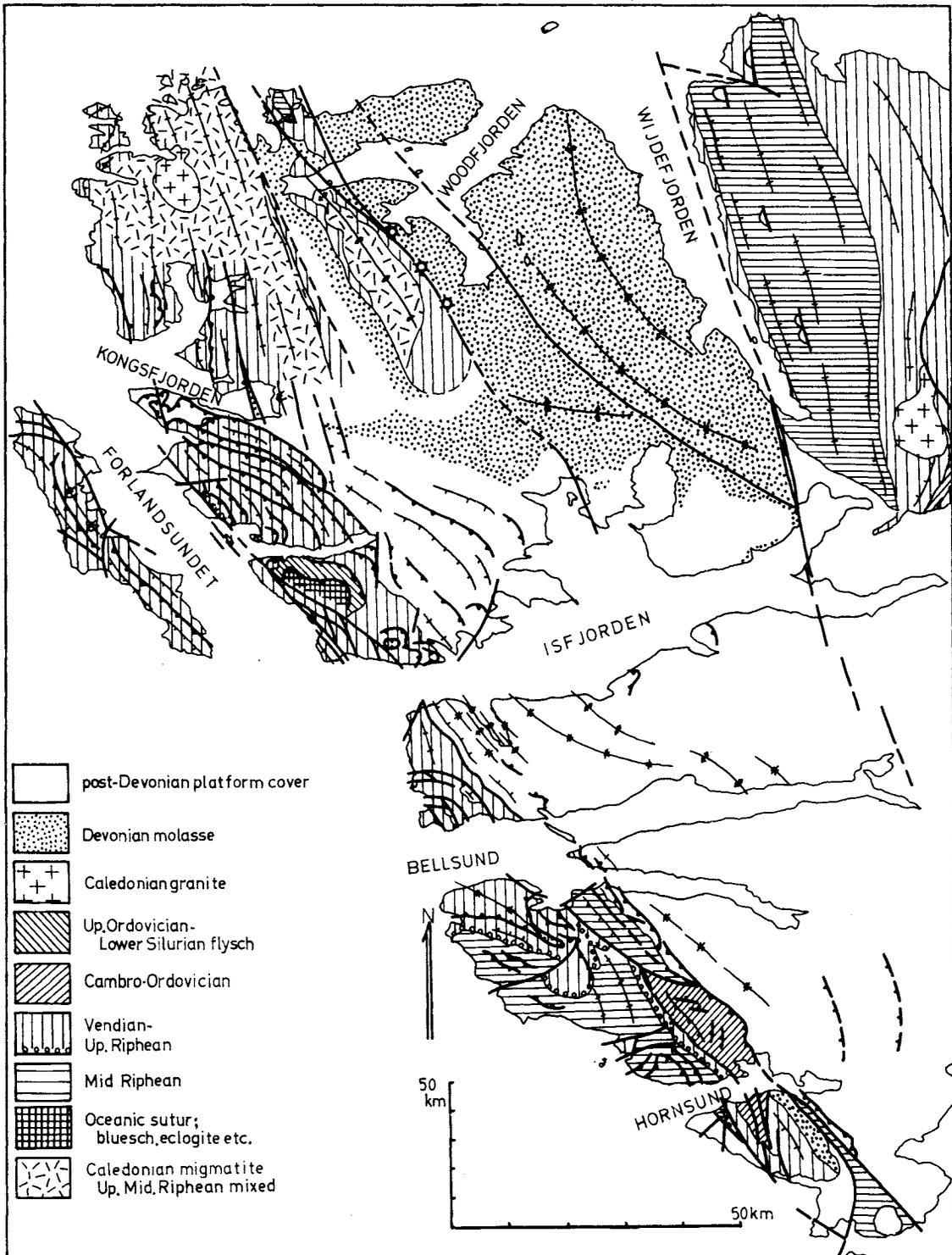
David Worsley

LATE PALEOZOIC AND MESOZOIC HISTORY OF SVALBARD

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Tertiary tectonic movements in the archipelago to a large extent repre-
sent reactivation of a series of major lineaments with a long history
of differential movement. The most important of these are the Lomfjor-
den/Agardhbukta, Billefjorden, Inner Hornsund and Paleo-Hornsund Fault
Zones.

The late Devonian Svalbardian deformation has often been advocated as
representing sinistral movements along the Billefjorden Fault Zone in
the order of several hundred kilometres. Recent work has suggested that
this is not the case, but a detailed reappraisal of the entire Svalbard-
ian deformation zone is necessary.

The Carboniferous and Permian were characterized by by the development
first of isolated narrow grabens, then by ongoing regional transgression
and increasing tectonic stability. This general trend was however inter-
rupted by marked local basin inversions - e.g. in Hornsund and on Bjørn-
øya. These features, together with the possible en echelon arrangement
of western depositional basins, may suggest lateral movements along the
Paleo-Hornsund Fault Zone.

The late Permian to Cretaceous is generally characterized by flexuring
and differential subsidence along most lineaments. More marked move-
ments may have occurred along the Lomfjorden/Agardhbukta and Billefjor-
den lineaments around the Jurassic/Cretaceous boundary; these, together
with penecontemporaneous intrusive and extrusive magmatic activity, may
reflect late Kimmerian tectonism. The Svalbard platform was however a
largely stable entity during the entire Kimmerian phase - major move-
ments being taken up along the platform's southeastern and western mar-
gins.

An increasingly important constraint on depositional patterns from the
late Triassic onwards was a general uplift of the platform's northern
margins. This trend culminated in marked regional uplift and erosion
during the late Cretaceous.

F. Thiedig

POST-CALEDONIAN THRUST STRUCTURES ON BLOMSTRANDHALVØYA, KONGSFJORDEN, NW SPITSBERGEN

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Detailed 1:10.000 mapping of ca. 20km^2 of Blomstrandhalvøya has revea-
led several previously undescribed outcrops of red sandstones and con-
glomerates which have, together with the underlying basement, been sub-
jected to high-level post-Caledonian folding and thrusting.

Lithologically, the peninsula is dominated by low-grade, late Precam-
brian (Hecla Hoek) marbles and blue-grey calcareous to dolomitic schist-
ose limestones. The schistosity of the marbles strikes N-S and dips
steeply to the east. Fold axes within this fabric plunge mainly to the
SW or NE, although some NW-SE and N-S directions are found.

The intersections of the earlier schistosity and later brittle fabrics
causes these rocks to fracture, and it was this property which frustra-
ted the London Marble Company's attempts to quarry the marbles for de-
corative purposes some 80 years ago.

In addition to the Old Red Sandstone outcropping along the eastern sea-
board of the peninsula (Gjelsvik 1966) four other localities have been
discovered. The largest, to the NE of London, is ca. 100m wide and
about 20km long from N to S. Along the western flanks the red beds of
all localities are in normal transgressive/erosional contact with the
underlying Hecla Hoek marbles. However, along their eastern margins,
they are overthrust by the marbles which exhibit thrust-related NW- to
W-vergent folds, and the red beds themselves are imbricated by many
small thrust faults. Therefore, whilst these red beds may have been
deposited in a N-S trending graben-like structure, they have subsequent-
ly been displaced by N-NW directed thrust faulting. The transport direc-
tion of this thrusting contrasts with the N to NE high level (Tertiary)
displacements seen on Brøggerhalvøya.

The age of the red beds on Blomstrandhalvøya is uncertain, but on the
nearby Lovén Islands similar rocks contain Devonian plant remains. On
Brøggerhalvøya, mid-Carboniferous microfossils are found in limestones
associated with red beds. The high-level semi-brittle to brittle defor-

mation is **clearly** **post-**Caledonian, but is it the product of Svalbardian
or later Tertiary strike-slip related tectonics?

Geoffrey M. Manby

TERTIARY FOLDING AND THRUSTING IN NW SVALBARD

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The Brøggerhalvøya-Engelskbukta area of NW Svalbard presents an excellent opportunity to assess the extent of basement (Hecla Hoek) involvement in the Tertiary fold and thrust belt. The principal structural features of the area from the thrust belt to the foreland are outlined (Fig 1a & b) and their implications for tectonic models are discussed.
    The gross structure of the area consists of a series of N-NE vergent thrust nappes dominated by post-Devonian strata in the NW of Brøggerhalvøya and by the Hecla Hoek in the SE of the peninsular, Engleskbukta and northern Oscar II Land. A major N-S fault zone in the vicinity of Brøggerbreen (Fig 1a) separates the nappes in the NW from those to the SE and S but does not penetrate the structurally higher nappes to the S. This fault is interpreted as a transfer zone which has accomodated a more northerly displacement of the south-eastern nappes.
    In the NW of Brøggerhalvøya the younger rocks are stacked into three major nappes. The broad open folding of the Brøggertinden fm, along the Kongsfjorden coastline indicates that the floor thrust to the lowest exposed nappe is ramping up at this point and may outcrop in fjord. The roof thrust to this nappe coincides with two N vergent duplex structures both in the Nordenskioldbreen fm, which are well exposed on the SE slopes Scheteligfjellet. The upper duplex is considerably more deformed than the lower. The ommision of the Gipshuken to Tertiary strata suggests that this nappe is not lowest in the stack and thrusts cutting up-sequence should be present beneath the fjord. Although the floor thrust to the overlying nappe is in the Nordenskioldbreen fm, S, towards the hinterland, it cuts down sequence into the basement (Hecla Hoek). The narrow strip of Hecla Hoek along the shore SE of Kulmodden represents the lowest exposed segment of this nappe. The whole of this higher nappe is folded into an overturned (N vergent) anticline-syncline pair and a late thrust repeats part of the lower limb of the syncline carrying Gipshuken over Kapp Starostin strata. The highest of the three nappes in the NW contains a Hecla Hoek to Gipshuken sequence floored by a low angled S-SW dipping thrust. The high cut-off angle between this thrust and the steeply dipping, overturned hanging wall rocks indicates that overfolding preceeded thrusting and that this is a fold nappe in contrast to the lower thrust nappes. At least 12km of crustal shortening are required to account for the deformation recorded in the uppermost nappe. Taken together the whole nappe sequence in NW Brøggerhalvøya must represent a minimum of 18km of crustal shortening.
    SE of the Brøggerbreen fault the lowest nappe contains Tertiary down to Brøggertinden strata folded into a broad NW plunging syncline which is itself overthrust by the recumbent Zeppelinfjellet syncline (Fig 1a). Throughout this thrust sheet there are many examples of small scale imbricates, duplex structures and folded thrusts. The overlying thrust is topographically at its highest above the Zeppelinfjellet syncline but to the SE it cuts down through the syncline removing it altogether before Sherdahlfjellet. The Hecla Hoek rocks in the

overthrust sheet are high grade schists, migmatitic gneisses, phyllonites and marbles of the Kongsvegen Group (Harland et al 1979), The whole sequence is characterised by strong (Caledonian) shearing fabrics and mylonitic zones refolded on all scales by N-NE vergent crenulation type folds consistent with the Tertiary deformation of the lower nappe,

Separating this and the overlying Trondheimfjellet nappe are two thin slices of Brøggertinden and Culm rocks (Fig 1a & b) both of which are very strongly cleaved, The Caledonian S_1 metamorphic (greenschist facies) fabric of the Trondheimfjellet phyllites, psammites and flaggy limestones with diamictite horizons is refolded by a large N vergent antiform-synform pair, The folds, accompanied by a spaced pressure solution (S_2) cleavage, have distinct box-like to chevron profiles with accomodation structures typical of locked-up flexural slip folds,

Above the Trondheimfjellet nappe is a strongly imbricated sequence of light grey Moefjellet marbles, On the narrow col at the head of Nordenfjeldskebreen these marbles are unconformably overlain by a synclinally folded and cleaved sequence of Culm-type pebbly conglomerates and coarse sandstones, The Culm rocks are then overthrust by the Haaken tillitic succession (Waddams 1983), However SE of the col the Haaken and Moefjellet rocks are repeated by thrusting in which Dahlbreen (Harland et al 1979) marbles also become involved, The incorporation of post-Devonian rocks in these higher nappes combined with the identical vergence directions in both rock sequences clearly indicates the Tertiary age of the later deformation in the older (Hecla Hoek) rocks,

In the triangle of mountains between Comfortlessbreen and Sarsøyra the wide expanse of ground occupied by the Haaken tillites reflects the shallow SW sheet dip of these rocks, These and the succeeding dark grey calcareous slates, white marbles and phyllites are well exposed on the southern shore of Engleskbukta, Here again the Caledonian S_1 foliation is refolded by open box-like folds overturned to the NE and associated with a steep SW (81/220) dipping S_2 pressure solution cleavage,

To the west of Kapp Graarud Tertiary conglomerates lie above the Hecla Hoek and both sequences are cut by steep west dipping to vertical faults, In the conglomerates small scale sinistral and dextral displacements of pebbles occur in association with anastomosing fractures parallel to the faults, On similarly oriented fault surfaces in the Hecla Hoek close to the contact with the Tertiary sediments slickensides show both reverse slip and down-dip movements to have occured,

Post Caledonian deformation of the foreland,
On most maps of NW Svalbard the northern limit of the Tertiary fold and thrust belt is shown to be coincident with a WNW-ESE fault zone located in Kongsfjorden-Kongsvegen, However folding and thrusting of the Permo-Carboniferous rocks on the nunataks in Kongsvegen, N of the supposed fault, is at variance with this assumption, The presence of N-S fault controlled Devonian breccias and conglomerates has long been recognised on the foreland, Recent fieldwork on the Lovénøyane and Blomstrandhalvøya has brought to light several previously unrecognised post-Caledonian deformation features, On Blomstrandhalvøya, in a narrow strip east of Bratliek, strongly cleaved (SE dipping) Devonian breccias and conglomerates are overthrust to the E by Hecla Hoek marbles exhibiting a NW vergent fault-bend fold, The orientation of this fold and the cleavage in the Devonian rocks are consistent with sinistral transpression along the N-S lineaments, A well exposed fault surface on the western edge of Juttaholmen exhibits near horizontal slickensides with a clear sinistral sense, Red sandstones and conglomerates on Observasjonsholmen are also weakly folded, cleaved and imbricated, Whilst a Svalbardian age for this deformation cannot be ruled out it is interesting to note that the controlling N-S faults have the same orientation as the Brøggerbreen transfer zone which is effectively a sinistral fault,

In several localities over Blomstrandhalvøya and particularly well developed in the Hecla Hoek marbles NW of London are high level imbricate thrust fans with a consistent northerly vergence, Because these imbricates have the same transport sense as those to the S it seems reasonable that they are expressions of Tertiary shortening on the foreland, The development of the imbricates requires the presence of floor thrust, probably at no great depth, which could be the sole thrust to the Tertiary folding and thrusting, There is no evidence to suggest that this thrust breaks the surface to the N and it is presumed to be blind,

It is not yet known to what extent the N-S faults have influenced the progression of these imbricates on the so-called foreland,
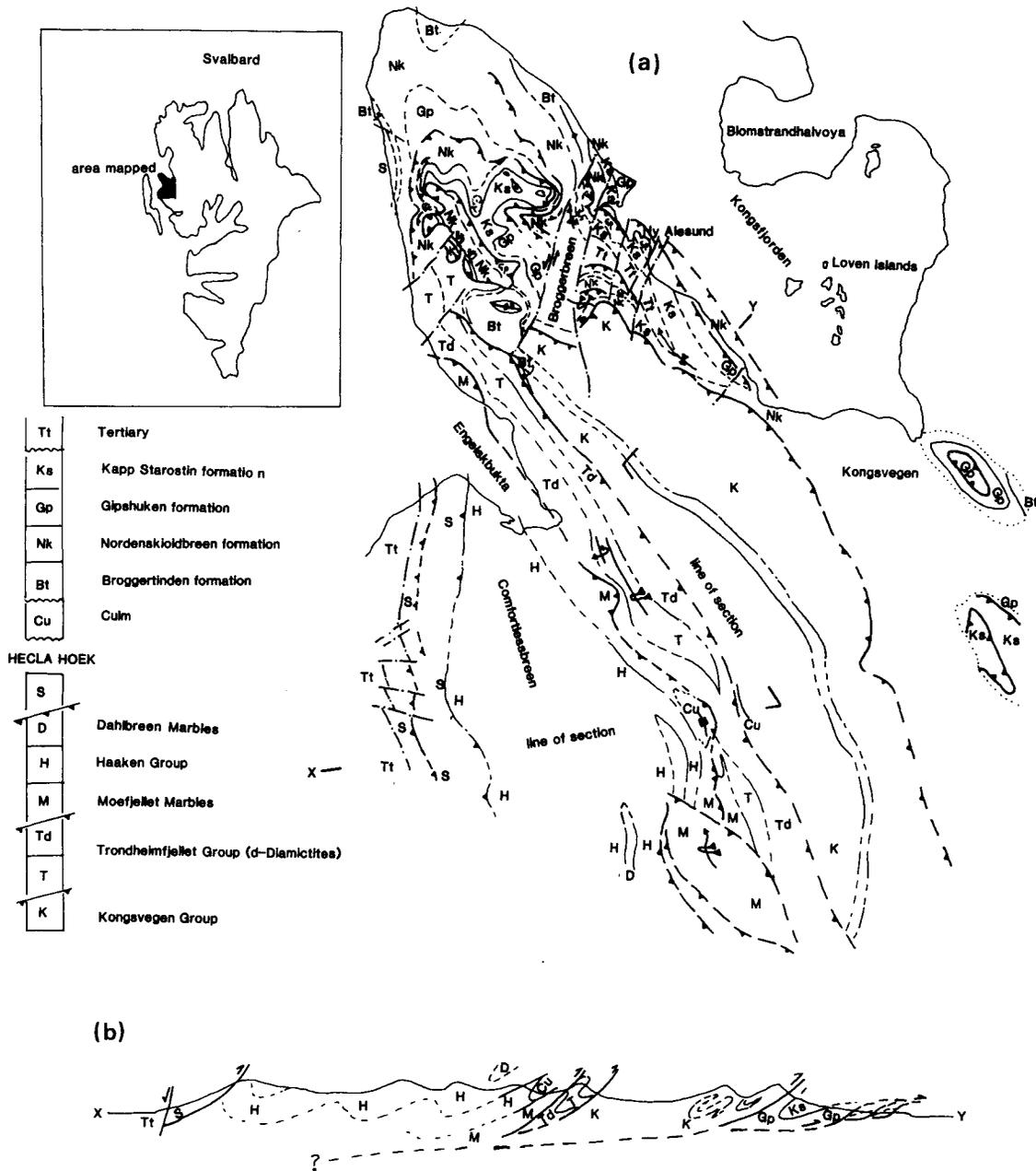

Figure 1. Sketch map and cross-section of the Brøggerhalvøya-N Oscar II Land area.

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Conclusions and discussion,
The Tertiary folding and thrusting in NW Svalbard like that in foreland fold
and thrust belts is characterised by the development of imbricately stacked
thrust nappes in which older deeper sections of the stratigraphy have been
emplaced above younger sections in the direction of the foreland, Successively
higher nappes are more deformed and contain basement (Hecla Hoek) rocks, The
highest, basement dominated nappes, occasionally incorporate discontinous slices
of younger rocks which are folded and cleaved in the same style and with the same
sense of vergence as the D_2 structures developed in the older rocks, The post
metamorphic D_2 deformation of the Caledonian D_1 fabric in the Hecla Hoek rocks
is therefore assigned to the Tertiary event, The active involvement of the older
rocks demonstrates the thin-skinned to thick-skinned nature of the Tertiary
folding and thrusting in NW Svalbard, The stacking of the lower grade
Trondheimfjellet nappe above the high grade Kongsvegen rocks is somewhat
anomalous and may be due to Tertiary backthrusting, to the N-NE, of earlier SW
directed Caledonian nappes stacked in order of increasing metamorphic grade,

   Throughout the fold belt there are a number of features which are not readily
accounted for by published flower structure or transpressional models, For
example major thrusts rather than steepening towards the supposed axis of the
flower structure usually have fairly shallow dips, The folding and thrusting of
the Hecla Hoek described here demonstrates that these rocks, rather than acting
as passively upfaulted blocks, have actively participated in the Tertiary
deformation, En echelon arrays of folds with transecting cleavages and thrusts
are not the rule and, except for the anomalous N-NE transport in the NW sector,
deformation is generally east directed,

   The Tertiary fold belt as whole is dominated by E-W compression and minor
changes in transport directions (eg in the NW) may; relect differences in the
degree foreland directed transport along surging thrust fronts, or evidence
lateral ramping and /or the presence of transfer faults,

  It is suggested that the bulk of the deformation in the fold and thrust belt was
accomplished by collision of Greenland and Barents Sea platforms brought about
by the clockwise rotation of Greenland as the Mid Atlantic ridge began to
propagate northwards in Oligocene time(?) Modification of the initial E-W
compressional structures, particularly along the western margin of Svalbard, by
dextral strike-slip motion on N-S faults coincided with the separation of
Greenland and Svalbard, In this scenario the Forlandsundet graben could have
formed as a northward migrating extensional basin between two parallel right-
stepping dextral wrench faults possibly coincident with present bounding faults,
Rotation and reactivation by the intervention of a left-stepping dextral wrench
fault array could alternatively explain the apparently anomalous N-NE verging
nappes in the NW, With the development of the Knipovich ridge most transpressive
stresses would be expected to have been absorbed by the Greenland-Svalbard
transform and subsequent tectonism on Svalbard be dominated by extensional
faulting to the present day,

Winsnes, T. S. and Y. Ohta

FOLD STRUCTURES OF CARBONIFEROUS TO TRIASSIC ROCKS IN THE INNER PART OF ST. JONSFJORDEN

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Between Isfjorden and Kongsfjorden a wide zone of folded Carboniferous to Triassic sequences form characteristic long and narrow mountain ridges, like Gestriklandkammen and Jemtlandkammen. From a short stay in the area of inner St. Jonsfjorden for geological mapping purposes and profiles further south by D. L. Dineley, produced more than 20 years ago, an impression of the fold structures is obtained.

The border between the Hecla Hoek and younger rocks does not form a straight line but shows a step-like trend, where the north part has been pushed farther to east-northeast (Fig. 1). At the junction more complicated tectonic structures are seen, including strike-slip faults, over-thrusts and folded thrust planes. Between Isfjorden and Kongsfjorden four such breaks are seen.

Between them north-northwest running, more regular fold patterns are met with. They consist of open and stacked folds, monoclinal and overturned (Fig. 2). The eastern limbs are mostly steep and small thrusts are also seen. East of the head of St. Jonsfjorden the shortening along the border between Perman and Triassic sequences is about 20 % towards east. The fold axes mostly climb gently towards north and the Triassic exposures narrow this way. To the north most of the tectonic movements are restricted to major thrust and faults where slices of Devonian and Lower Carboniferous can be seen.

The general tectonic picture is one of compression. No indication of extension was seen.

An anticlinal axis of a step-fold extends from Trygghamnna to Vegardfjellet and forms a complex of thrust-overfolds, involving the basement rocks.

On the B section (Fig. 3), an overturned syncline occurs in the north and steep younger faults, possibly extensional ones, cut the lower limb of the fold in the south. Two bed-slip thrusts occur in the limb, moderately dipping eastward. The A section (Fig. 3) to the north of B has two

Fig.1

Fig.2

22
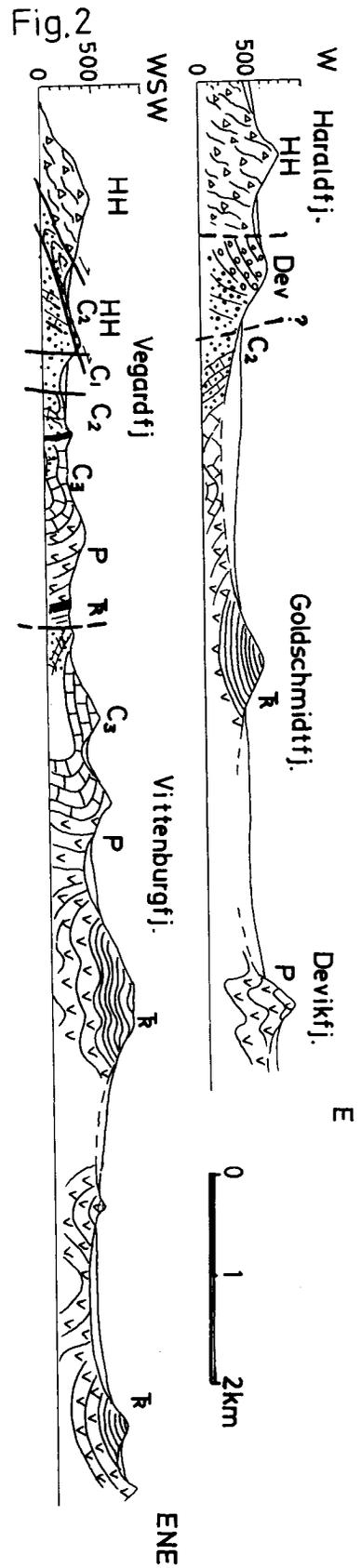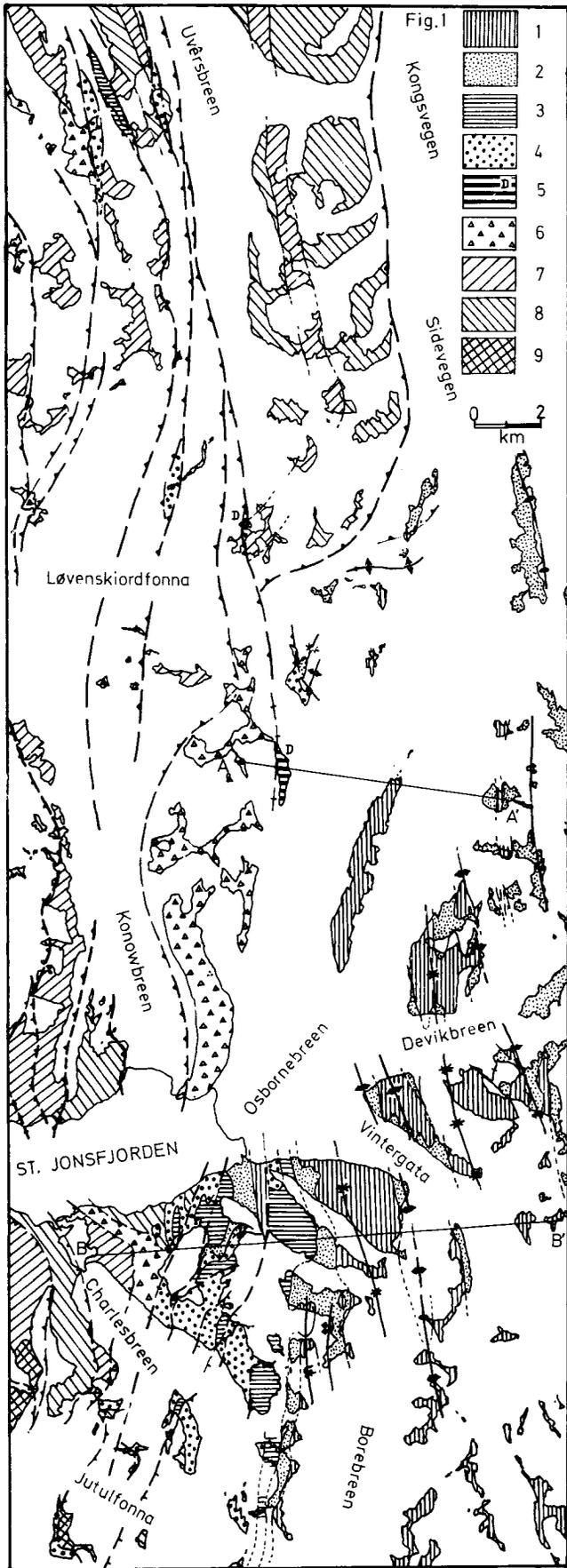
Fig.3
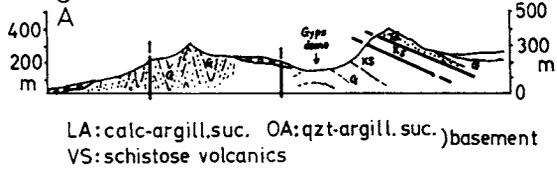
Or : Orustdalen Fm.
Vg : Vegaard Fm.
Pt : Petrelskardet Fm.
Tå : Tårnkanten Fm.
G : Gipsdalen Gr.
KS : Kapp Starostin Fm.
Ŧ : Triassic strata

LA : calc-argill.suc.   OA : qzt-argill.suc.) basement
VS : schistose volcanics

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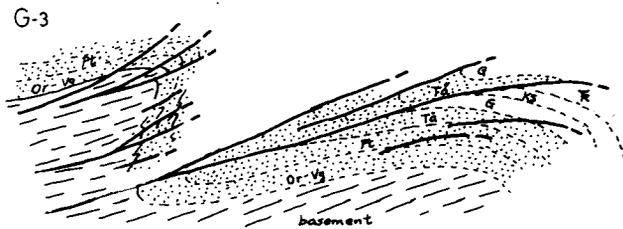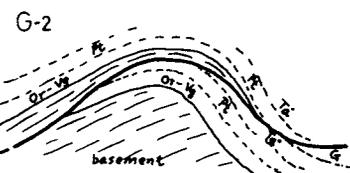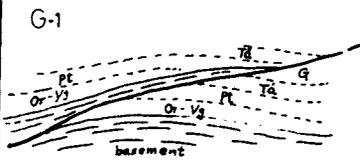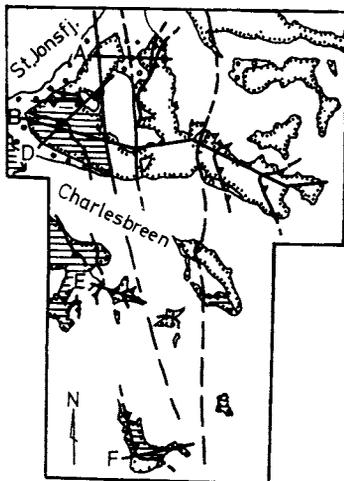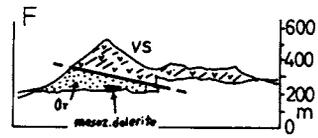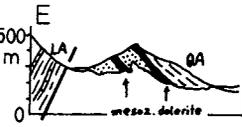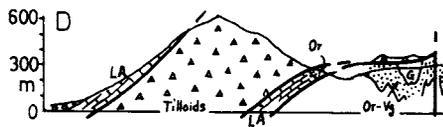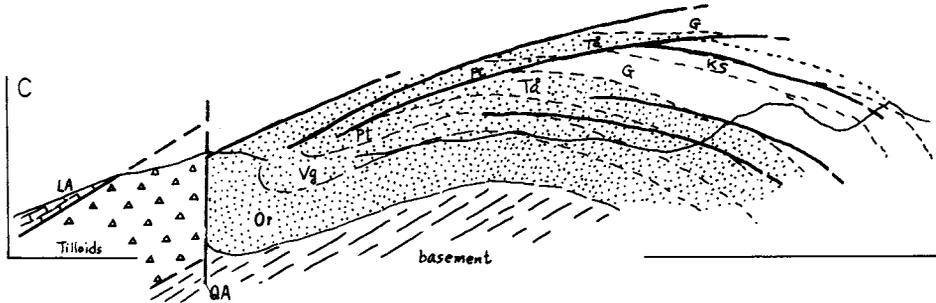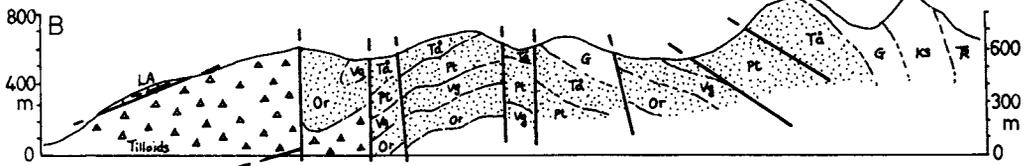
gently eastward dipping thrusts and the sandstones of the Tårnkanten Fm. overlie the Kapp Starostin Fm.. The A section is possibly situated on the eastern extension of the axial part of the overturned syncline of the B section. A composite profile of A and B is presented in C, Fig. 3, to show the structure prior to the steep extensional faulting.

At three localities, the D, E and F sections, Fig. 3, the basement rocks overlie the Carboniferous white sandstones of the Orustdalen Fm.. The Vendiann tilloid unit horizontally overlies by thrust steeply folded Carboniferous sandstones in the D section. In the E and F sections, pelite phyllites and basic metapyroclastic rocks of Late Riphean age, respectively, overlie the Carboniferous quartzitic sandstone by thrust faults with moderate to gentle easterly dips. These occurrences of Carboniferous rocks under the basement rocks, can be explained by a successive folding of thrust sheets which involve the basement rocks, as shown in G-1 and G-2, Fig. 3. The east-ward dipping thrust surfaces observed in all sections, are inter-pretated to be the result of successive roatation result of initially westward dipping surfaces. The inferred positions of the sections are shown in the idealized cross-section, G-3, Fig. 3.

If a dextral transpression system is asssumed along the basement-platform boundary, the Brøggerhalvøya area is a restraining, contractional area, while the inner St. Jonsfjorden area may be a releasing, extensional site. But all observed structures, except for the later steep faults, in the latter area are undoubtedly compressive ones, produced by an ESE directed stress. Thus, a local deviation of the main compressive stress is inferred, from W to E in the north and WNW to ESE in the south of St. Jonsfjorden. Isolated narrow wedges of Carboniferous rocks in the northern part of Fig. 1 are the roots of thrust sheets, and main parts of thrust-folded Carboniferous rocks which might have had similar structures as in Vegardfjellet, may have been removed by erosion. Occurences of two narrow Devonian rocks in NW Osbornebreen and E Løvenskioldfonna (Fig. 1), indicate that the western boundary faults of the Devonian graben extend to the south into the present area, and controlled the position of the basement-platform boundary.

Legend of Fig. 1

1) Triassic strata, 2) Kapp Starostin Fm., 3) Gipsdalen Group, 4) Lower to middle Carboniferous clastic rocks, 5) Devonian sandstones, 6) Vendian tilloids, 7) Calc-argillaceous succession, 8) Quartzite-argillite succession, 9) Basic, meta volcanic rocks. 7, 8 and 9 are of the Late Riphean age.

Yoshihide, Ohta.

STRUCTURES OF CARBONIFEROUS STRATA AT TRYGHAMNA AND ALONG THE SE
MARGIN OF THE FORLANDSUNDET GRABEN

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Norway.

(1). Trygghamna region.

The eastern and northern sides of Trygghamna are composed of
subvertical Carboniferous-Triassic strata and an anticlinal crest
is expected to the west. A coal-bearing, white sandstone occurs
on the inner-west coast of Trygghamna and a limestone-sandstone
alternation forms Knuvlen to the west (Fig. 2). The strata show
folds of less than 100 m wavelength and the beds often show an
inverted position. Tight overturned folds are well exhibited on
the eastern cliff of Knulven, with NW-SE striking, gente SW
dipping axial planes. A distinct thrust occurs in the same
direction. The rocks are faulted down at least 750 m by a
ESE-NWN trending fault along the northern slope of Protektor-
aksla.

To the south and west of the Carboniferous rocks a thick
Precambrian limestone-pelitic phyllite succession occurs with
gentle W-dipping structures. Both limestone and pelite layers
often include small scale isoclinal folds and preferred orien-
tation of constituent minerals defines the cleavages. Gentle W-
dipping thrust faults develop in the limestone-pelite succession
(Fig. 1.), locally showing discordant, ascending sections (Fig.
3-1). Several overturned folds with E-verging structures are
associated with the thrusts. The compositional layering and
cleavages are folded, while a new generation of cleavage is very
weak. One fold at Alkhornet is an overturned synform with a few,
E-dipping backthrusts under major thrusts. Another on the SE-
ridge of Daudmannen (Fig. 3-2) shows brittle box-shaped folds,
contrasting the strongly ductile Caledonian deformation. When the
Carboniferous rocks of Knuvlen are restored to the position
before the ESE-WNW normal faulting, the SE-Daudmannen thrusts are
on the southern extension of the Knuvlen thrust. Thus, the Daud-
-mannen thrusts are inferred to be of Tertiary in age, or at
least reactivated in the Tertiary time. The brittle nature
of associated folds is consistent with this interpretation.
Extending this interpretation, most W-dipping thrusts in the

Precambrian rocks on the northern coast of Isfjorden also reativated in the Tertiary deformation period. These thrusts do not show steepening to the west up to the subvertical graben margin faults near Daudmannsodden, where the latter clearly cut the gentle structures.

(2). SE margin of the Forlandsundet graben.

At least two horst-graben pairs occur along the margin from St. Jonsfjorden to Daudmannsodden, and a narrow (max. 1.5 km wide) sliver of Carboniferous rocks occupy the eastern graben. The eastern border of the Carboniferous rocks is a steep fault, while the western one is locally a fault and locally an unconformity (Fig. 4-1). The unconformity is preserved at the northern side of Eidembukta and south of Tordenskioldbukta to Kapp Scania, with gentle E-dips. The strata involved in the graben are from Orustdalen Fm. to the Nordenskioldbreen Fm., a max. thickness = 1415 m. The source area is estimated to be to the west from the current directions.

Two types of folding have been recognized, 1) tight-isoclinal, E-ENE verging folds with local, spaced axial plane cleavages without new mineral growth (Fig. 4-2), and 2) open folds with sub-vertical axial planes, roughly parallel to the marginal faults. The 2) can be explained by down-throw of the graben zone, but the 1) can not. The 1) indicate definite compressional structures which are older than the graben faulting.

The marginal faults have a NNW-SSE strike and steep dips. Regional structures including Precambrian rocks appear to be NNW tapering wedges, the tips of which are at about the St. Jonsfjorden coast and north of Eidembukta. The faults inside the Carboniferous zone at the latter area show a sinistral wedging. The structures of Precambrian rocks are distinctly different in trend on either side of the zone and this difference existed before the formation of the graben zone.

The faults cutting the Carboniferous rocks form two groups; one group at a small angle to the marginal faults, with mainly a normal throw, and may be splay faults to the marginal ones, and the other group at a high angle to the marginal faults, with both normal and reverse displacements, and some of which have gently plunging slip striations indicating strike-slip movement.

An attempt to explain all these structural parameters by a single sinistral transpressional system is shown in Fig. 5. However, the orientations of some faults and many observed fold axes do not fit with this model. An alternative interpretation is that these structures were formed under different stress fields at different times; 1) the E-ENE converging folds formed by a compression from the W, and 2) the extensional graben faulting, 3) weak compressional stage to producing a conjugate set of faults in NE-SW and NW-SE strikes, which cut the graben margin faults. If this is the case, the compressional tectonic regime, typically developing along the basement-platform boundary about 20 km to the east, occured in this area, before the formation of Forlandsundet graben.

Fig. 1

Fig. 2

Fig. 3-1

Fig. 3-2

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Fig.5
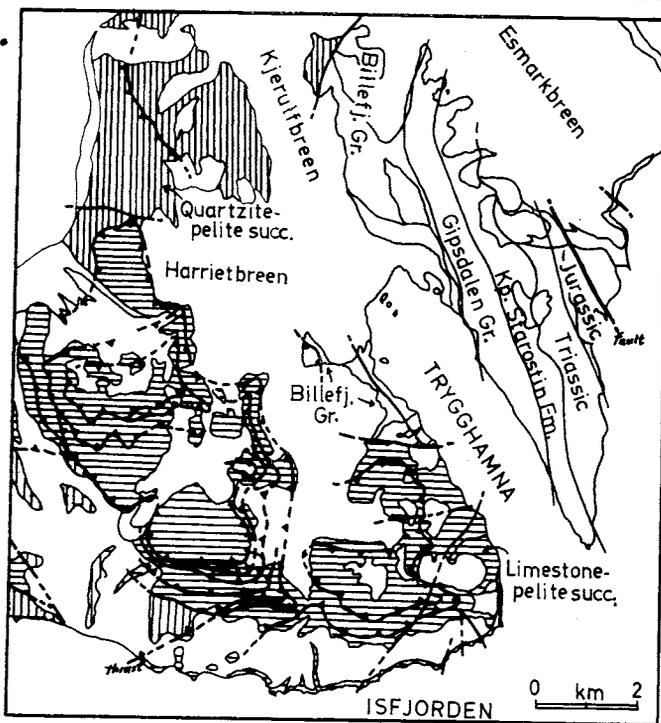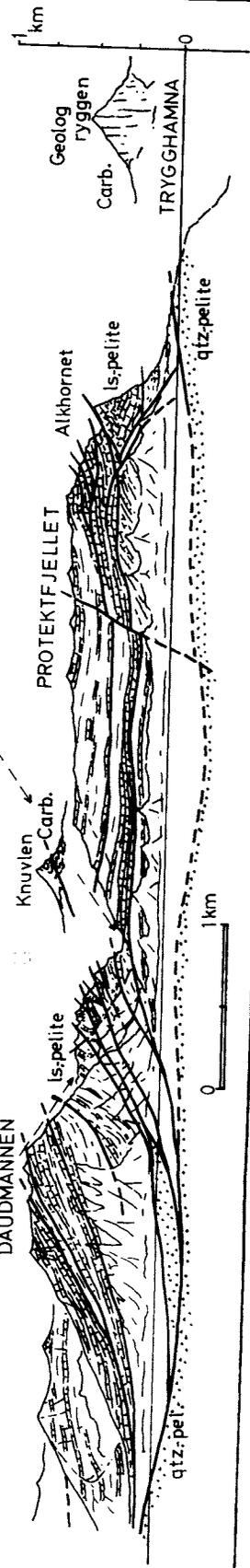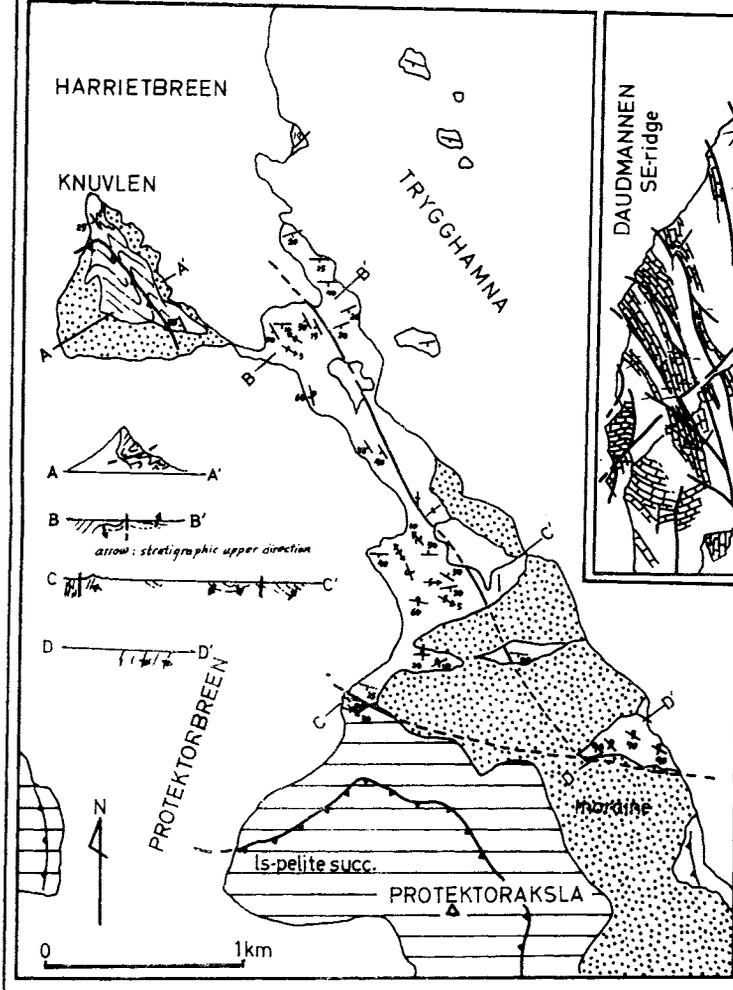
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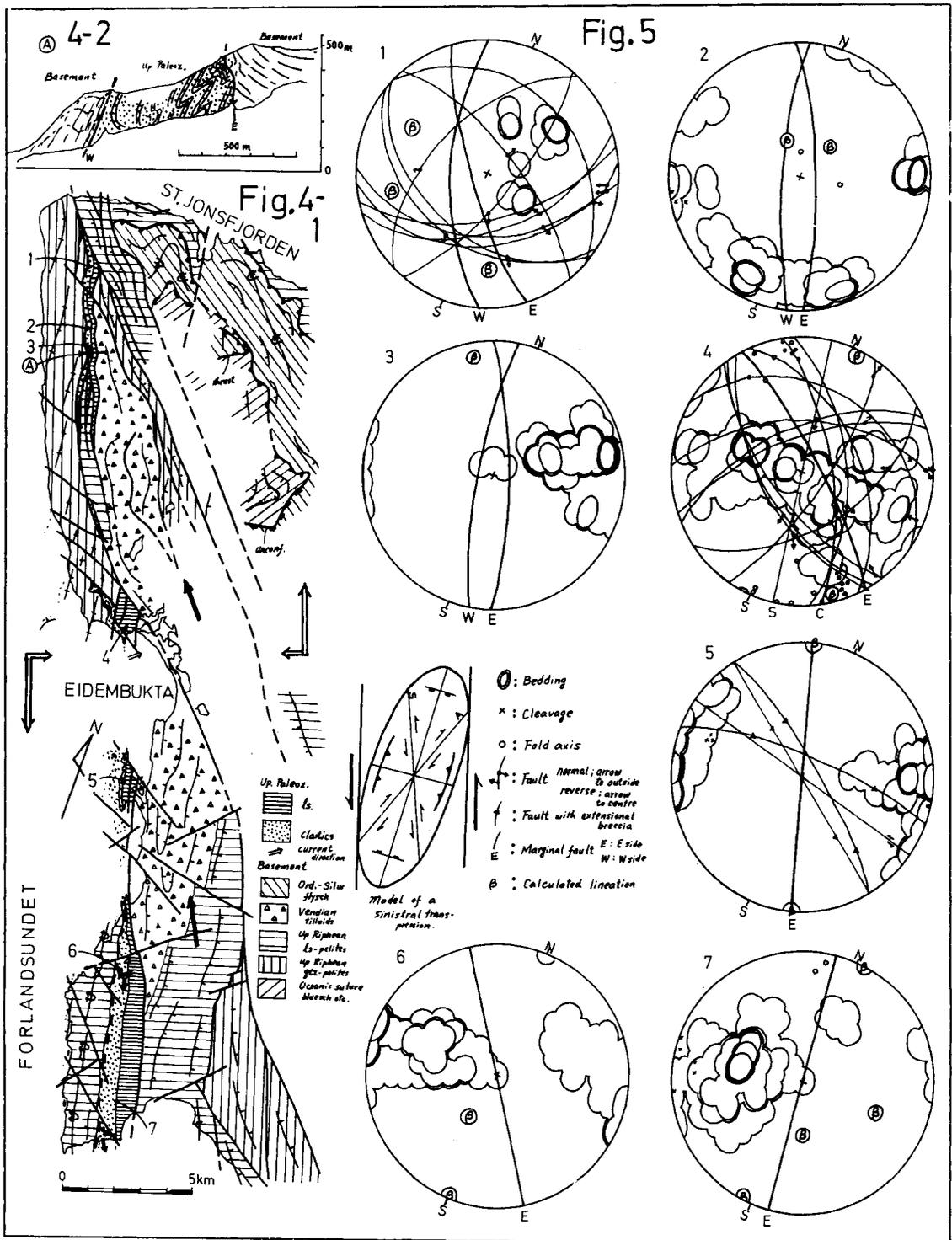
Audun Hjelle

TERTIARY STRUCTURES IN WESTERN NORDENSKIOLD LAND

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1. Kapp Linné

A prominent NNE/SSW-trending fault passes to the east of Strokdammane-
Tunsjøen (Fig.). No Paleozoic or younger rocks which would indicate the
absolute or relative age of the fault occur here. The rocks on the east
side of the fault most likely belong to the ´pre-Vendian limestone beds
with phyllite´ (´unit 8´ of Hjelle & Lauritzen 1986). On the west side
Vendian tillites occur and suggest a downthrow to the west of more than 200
m. Due to the straight course of the fault a young, probably Tertiary age
is assumed.

To the west the fault cuts older curved faults of NNW/SSW trend. These less
pronounced faults split the western area into at least 3 blocks. The pat-
terns of bedding, cleavage and mesoscopic folds differ significantly from
one block to another. If these structures primarly developed during the
Caledonian deformation the faults are of post-Caledonian age, probably
Tertiary. The fault passing just east of Kapp Linné contains breccias and
strongly developed slickenside on local fault planes and is easily recog-
nized in the field. The local fault planes dip c. 60^g towards the WSW.

Faults with downthrow to the NW can also be seen to the south of Kapp Linné
A sinistral movement between the two western blocks might explain the
structural difference between them.

Uncertain observations of sandstone with possible plant remains from a
skerry to the SW of Kapp Linné suggest that late Paleozoic rocks could have
been preserved due to near-shore faults. A small basin revealed by seismic
profiling some 5 kilometres to the NW of Kapp Linné (Eiken & Austegard
1987) might be related to such faults.

2. Orustosen

A narrow wedge of Carboniferous sandstone with thin shaly, plant bearing
horizons occurs here in the basement rocks (Fig.). The beds are striking
c. NW-SE i.e. parallel to the trend of the wedge, with dip c. 65^g NE. The
calculated stratigraphic thickness of the sandstone is c.400 m. and the
lithology suggests a correlation to the Orustdalen Fm. of the Bille-
fjorden Group. Basal conglomerate or other primary depositional contact to
the basement rocks is not observed.

Basement rocks to the south of the sandstone are faulted and brecciated and
their mesocopic structures show scattered patterns compared to those of
surrounding areas, probably due to splitting up of the area in numerous
small blocks by faulting. As a whole, this area is the most dissected and
structurally least homogenous one seen in the coastal area between
Isfjorden and Bellsund. The sandstone is also partly brecciated, especially

at its NE contact to the basement rocks, and, except for a few outcrops, only occurs as loose blocks from underlying beds. The Carboniferous rocks are thought to be preserved as a half-graben by faulting on its NE side.

Several thrust faults close to and parallel to the southern sandstone-basement contact and the lack of a Carboniferous basal conglomerate indicate that the contact here might be of fault origin. Extensively developed slickenside to the south of the sandstone and the Orustosen outlet suggest thrusting towards the NE. To the SW of the Carboniferous sandstone the structures in the basement rocks bend into parallelism with the trend of the basement-sandstone-contact. The lithology and assumed stratigraphical position of the basement rocks are similar on both sides of the sandstone wedge, and the displacement due to thrusting therefore does not seem to be great.

Considering the observations mentioned, the Orustosen faults are of post Billefjorden age, probably Tertiary. Assuming a fault plane dipping 75^g towards the SW the relative downthrow in the suggested half-graben may have exceeded 320 m. The deformation of basement rocks to the SW of the sandstone, with chlorite on slaty cleavage surfaces might have developed during the Tertiary, and reworking of older structures should not be precluded. The faulting and the bend of the common NNE-SSW trend of the basement rocks into the WNW-ESE direction suggest a SW-NE compression combined with left simple shear.

3. Kapp Martin

A narrow NNW-SSE trending outcrop of conglomerate, and sandstone with plant remains occurs to the north of Kapp Martin along the east side of Lågnesrabbane (Fig.). The outcrop is c. 5 km long and of max. 250 m width. The bedding parallels the outcrop, with a dip of c. 50^g to the ENE and a calculated max. thickness of c. 130 m. Lithology and fossil content suggest correlation with the Orustdalen Formation of the Billefjorden Group. Similar Carboniferous rocks are preserved by faulting c. 5 km to the east. Basal conglomerates in the lowest part of the Carboniferous succession suggest a primary contact. The eastern boundary reveals breccias and a main NNW-SSE fault is assumed. If the fault plane dips c. 75^g WSW the relative downthrow must exceed 120 m. E-W sinistral faults displace the main fault.

Comparing the basement rocks to the west and east of the main fault, a contrast occurs in both lithology and structure which at present is explained by faulting. Much less variation occurs in the Carboniferous rocks. This suggests that the main observed differences in lithology and structure of the basement rocks could have been established in pre-Carboniferous time and was reactivated during the Tertiary orogeny, preserving the Carboniferous rocks by faulting.

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ISFJORDEN

GRØNFJORDEN

5 km

NORDENSKIÖLDKYSTEN

BELLSUND

Carboniferous
(Billefjorden Gr.)

Late Riphean and Vendian

1

Isfjorden

?

Kapp Linné

15

80

Linnévatnet

20

15

75

Fyr-
sjøen

Tun-
sjøen

50

15

?

2

50

Orust-
osen

65

55

85   35

35

25

55

30

Gravsjøen

30

50

80

3

50

20

25

30

30

40

30

Lågnes-
bukta

40

Kapp Martin

Bellsund

31
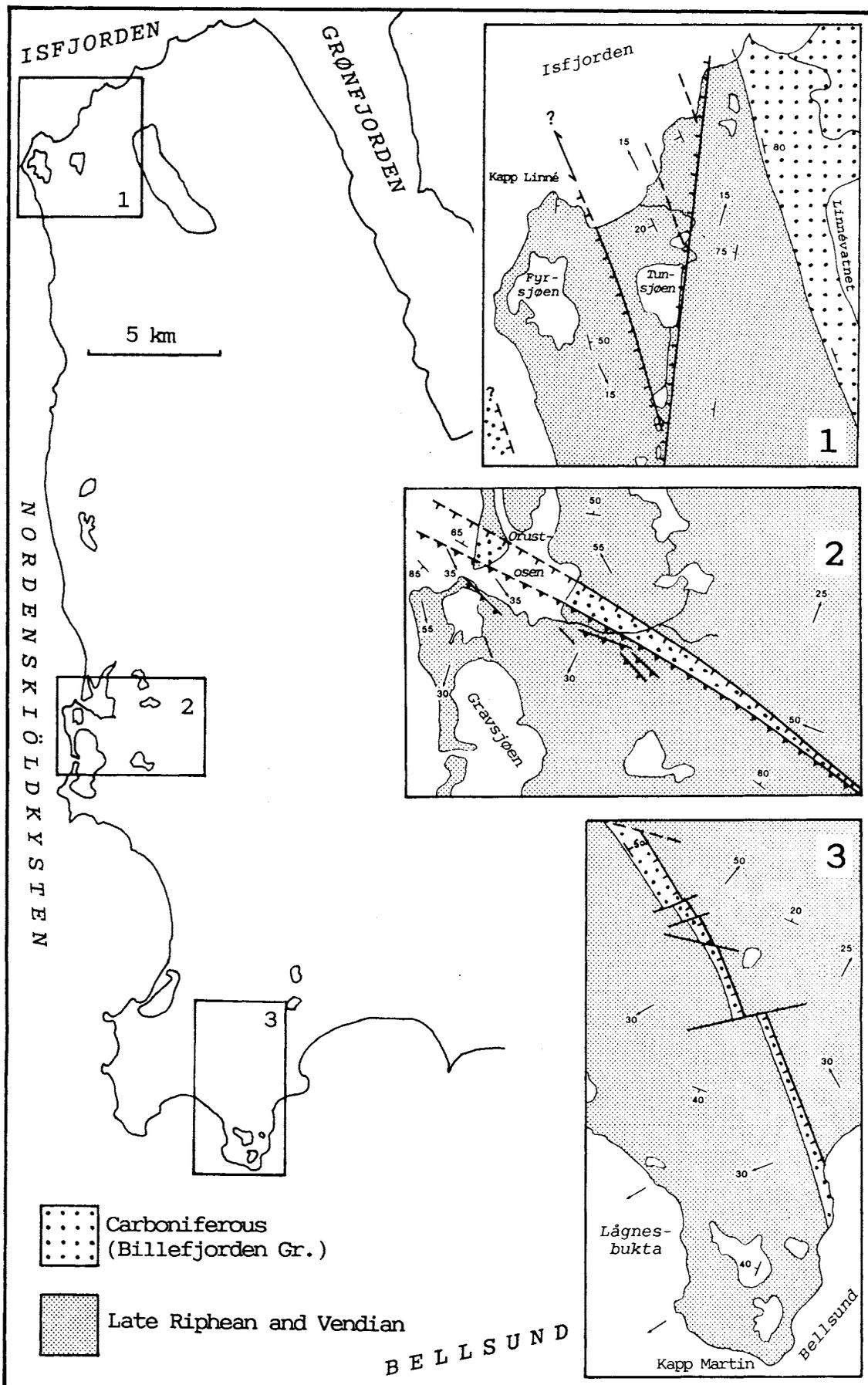
AN ADDITIONAL PRESENTATION ON THE BASEMENT-PLATFORM BOUNDARY STRUCTURES IN NW NORDENSKIØLD LAND

Yoshihide Ohta, Norsk Polarinstitutt

1. Sinistral extensional faulting along the basement-platform boundary, west of Linnédalen.

The sub-Carboniferous unconformity is subvertical at the Isfjorden coast, ca. 1 km west of Linnéelva, and extends to the N ridge of Griegaksla, then along the eastern foothill of Griegfjellet. A small, NNW-SSE trending Culm sandstone-conglomerate sliver within Precambrian rocks has been mapped and two more slivers of the same rocks are clearly seen on vertical airphotos. These rocks have a moderately E-dipping uncomformity surface along their western margines, while the eastern margins are steeply W-dipping normal faults. The structures inside the slivers are NNW-SSE striking, moderately E-dipping monoclines, while the basement rocks between the slivers have a N-S strike and steep W-dipping cleavages.

The echelon arrangement of these Carboniferous slivers with normal faults borders, infers an extensional event, possibly a result of a sinistral transpressional stress system. The timing of this event is not clear, but the moderate E-dips of the unconformity surfaces, contrasting to the steep dip of the same surface in adjacent areas, may indicate that this event preceded the major compressive event.

2. Southern Isfjorden profile off Kapp Starostin.

A seismic profile has been presented by Gudlaugsson and Faleide, along a ENE-WSW striking line a few km off the coast. The profile shows that the Carboniferous-Permian strata exists about 3-4 km below sea level, while the same strata are exposed on the surface of shoreline. Thus, the strata occur at two different levels in the profile.

These general profile structure obtained from the surface data and oblique airphotos along the coast, has been projected on the seismic profile, and their structural relation were considered. The surface structures show a step-like fold geometry, with some subordinate folds on the gentle limb, one steep limb along the western side of Linné dalen and another along the west coast of Grønfjorden. The most probable structural interpretation is that the steep limb along Grønfjorden is cut by many W-dipping thrusts which push up the shallow rocks onto the underlying Upper Paleozoic strata. A large part of the resultant strain was probably absorbed by complex imbrication structures within ductile Triassic shaly strata. This profile agrees very well with those of adjacent areas both to the north and south along the basement-platform boundary.

surface data GRÖNFJ.   20 km

Tertiary
m.Cret.
l.Cret.
u.Jura.
m.Jura.
m.Trias.
l.Trias.
Perm.
m.Carb.

sesmic interpretation

twt s

pre-Cam.   pre-C.

Gipsd.
Billefj.

ISFJORDEN

seismic line

Festningen

Tert.

0   2 km

N

GRÖNFJORDEN

K.Star.
Gipsdalen Gr.
Billefj. K.Starostin

Linnéelva

Varde-
borg

Linnévatnet

Grieg
aksla

Vöringen

Grieg
fjellet

Linnédalen

Braganza
toppen

Kalkegga

Precambrian

Billefj. Group

Gipsdalen Gr.

K.Starostin Fm.

Triassic

Jura.   Cret.

33

Harmon D. Maher, Jr.

MINIMUM ESTIMATE OF TERTIARY SHORTENING SUGGESTED BY
SURFACE STRUCTURES EXPOSED ON MIDTERHUKEN, BELLSUND,
SPITSBERGEN

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While the dextral transcurrent component of the
Tertiary, intracontinental, transpressional zone within the
then-contiguous Greenland-Barents Shelf area is constrained
by geophysical seafloor data, the convergent component must
be constrained by evidence from crustal structures on
Svalbard and Greenland. No evidence of significant wrench
tectonics occurs on Midterhuken. Indications of transport
direction are sub-perpendicular to the present shelf
margin, and by inference to the overall zone of dextral
transpression. Dextral and convergent components were
likely decoupled. Therefore, a cross section of Midterhuken
structures (Fig. 1) can provide minimum constraints for
crustal shortening in this segment of Svalbard's Tertiary
fold-and-thrust belt. Significant structures and related
shortening are discussed below from W to E.
    The E-dipping Midterhukhamna fault (MF) has a footwall
flat of Nordenskioldbreen Fm. strata and a hangingwall flat
of Billefjorden Grp. strata. Down dip it splits into the
shallowly E-dipping Bravaisknatten fault (BF) which offsets
Kapp Starostin strata 1.2 km, and a continuation with
normal stratigraphic relations across the fault (i.e.
Gipshuken Fm. hangingwall). This set of faults is best
interpreted as a foreland rotated flat (MF) and ramp (BF).
A minimum estimate of 800-1000 m of slip on the flat is
given by the dip-length of the exposed fault with
Billefjorden Grp. hangingwall strata plus the stratigraphic
interval traversed in order to produce the observed
stratigraphic inversion. Notable folding and small scale
faulting within the rocks overlying the MF (Fig. 1)
indicate stratal shortening of some 900 m above the
underlying flat; i.e., restoring hangingwall internal
deformation and then reversing MF movement moves a point in
the hangingwall some 1.7 km up-dip with respect to a point

below the inclined footwall flat. While some 1.2 km of this
transport was transferred to the BF the rest must have been
accommodated along the flat continuation. Due to an
original angular discordance between Billefjorden Grp. and
overlying younger strata across an angular unconformity,
movement along the MF also tilted hangingwall rocks farther
E some 30-35 degrees (Fig. 1). The BF projects into the
subsurface to the E, probably as a flat within Botneheia
Fm. strata. Its connection with overlying structures here
is a critical aspect of kinematic models.

The steeply E-dipping Midterhuken decollement (MD) lies
at the base of Botneheia Fm. strata. Overlying upper
Triassic and Jurassic strata strata are notably folded,
while underlying strata are tilted, but mostly unfolded.
Sinuous bed estimates of shortening (5 cross sections) are
all within the 1600-1800 m range. A S shore cross-section
shows a notably lower value and represents an anomaly
(discussed later). Offset of a dike on the N side of
Midterhukfjellet on some of the lower slip surfaces that
characterize the MD suggests hanging-wall down movement.

Three possible models for these structures with
different implications for their contribution to shortening
are: 1) they are E-directed structures which formed over an
originally subhorizontal thrust-flat and were later rotated
into their present position (e.g. Ringset, this vol.); 2)
they are gravity induced structures that formed after or
during tilting of their present steep position (Maher and
others, 1986), or 3) they are structures above a backthrust
(Dallmann, this vol.), i.e. slip was up-dip and
syn-tilting. Observations made by Dallman (this vol.) on
Berzeliustinden to the S indicate that folding above a
NE-dipping detachment also at the base of the Botneheia
folding a backthrust associated with the Berziuliustinden
thrust. Since the Berzeliustinden thrust produced the
tilting of the overlying Triassic strata (including the
Botneheia), folding and detachment with a geometry very
close to that on Midterhuken occurred syn- or post-tilting.
In summary the first model is inconsistent with the best
argument for relative timing of tilting versus detachment
and folding, while the third model is inconsistent with the
dike offset, leaving the second model by default.

However, the third model also explains a structural
anomaly as a result of a subsurface connection between the
BF and MD. On Midterhuken's S shore two important changes
occur. First, there is an overall swing in the structural
trend of the rocks and structures above and below the MD to
a more N-S trend. This suggests less offset on the
BF (arrows - Fig. 2). Second, there is a change from a
distinctly cylindrical to a distinctly conical fold form,
with folds diminishing along axis to the SW. In the first
two models this would be coincidence, but it would be a
consequence of the backthrust model with a decrease in
movement along the BF connected to the MD producing the
conical forms. The dike offset will be reinvestigated -
perhaps more than one dike exists in the area.

Farther E a series of folds in Helvetiafjellet and Carolinefjellet Fm. sandstones have subhorizontal enveloping surfaces, a sinuous bed shortening of 800-1000 m, and an underlying decollement estimated to lie some 1200 m under the Festningen sandstone within the synclinal keels (i.e., about 800 m below sea level). Janusfjellet Grp. shales exposed below the sandstones show a complexity of small scale E and W directed thrusts and tight folds. These structures likely represent the accommodation of slip above a subsurface thrust within Botneheia or deeper strata. A lack of marker horizons within the Janusfjellet Grp. makes estimation of stratal shortening of these structures difficult. It should be equal to or greater than that of the overlying Cretaceous sandstones.

Farther E Carolinefjellet Fm. and Tertiary strata dip moderately to shallowly E as the W limb of the central basin syncline. Recent work by Nottvedt and Rasmussen (1988) and Nottvedt and others (1988) indicates that Tertiary structures extend under these tilted but otherwise mostly undisturbed strata. On a speculative note, assuming conservation of area and different depths to a flat basal decollement estimates ranging from 2.0 to 8 km can be made for the amount of blind subsurface shortening necessary to cause the observed W-limb tilting. A basal detachment within the Triassic would imply 4-5 km of shortening.

What subsurface structure(s) produced uplift and tilting of the basement Hecla Hoek rocks unaccounted for by surface structures? The Berzeliustinden thrust to the S (an extension of which may very well underly Midterhuken – Dallmann, this vol.) indicates basement involvement is in the form of of an earlier-formed, high-angle, fault propogation fold that later moved over a low-angle ramp and/or flat within Triassic strata. Taking a simple anticlinorium arch and an angular, fault-bend fold style (Fig. 1) as endmember geometries, and assuming a range of reasonable depths to autochthonous basement, shortening of the unconformity surface can be bracketed between 1 km to 6 km. While the subsurface geometry is poorly constrained, several kilometers of shortening are likely associated with basement uplift and tilting. Importantly, related thrust faults must be blind since surface structures to the E are inadequate and already accounted for in terms of the overlying BF. Structures underneath the W limb of the central syncline may represent eastern accommodation of fault movement responsible for basement uplift.

In summary, at least 4 km of stratal shortening are required by Midterhuken structures. If model 1 for the MD is adopted, an additional 1.6-1.8 km is required. Up to 8 km of shortening is permitted by the mapped structures. Considering that this is only a partial transect of Tertiary deformation and that Tertiary structures may exist farther W and E of the segment described here (e.g. Haremo and Andresen, this vol.), total shortening is probably significantly greater than this (tens of km with a simple extrapolation).

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Ringset, N., this vol.: The thrust system of Midterhukfjellet, Bellsund. Norsk Polarinstitutt Report Series # 42.

Figure 1: Midterhuken cross section identifying major structures. HH - Hecla Hoek basement, Cb - Billefjorden Grp., Pk - Kapp Starostin Fm., J - Janusfjellet Grp. Small dots - Kapp Toscana Fm. (Triassic), large dots - Helvetiafjellet Fm. Several geometries for fault-bend uplift and tilting of HH depicted - see text for discussion.

Figure 2: Geologic map of Midterhuken's S shore area. BF and MD as in text. Pk - Kapp Starostin Fm.
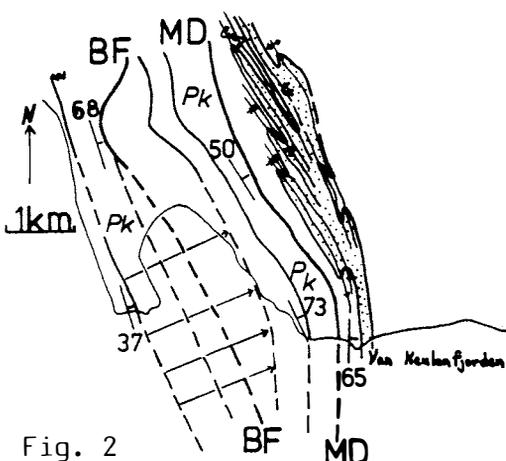
Fig. 2
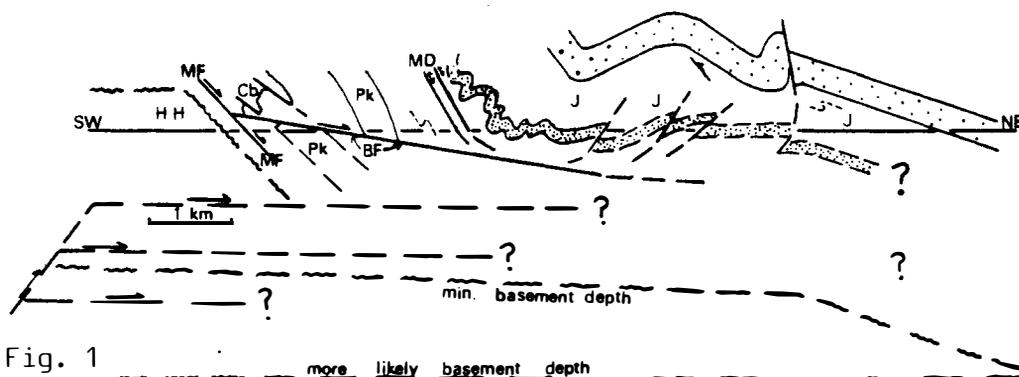
Fig. 1

Narve Ringset

THE FOLD AND THRUST SYSTEM OF MIDTERHUKFJELLET, BELLSUND

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The exceptional exposures on the north face of Midterhuk-
fjellet provide a display window of the structural styles
of the Tertiary fold and thrust belt of Spitsbergen on
the whole range of stratigraphical levels.

Structures in the Mesozoic rocks were interpreted by
Maher et. al. (1986) as a possible result of gravity
gliding. An alternative model for the evolution of these
structures is presented here.

Two décollement zones are located in Mesozoic strata in
the Midterhukfjellet area. The lower Midterhukbreen
Décollement (Maher et. al. 1986, fig. 1), or the floor
thrust, is located in the Triassic Bravaisberget Fm. The
upper Nordlikollen Décollement (fig. 1), or the roof
thrust, is located near the Jurassic / Cretaceous border,
or between Agardhfjellet and Rurikfjellet Mbs. of the
Janusfjellet Fm. The intervening strata are extensively
deformed. Two principal styles of deformation are
recognized, both of which are controlled by lithology
(fig.1).

The Triassic/Jurassic Kapp Toscana Group is concentric-
ally folded. A dominant, competent sandstone, sandwiched
between two thin-bedded, incompetent sequences controls
the fold geometry. This style of deformation requires
detachment zones both above and below the folded strata,
as showed in fig. 2. The detachment zone below the fold
train may be identical with the floor thrust, and an
upper detachment may be located in the lowermost part of
the Agardhfjellet Mb. (fig. 1).

CROSS SECTION LÅGKOLLANE - MIDTERHUKFJELLET
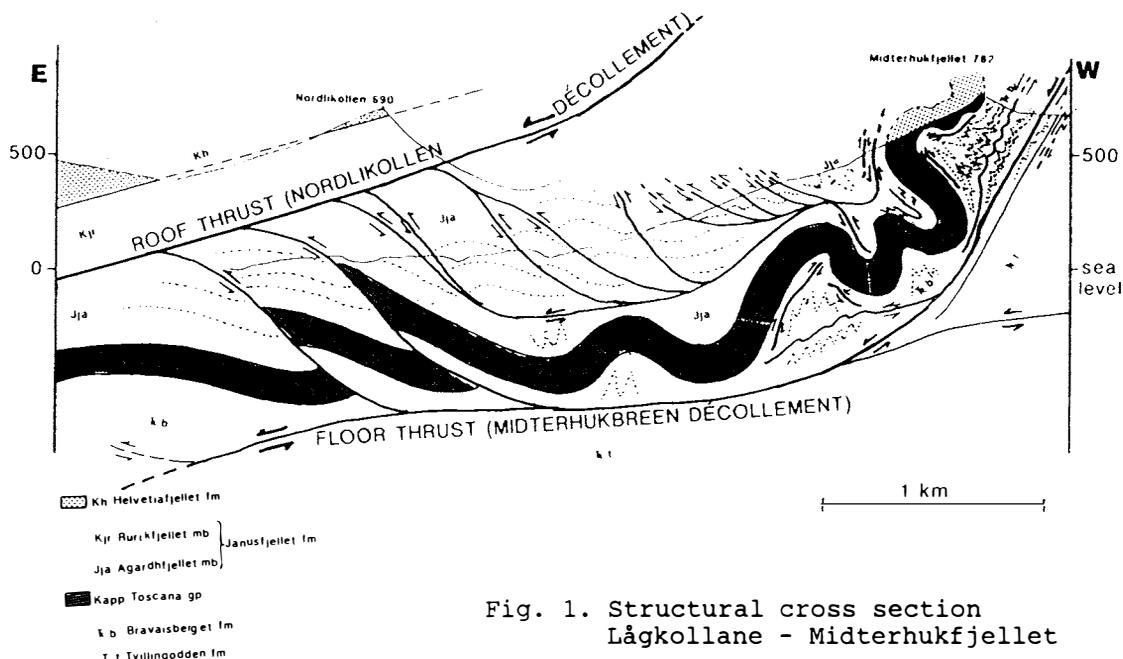
Fig. 1. Structural cross section
Lågkollane - Midterhukfjellet
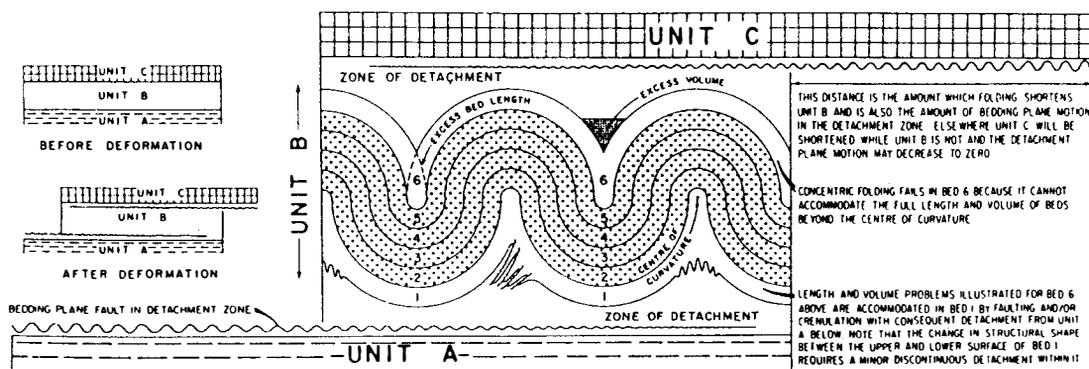
Fig. 2. The ideal concentric fold (Dahlstrom 1970)

The basal beds of the shale-dominated Agardhfjellet Mb., lying below this detachment zone, fills the cores of the concentric synclines. They show minor out-of-syncline fashion drag folds.

The Bravaisberget Fm., underlying the Kapp Toscana Group, fills the cores of the concentric anticlines. Its incompetent, thin-bedded strata are characterized by chevron folds, as well as numerous slippage zones and imbricate thrusts. These imbricate thrusts branch out from the floor thrust (Midterhukbreen décollement), which is parallel to the Lower Triassic/Permian foot wall strata.

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Between the concentric fold train and the roof thrust, Janusfjellet Fm. contains several imbricate thrusts, joining the roof thrust asymptotically. The roof thrust is parallell to the bedding of the relatively undeformed hanging wall.

In westerly exposures of Janusfjellet Fm., these imbricate thrusts are interpreted to branch out from the detachment zone above the folded sequence. Eastwards, the amplitude of the concentric folds decrease, and the floor thrust probably cuts up section. In its easternmost exposure, the Kapp Toscana Group is involved in an imbricate thrust sheet. From this point and eastwards, the imbricate thrusts are interpreted to branch out from the floor thrust in the Bravaisberget Fm. Thus, we have here a classic **duplex** (Dahlstrom 1970), causing a significant shortening and thickening of the shale-dominated Jurassic sequence.

The effect of this fold and thrust system is to transfer the eastwards propagating displacement gradually from the lower Midterhukbreen décollement to the higher stratigraphic level of the Nordlikollen décollement. This comprises roughly a doubling of the stratal thickness between the two décollements.

The two described décollement horizons exhibit easterly dips, and folds are overturned towards east. This feature may be interpreted as a result of folding above an **antiformal stack** (Boyer & Elliot 1982), produced by the development of younger, deeper thrusts. These thrusts involved Late Palaeozoic strata, and eventually the structural basement, Hecla Hoek rocks. Folding of the strata above the antiformal stack induced out-of-syncline directed shear, which caused the development of small, west-vergent thrusts and drag folds on the east-dipping limb (fig. 3).

FLEXURAL SLIP
ON HANGINGWALL
DETACHMENTS
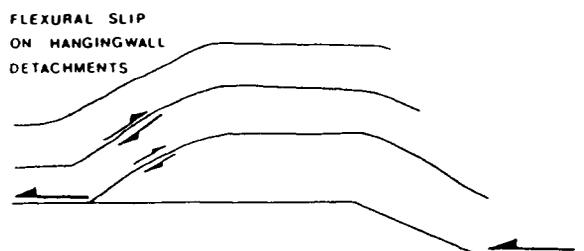
Fig. 3. Flexural slip on hangingwall detachments in a frontal culmination wall (Butler 1982)

The duplex in the Janusfjellet Fm. shales continues eastwards at the same stratigraphical level, but dips under sea level at Lågkollane. Thus, the Tertiary fold

and thrust belt does not stop abruptly, as supposed by
Maher et. al. (1986). Instead, it continues underneath
the Central Basin, to reappear at the surface along the
Billefjorden Fault Zone.

The structural assemblage at Midterhuken includes low
angle reverse faults, décollement, duplexes, folded
thrusts and concentric folds. These are structures that
can be expected in a classic, foreland prograding fold
and thrust belt. They indicate that the tectonic scenario
in the vicinity of Midterhukfjellet can be ascribed to
eastward thrusting. This thrusting presumably happened in
Late Eocene time, as Eocene stata in the Central Basin
are folded above the duplex thrust zone.

When attempting to construct balanced cross sections
through the thrust belt, a pin line must be placed some
150 km east of Midterhukfjellet, in the Storfjorden-
Edgeøya region. Since Mesozoic strata show a great deal
of displacement for a long distance eastwards, cross
sections through this part of western Spitsbergen must
show Palaeozoic strata in excess at depth, as they are
piled up in the core of the Midterhuken antiformal stack.

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THRUST TECTONICS SOUTH OF VAN KEULENFJORDEN

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In the area between Hornsund and Bellsund (SW Spitsbergen, Fig. 1), the
boundary between the Caledonian and post-Caledonian strata is complica-
ted by thrusting in Early Tertiary times. Later tilting of ca. 1° of
southern Spitsbergen to the north-northwest exposed continuously lower
structural levels of the Tertiary orogen to the south. An approximately
1 km depth interval of the thrust belt structure can thus be observed.

Restoring the section of this interval, it is shown that the Caledonian
unconformity dipped moderately eastward prior to the onset of thrusting.
Furthermore, thrusts have been progressively rotated causing more gen-
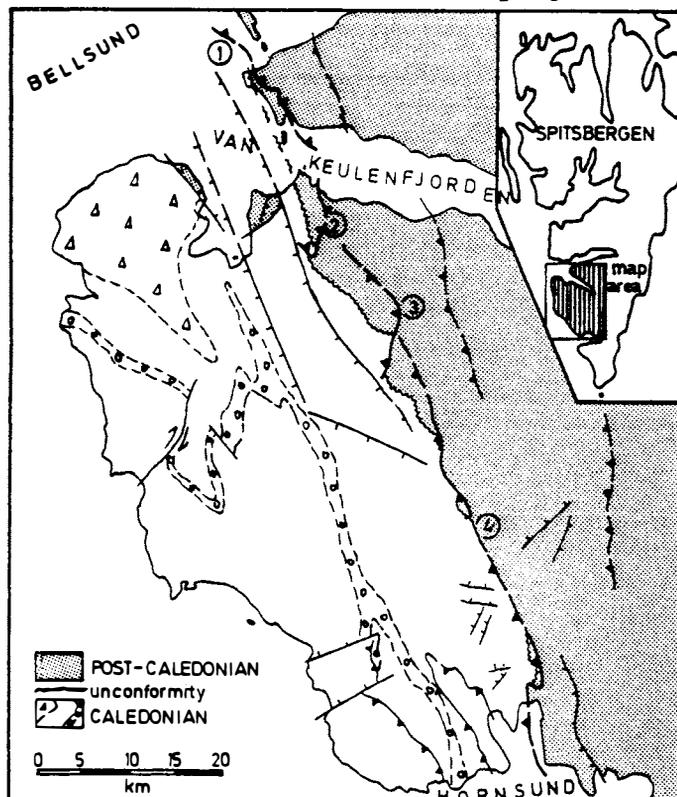
Fig. 1: Location map of
major thrust faults (1-4)
between Bellsund and Horn-
sund.
1: Bravaisknatten T. F.
2: Berzeliustinden T. F.
3: Saussureberget T. F.
4: Hornsund-Zittelberget
   T. F.

tle westerly, and finally easterly dip (Fig. 2) at higher structural
levels, indicating that thrusting happened at progressively lower lev-
els, and that the Caledonian basement was continuously rising during
that time.
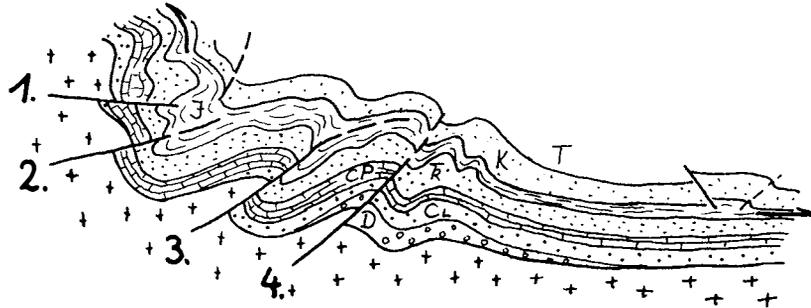
Fig. 2: Hypothetic composite section across the western
margin of the platform area. Heights are 3x exagerated.
Numbers 1 to 4 correspond to thrusts faults indicated on
Fig. 1.

One of the thrust faults, the Berzeliustinden Thrust Fault (no. 2 on
Fig. 1), and its associated structures are well exposed and have been
analysed in detail. The thrust fault ends blind in the Triassic strata,
and deformation is accommodated by fold-propagation folds in the Middle
and Upper Triassic strata, and by different systems of shear zones in
the Jurassic/Lower Cretaceous black shales (Fig. 3). Structures within
the overlying strata (stratigraphical repetition, décollement zone,
westward and eastward vergent shear zones at different levels) suggest
interacting backthrust movement within two black shale formations (the
Middle Triassic Bravaisberget, and the Jurassic/Lower Cretaceous Janus-
fjellet Formations). The Berzeliustinden Thrust Block is thus wedging
into the foreland strata, splitting it along stratigraphic horizons of
very low shear strength. Basement shortening is thus, at least partly,
transferred to the hinterland side of the thrust within the Cretaceous
and Tertiary strata. This model does not exclude that parts of the
shortening may have been transferred eastward (Fig. 2).

This sort of wedging may be an important, but not the only mechanism
controlling deformation of the western margin of the Central Tertiary
Basin of Spitsbergen. The structural thickening of parts of the Juras-
sic/Early Cretaceous black shales and the progressive uplift of the
overlying more competent strata to the west as confirmed by seismic
sections can be explained by this model (Faleide et al. , this volume).

The thrusting and folding within the post-Caledonian strata of the wes-
tern margin of the Central Tertiary Basin must consequently be regarded
as a response to progressive basement uplift in the west. Structures
along this margin suggest mostly compressional tectonics, whereas the
uplift of the basement itself may be caused by transpressional move-
ments along the plate boundary between Greenland and the Barents Shelf.

Reference:

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    belt. Polar Research.

THE STRUCTURE OF
THE BERZELIUSTINDEN
AREA
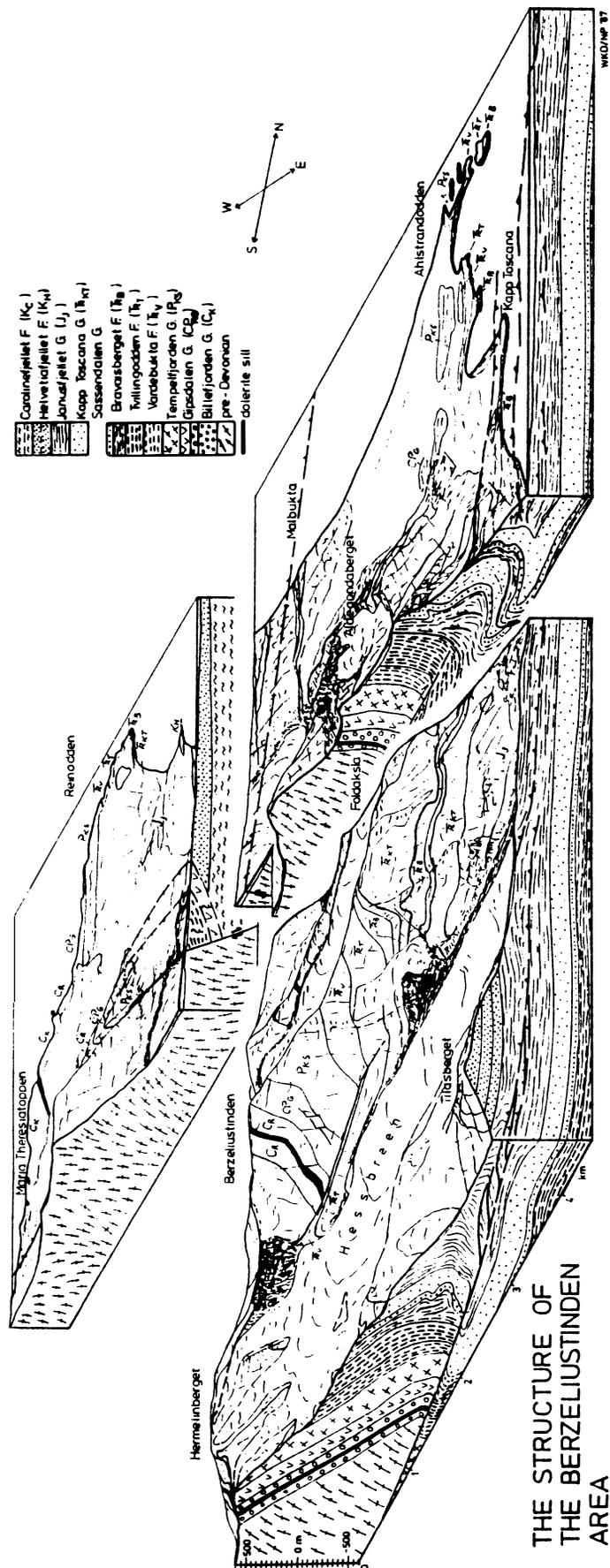
Fig. 3: Block diagram of the Berzeliustinden - Reinodden area. Note the stacking of thrusts:
The The Berzeliustinden Thrust Fault (no. 2 on Fig.s 1 and 2) occurs at a higher level than
the Saussureberget Thrust Fault (beneath Hermelinberget, no. 3 on Fig.s 1 and 2). In front
of the Berzeliustinden Thrust Block deformation is accommodated by fault-propagation folds,
backthrusts and décollement structures.

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Jan Inge Faleide, Steinar Thor Gudlaugsson, Ola Eiken and
Nils-Martin Hanken:

SEISMIC STRUCTURE OF SPITSBERGEN: IMPLICATIONS FOR TERTIARY DEFORMATION

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Seismic reflection data from Spitsbergen's fjords, acquired by
Nordisk Polarinvest in 1984 and 1985, show that the post-Caledonian
succession may be divided into two different, superimposed and
detached structural regimes: Pre-mid Carboniferous sediments are
preserved in an extensional structural setting whereas mid-
Carboniferous to Paleocene rocks form a sedimentary platform later
deformed by compression, or transpression related to the early
Tertiary opening of the Norwegian-Greenland Sea.

Structural features revealed by the seismic data and attributed to
Tertiary compression are:
(1) A wedge of thrust slices underneath the Cretaceous-Tertiary
layers at the western rim of the Central Basin. The wedge is bounded
above by bedding-parallel décollement surfaces within Late Jurassic
shales and below by similar surfaces within Late Paleozoic and
Triassic layers.
(2) Internal deformation structures within the platform sequence such
as thrusts, reverse faults, low amplitude folds and anticlines cored
by duplexes.
(3) A tilting of the sedimentary platform west of the Billefjorden
Fault Zone towards the margin.
(4) There is a systematic decrease of compressional deformation in
the platform sequence eastwards from the exposed orogenic front
across the Central Basin. In Isfjorden compressional features are
lost beneath the limit of seismic resolution some distance west of
the Billefjorden Fault Zone.
(5) The Late Paleozoic extensional relief beneath the platform cover
is almost totally unaffected by the compression evident in the layers

above. The presence of important sub-horizontal décollement surfaces is thus implicit in the overall structure of Spitsbergen.

The pure compressional style of deformation has led several investigators to suggest a phase of more E-W oriented compression prior to the latest Paleocene-Eocene transpressional phase. There is, however, no evidence in the seismic data across the Central Basin for a Late Cretaceous-early Paleocene onset of the Spitsbergen Orogeny as suggested by analogy to the Wandel Sea Basin in NE Greenland (Håkansson, this volume). In fact the Cretaceous-Tertiary sequence boundary is perfectly conformable within the limits of resolution of the seismic data. The abovelying early-mid Paleocene formations are also devoid of any signs of synsedimentary tectonic activity. The whole sequence of Cretaceous and early-mid Paleocene rocks is bent upward by later compressional movements to form the western rim of the Central Basin.

The cause of the Tertiary deformation of Spitsbergen is thought to be the wedge driven by plate tectonic forces into the upper crustal layers along the western margin of the island. The upper, brittle, crust can be divided into three main units based on differences in overall mechanical properties and response to Tertiary compression:
(1) The lowermost unit consists of autochtonous Late Paleozoic sedimentary rocks and underlying Hecla Hoek basement.
(2) The middle unit, which consists of Late Carboniferous-Jurassic layers, shows significant internal deformation indicating eastward transport. Soft, organic rich, marine shales within the Triassic and Jurassic, and gypsum layers within the Permo-Carboniferous carbonate platform have acted as décollement surfaces. Movements on ramps connecting these surfaces have caused considerable disruption of this unit.
(3) The uppermost unit, which consists of Cretaceous and Tertiary layers, is relatively competent and reacted to the eastward directed compression by flexural upbending at the western margin without much internal deformation.

The structure observed on seismic sections beneath the western rim of the Central Basin adds a few kilometers to the minimum estimates of total crustal shortening in the orogeny based on structures exposed along the western coast. This part of the crustal shortening is accommodated within the middle unit in the form of eastward movement of its upper part with respect to the lower parts across the Central Basin and tectonic thickening through imbrication. Because of the detachment at the base of the uppermost unit, its movement relative to the substratum is not easily determined, but some backthrusting towards the west relative to the middle unit is likely and is easily compatible with the observed structures.

New data from various sources enable us to test Harland's (e.g. 1969) hypothesis of a transpressional origin for the Spitsbergen Orogeny, as well as Lowell's (1972) model for the deformational mechanism within it. The plate tectonic aspects of the formation of the Spitsbergen fold and thrust belt are discussed by Vågnes et al. (this volume). As far as overall geometry is concerned, the belt is readily

explainable in terms of transpression. An average maximum crustal shortening across the orogeny of 30 km may be accomodated within known constraints.

Lowell's (1972) interpretation of the orogeny as a large-scale flower structure, in which the roots of the orogeny are directly coupled with marginal thrusts through fault planes that steepen with depth, implies a substantial strike-slip component on the marginal thrusts. Structural relationships implied by this model are neither substantiated by surface mapping nor seismic investigations. Because of this and because Lowell's mechanism is highly inefficient in accomplishing the deformation caused by the independent along-plate-boundary and across-plate-boundary components of lithospheric deformation, we suggest a different model for the formation of the Tertiary Spitsbergen fold and thrust belt:

In this model, horizontal slip along the plate boundary occurs on a vertical strike-slip master fault through the lithosphere. Lithospheric shortening due to compression across the plate boundary is accomodated in different ways above and below the brittle-ductile transition. The lower ductile part of the crust forms a root by downward flow. The upper, brittle, part of the crust forms a thin-skinned fold and thrust belt floored by a sub-horizontal décollement surface at the brittle-ductile transition. Movement in the belt is all in a vertical plane normal to the plate boundary. The fold and thrust belt is generated as an imbricated stack of thrusts on several inward dipping ramps.

Thus, the components of deformation normal and tangential to the plate boundary are accomplished through separate deformation mechanisms that coexist at the plate boundary but that are both linked to the primary plate tectonic cause of the orogeny i.e. transpressive rotation of the plate boundary as Greenland slides past Svalbard. The model is in agreement with both the plate tectonic history and structural evidence from Svalbard. Such a mechanism has recently been invoked to explain the seismically active fold and thrust belt in the San Joaquin Valley east of the San Andreas Fault in central California (Mount & Suppe, 1987; Namson & Davis, 1988).

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TERTIARY THIN-SKINNED COMPRESSIONAL DEFORMATION ON OSKAR II LAND, CENTRAL VEST-SPITSBERGEN

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Structural mapping of Paleozoic and Mesozoic rocks in
Oskar II Land, central Vest-Spitsbergen, reveals a system
of major, asymmetric to overturned, east-verging folds
with NNW-SSE-trending axes, accompanied by thrust faults
and imbricated faults with a shallow to moderate
southwesterly dip.

Most of the major folds display asymmetric styles with
wavelengths up to 2 km. Others display typical chevron
and box-like geometries. Such folds probably overly
frontal ramps/thrust detachments in competent Permian/-
Carboniferous strata. During upsection movements along
frontal ramps complex folds, stacked imbricate thrusts
and associated backthrusts and backfolds were developed
in the Mesozoic (Triassic) cover. A genetic relationship
between folding and thrusting is demonstrated in the
Mesozoic rocks by thrusts dying out or passing along
strike into major folds. Most of the imbricate thrusts
developed by forelimb cutoffs of inverted major folds. The
imbrications have produced numerous repetitions of sand-
dominated Triassic formations in the area north of
Erdmannflya. Most of the mapped frontal ramps cut through
the competent Permian layers while they seem to flatten
out in the less competent shaly Mesozoic formations, such
as the Botneheia and Janusfjellet Formations. Similar
complex deformation and staircase flat-ramp geometries of
thrusts are typical for many classic buried foreland fold-
and thrust systems (Dunne & Ferrill 1988).

A major NE-SW-trending fault, separating strongly
contorted Mesozoic rocks to the NW from almost flatlying
Cretaceous/Tertiary rocks to the SE on Erdmannflya (termed
The Isfjorden Fault by Harland & Horsfield 1974), is
interpreted as an oblique ramp. The rocks adjacent to the
fault, including both Cretaceous and Tertiary strata, are
characterized by numerous minor reverse faults/imbrica-
tions and tight upright folds with axial cleavage. Throw
associated with this fault is about 400 m since the
Jurassic-Cretaceous boundary lies 400 m stratigraphically
higher on the hanging wall than on the footwall block.

The Tertiary deformation in Spitsbergen is normally
placed in Lappdalen where a system of reverse faults cut
the surface. The rocks involved in the thrust front
include stacked and imbricated Permian strata, with
associated hanging wall folds, placed on top of little
disturbed, almost flatlying Triassic units to the east
along a major sole thrust fault. An intensely deformed,
about 100 m thick, Permian anhydrite/gypsum layer (i.e.
the Gipshuken Formation) is present in the core of a
collapsed hanging wall anticline near the basal sole
thrust. This thrust, which displays a smooth, listric
curved surface geometry, is interpreted as a basal detach-
ment/decollement layer, emerged to the surface near a
leading imbricate fan. The gypsum layer may have provided
an excellent glide zone for thrusting. The presence of
monoclinal structures and imbrications in Mesozoic shales
east of Ekmanfjorden, indicate that decollement thrusting
may continue even farther east.

We suggest a kinematic model of Tertiary compressional
deformation being transferred eastwards across Oskar II
Land by a combination of fault-bend/fault-propagation
folding and thin-skinned decollement thrusting. The
westernmost areas may represent a "buried/blind thrust
system" characterized by major folds overlying frontal
ramps and imbrications, whereas farther NE the
deformation is typically that of an "emerged thrust
system" with fault-propagation folds and thrusts reaching
the surface (Fig. 1). Structures typical of compressional
thin-skinned deformation, e.g. imbricate thrust stacking,
thrust ramps and flats etc., are also observed in Mesozoic
strata in Nordenskiøldland and along the Billefjorden and
Lomfjorden Fault Zones of eastern Spitsbergen (Andresen et
al. 1988, Haremo et al. 1988, Nøttvedt et al. 1988). This
suggests a modell of eastward transmittance of stress from
the Vestspitsbergen Orogenic Belt by thin-skinned decolle-
ment thrusting for the Tertiary deformation in central
Vest-Spitsbergen, a model which is also confirmed by
seismic data (Nøttvedt & Rasmussen 1988).

SW   TRYGGHAMNA   ERDMANNFLYA

BOHEMANFLYA   LAPPDALEN   NE

J Jurassic   Ca Carboniferous
T Triassic   D Devonian
P Permian   H Heckla Hoeck   0   5km
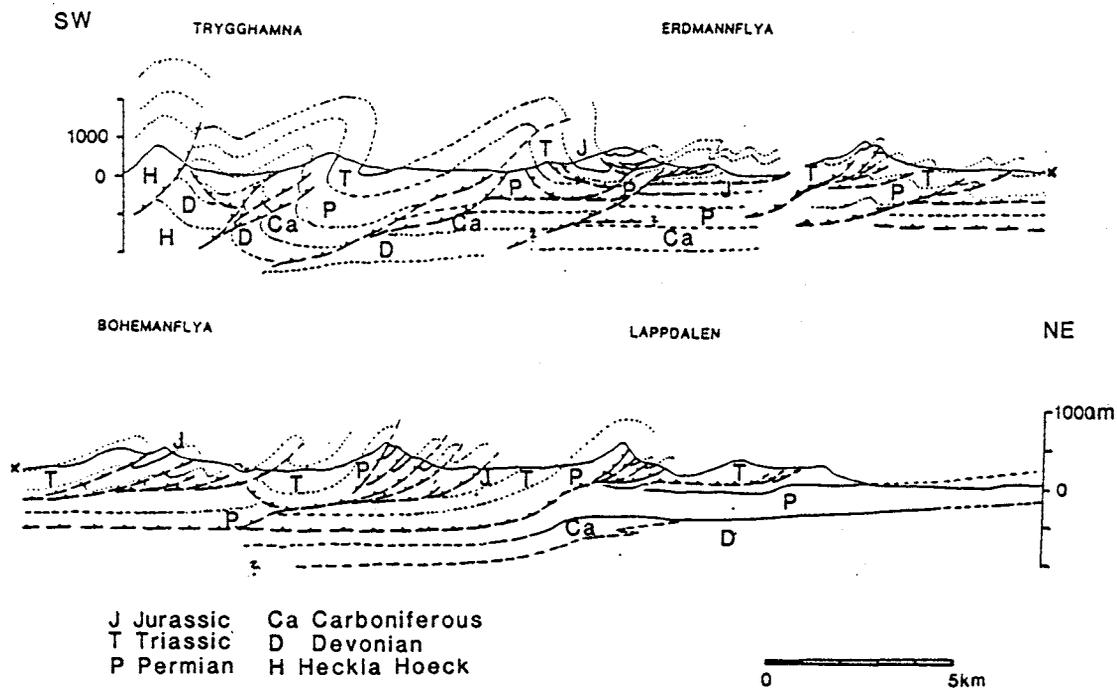
Fig. 1: SW-NE geological cross-section between Trygghamna
and Lappdalen, in Oskar II Land.

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Harmon D. Maher, Jr.

PHOTOINTERPRETATION OF TERTIARY STRUCTURES IN INTERIOR
OSCAR II LAND, SPITSBERGEN

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    Black and white air photos (scale approx. 1:17,000)
were used along with published maps and literature (e.g.
Orvin, 1934; Challinor, 1967; Flood et. al., 1971 and
Hjelle and Lauritzen, 1982) and with field maps and
recollections of Norsk Polarinstitutt geologists (Ohta,
Winsnes and Kielen) to compile a map (1:100,000) of
Tertiary structures (Fig. 1). Eight stratigraphic divisions
were distinquished from air photos on the basis of color,
slope, topographic character (smooth vs. irregular), and
structural context. Although a greater degree of
interpretation is involved in this map than in a
conventional geologic map, the air photos allowed an area,
much of which consists of nunatuks with difficult mapping
conditions, to be quickly covered in a reconnaissance
manner. The air photos, by their resolution, also act as a
filter, focusing attention in on the larger structural
pattern. On the basis of this compilation three zones can
be recognized within the deformed platform cover
sediments.
    The western most zone, with a min. width of 8 km, is
characterized in the N by a complex geometry of thrusts
emplacing Hecla Hoek basement rocks into and over the lower
platform cover strata (from the Broggerhalvoya area to St.
Jonsfjorden). In the S it is characterized by a series of
stacked monoclinal to overturned, shallowly S-plunging,
folds of Kapp Starostin Fm. strata that form a 'staircase'
type pattern in profile, descending to the E (from
Isfjorden up to the E end of St. Jonsfjorden). These folds
are readily traceable on the air photos. Their structural
position and style indicate they are fault-propogation
folds. The geometry of the underlying, basement involved
faults is significant in estimates of the contribution of
these structures to overall Tertiary shortening.

The 9-km wide central zone consists mainly of Kapp Starostin Fm. cherts and limestones and Triassic clastics. Folds with wavelengths of several 100 m up to 1 km are the predominant structure. Since many of these folds have subhorizontal enveloping surfaces and since roughly the same stratigraphic interval is exposed in cross section view of the zone the deformation is very likely thin-skinned, with a detachment horizon within the Gipshuken Fm. gypsums as suggested by Harland and Horsfield (1974). The gypsum is also probably responsible for unusually tight folding (interlimb angles of < 60 degrees) of the Kapp Starostin Fm. by allowing flowage into the fold core. Kapp Starostin Fm. strata act in a very competent manner elsewhere. Exposures of mainly Kapp Starostin strata in the N part of this zone change along strike to the S to mainly Triassic strata – this indicates the basal decollement has a component of dip to the SE. Conservative estimates indicate that 20% shortening exists in this zone. Since these folds appear to be 'buckle' folds and not of a fault-bend style, the associated shortening should not have been translated farther E, i.e., associated motion on the basal detachment is blind.

The 10 km wide frontal zone consists of Gipshuken Fm. through upper Triassic strata involved in at least two, major, W-dipping thrusts. Along Lappdallen a major thrust emplaces Gipshuken Fm. strata on Triassic strata and therefore has an absolute minimum displacement of 500 m (the stratigraphic throw) and a possible displacement in excess of 3 km. To the W of Sveabreen another major thrust locally (Mediumfjellet) repeats the Kapp Starostin Fm. with a hanging-wall flat and has a minimum displacement of 1100 m. Locally, the thrust geometry is more complex (Fig. 2). This frontal zone represents stratigraphic ascent of the basal detachment to a level whose structures would lie farther E but are no longer preserved.

From S to N in the study area there is a notable thinning of the middle zone. Changes along strike in map pattern may be due to erosion patterns, changing thickness of platform cover along strike, differing availability of incompetent horizons along which flats could form, a higher thrust sheet covering underlying structures, changes in transport direction, or some combination of these factors. It is suggested that the 2nd and 3rd factors are significant in this area.

Shortening estimates of this segment of the Tertiary fold-and-thrust belt from airphoto interpretation and map compilation indicate a minimum of 4 km, suggest 6.6 km and permit 9 km. Further discussion can be found in Maher (1988).

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Figure 1: Simplified map of major Tertiary structures in Oscar II Land. Box outlines study area of airphoto interpretation and map compilation. Dashed horizontal lines represent the edge of Hecla Hoek basement outcrops to the W. Small inset box is area shown in Fig. 2.
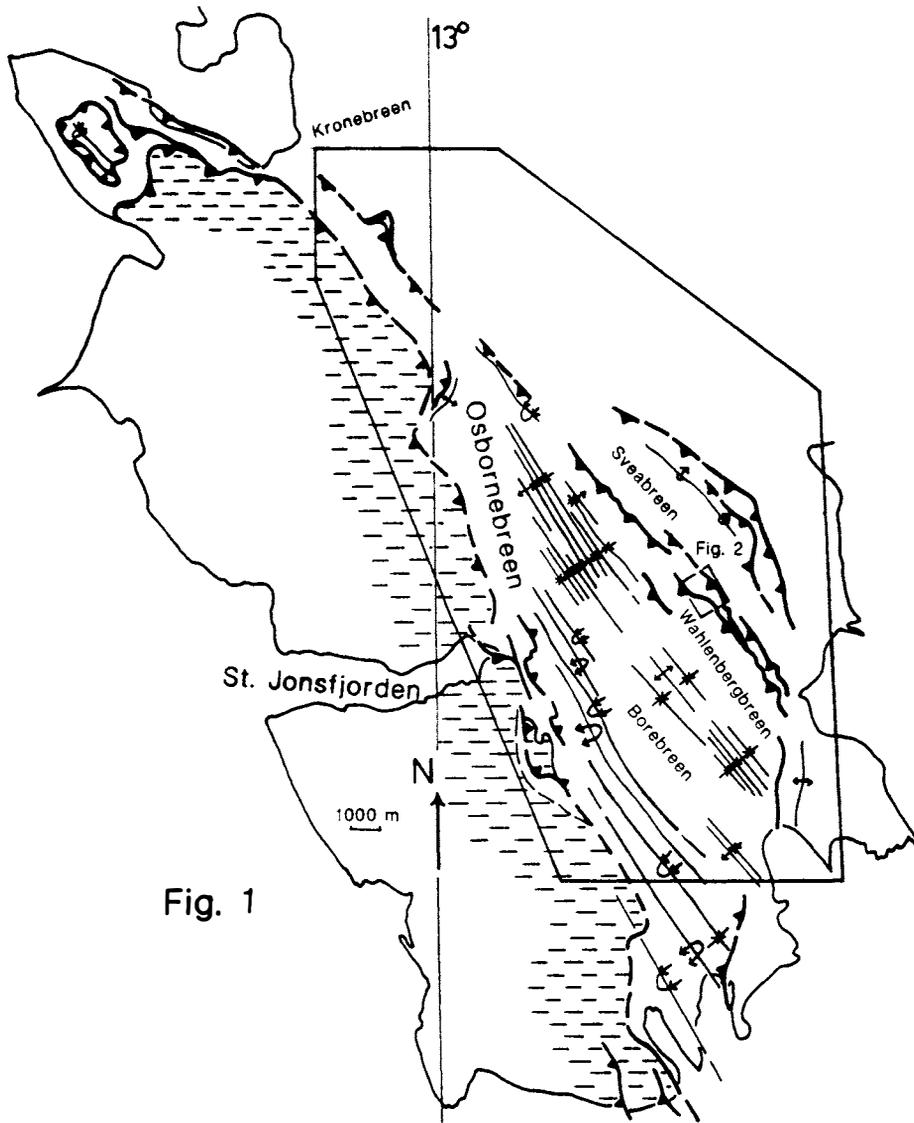

Fig. 1

Figure 2: a) Portion of Norsk Polarinstitutt airphoto # S70-4932. View is of ridge between Sveabreen to the E (rightside) and Wahlenbergbreen to the W. Tall mountain in the in the lower center is Triryggtoppen.
b) Interpretation of air photo. Pk - Kapp Starostin Fm.. Tr - Triassic strata.
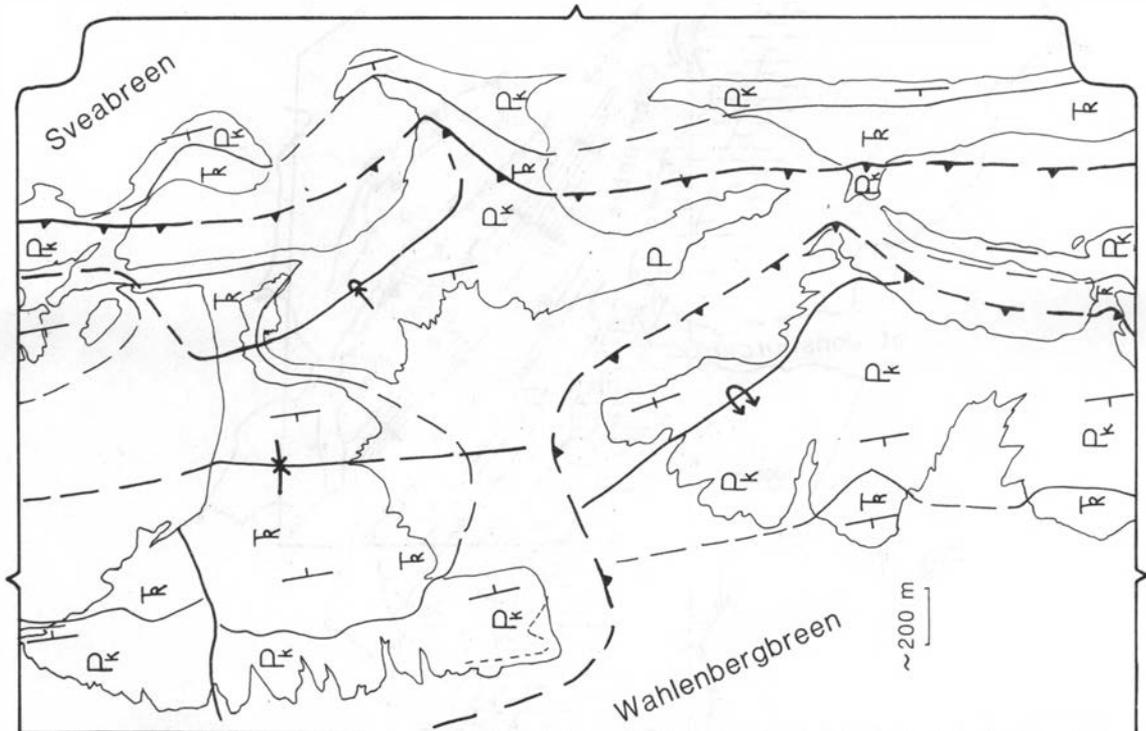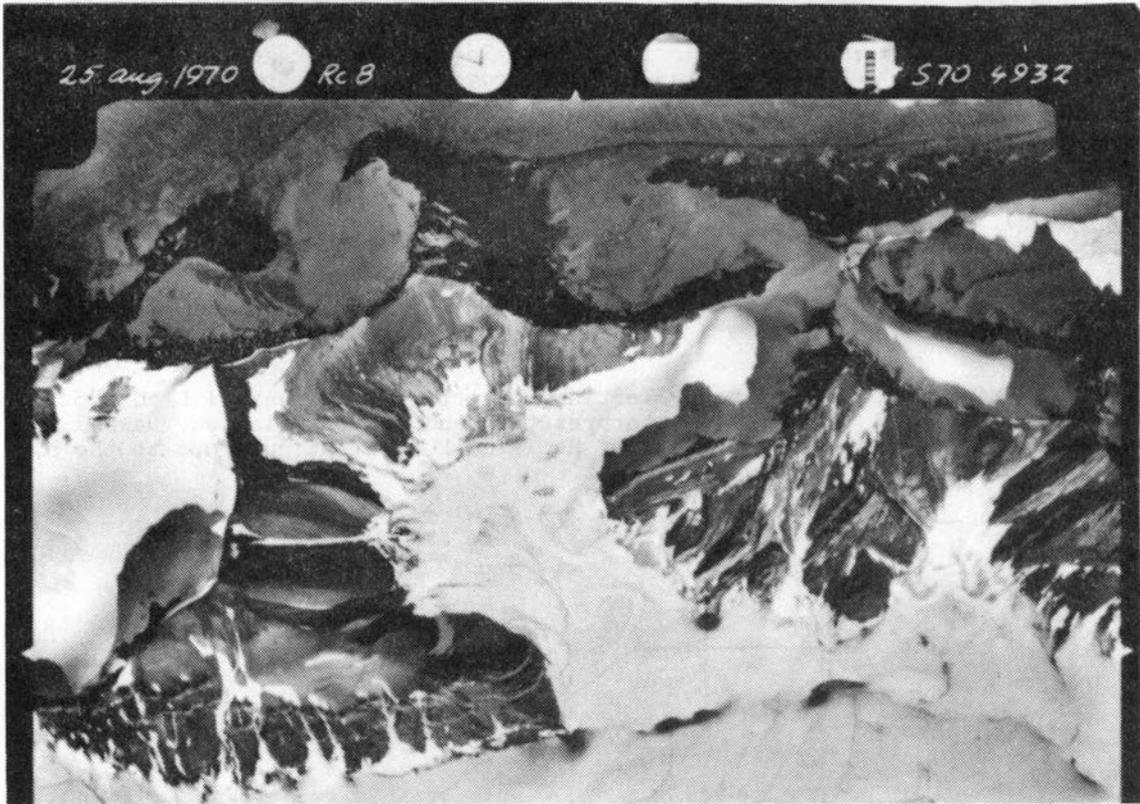
C. Lepvrier, F. Leparmentier, R. Seland

TERTIARY STRESS EVOLUTION ON SVALBARD

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                          Stavanger

Tertiary stress fields on Spitsbergen have been
determined from processing of fault-slip data
collected from several areas (West Spitsbergen Fold
Belt, central and eastern platform areas).
Measurements have been done in Early Tertiary deposits
(Central Basin, Forlandsundet, Ny-Ålesund and
Renardodden outcrops) and in the post-Devonian strata.
The evolution is polyphased: four stress regimes have
been discriminated and their succession deduced from
classical microtectonic criteria. They correspond to
compressional phases of NNE-SSW and ENE-WSW directions
and are followed respectively by two episodes of
subsequent and suborthogonal E-W and NNW-SSE
extension. The change from compression to predominant
extension can be explained by a permutation between
the two principal stress axes $\sigma 1$ and $\sigma 2$.

The first compressional (transpressional) event is
essentially expressed in northwestern Spitsbergen.
Faulted structures related to this stress pattern are
NWW-SSE to N-S dextral, NE-SW sinistral strike-slip
faults and NW-SE oblique-slip faults as well as
development of thrusts on Brøggerhalvøya. In Central
Spitsbergen this initial wrench regime has only been
noted along the southern continuation of the
Billefjorden Fault Zone (Flowerdalen area) showing
preserved dextral strike-slip movements.

The stress pattern corresponding to the ENE-WSW
compressional event is widespread and is recorded as
far as the eastern coast of Spitsbergen. The induced
faulted structures consist of east- or west-dipping
high angle reverse faults, low angle thrusts, flat-
lying decollement surfaces and conjugate tranverse
strike-slip faults (NE-SW dextral and E-W to ESE-WNW
sinistral). In easternmost Spitsbergen such small-
scale strike-slip faults are developed in the Mesozoïc
(Aghardbukta area) or late Paleozoïc formations (east
of Lomfjorden), possibly in relation to the reversal
nature of the adjacent Lomfjorden Fault Zone.

Only the latest NNW-SSE extensional event is supposed
to be related to the rifting regime which took place
after the change in the spreading direction at anomaly
13 time (Eocene-Oligocene boundary). The three
previous stages correspond to the transcurrent regime
which started at anomalies 25-24 (late Paleocene).

It is assumed that the structures on Brøggerhalvøya
and Forlandsundet have been produced concurrently
during the NNE-SSW transpressional stage as a
consequence of lateral offsets between basement wrench
faults. The former is interpreted as a contractional
relay zone, between two left-stepping dextral strike-
slip faults and represents a natural example of a
combination of dip-slip and strike-slip duplexes. In
the same way, the slices of Upper Paleozoic rocks
within the Hecla Hoek (SE of Engelsbukta, S of St.
Johnsfjorden) are considered as shear lenses or minor
Riedel-type duplexes. For the same reasons the
Forlandsundet is thought to have originated as an
extensional relay zone between right-stepping dextral
faults.

Towards the end of the wrench regime the clockwise
rotation from NNE-SSW to ENE-WSW of the direction of
maximum stress $\sigma 1$ gives rise to transverse strike-
slip faults and eastwards vergence structures and
deformation propagates further east by means of
decollement in incompetent horizons.

TERTIARY STRESS PATTERN

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A. Orheim, H.A. Aronsen, L.N. Jensen, O. Skarpnes & B.T. Larsen

SEISMIC MAPPING OF GRIMFJELLET AND ISFJORDEN, SVALBARD; TECTONIC
IMPLICATIONS

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In spring 1986 Statoil carried out one of the first
seismic reflection surveys on the glaciers of Svalbard.
Four lines, totalling 55 km, were aquired in Statoil's
licence area at Grimfjellet (Torell land) between Van
Keulenfjorden and Hornsund. The contractor was Geco.
Geoflex was the primary energy source. Processing of the
data was performed by SSL.

Statoil also collected a total of 1450 km of marine
reflection seismic data in Isfjorden and Van
Mijenfjorden/Bellsund in 1984 and 1985. This data was of
a relatively poor quality but has recently been
reprocessed with considerable improvements.

The interpretation of the Grimfjellet data was partly
based on field mapping, and also by correlation of the
seismic character and interval thicknesses with seismic
lines shot in Van Mijenfjorden that tie to the exploration
well at Ishøgda.

Six good reflectors were mapped: 1) Base of Billefjorden
Group (Top Devonian or top Basement), 2) Base of
Nordenskiøldbreen Formation (Upper Carboniferous), 3) Base
Sassendalen Group (Top Permian), 4) Top Dolerite sill
(intruded approximately at the top of Sassendalen Group),
5) Base Adventdalen Group (mid Jurassic) and 6) Base
Helvetiafjellet Formation (Lower Cretaceous). In the area
Cretaceous rocks of the Helvetiafjellet Formation crop out
at the surface.

The anticlinal axis at Grimfjellet is located about 10 km east of the thrust front, as expressed on the western side of Storbreen, and the axis strikes exactly parallel with the reverse faults in the area.

Four reflectors were digitized and depth converted, and contour maps drawn. At all four levels the surface structure of the Grimfjellet anticline can be seen. At the surface the anticlinal ridge strikes about 325° and the crest of the anticline is in the Grimfjellet area. The anticline seems to be symmetrical in an E-W direction at the surface. This pattern change in depth where the anticline becomes more asymmetric, with the steeper limb towards the east. At depth the strike of the fold axis also rotates anti-clockwise to about 315°.

Several reverse faults can be seen on the seismic data, and some minor normal faults. Most faults have dip at a small angle towards the west, and seem to flatten out at deeper levels. Some larger faults have a slightly steeper dip westward and involve the basement. Smaller duplexes and wedge shaped (delta-) structures can also be seen. Many of the faults are blind in the Cretaceous level. The large thrust fault that forms the Grimsfjellet anticlinal thrust front also terminates within the Cretacous sediments. The top of the Grimfjellet anticline, at most levels, is about 1500 m above the same beds in the gentle syncline to the east, and indicates the amount of uplift. The shortening in the area is in the order of 2 - 3 km. This , together with the fact that the fault is blind should, suggests that the flat lying beds in the Mesozoic sediments east of the Grimfjellet anticline should contain many small flat thrusts with minor ramps (below detection limits of the seismic data).

We conclude that the Grimfjellet anticline is an anticlinal structure formed just in the front of the Tertiary fold belt, and that in the area as the first basement-involved thrusts do not travel to the present surface. The parallel strike of the anticlinal axis with the fold belt indicates a compression perpendicular to the structures, with a compression stress axis oriented at about 50°. This setting can hardly be explained by transpression. It strongly indicated pure compression pre-dating transpression and transtension in early Tertiary times on Svalbard.

GRIMFJELLET

STRUCTURAL GEOPROFILE – SEISMIC LINE GR-002

Base Helvetiafjell Fm.

Base Adventdal Gr.

Top Dolerite sill

Base Sassendal Gr.

Base Nordenskiöldbre Fm.

Base Billefjorden Gr.

Datum: 300 a.s.l

Reverse fault zone

Base Helvetiafjell Fm.

Base Adventdal Gr.

Top Dolerite sill

Base Sassendal Gr.

Base Nordenskiöldbre Fm.

Base Billefjord Gr.

Devon or Hecla Hoek

km
SP
m below
datum
1000m
2000m
3000m
4000m

Legend

| Siltstone | Breccia |
Conglomerater	Dolerite
Shale	Evaporite
Dolomite	Chert
Limestone	Coal
Sandstone	

Key map

Fig. 1: Structural geoprofile – seismic line GR-002 Grimfjellet,
       Svalbard.
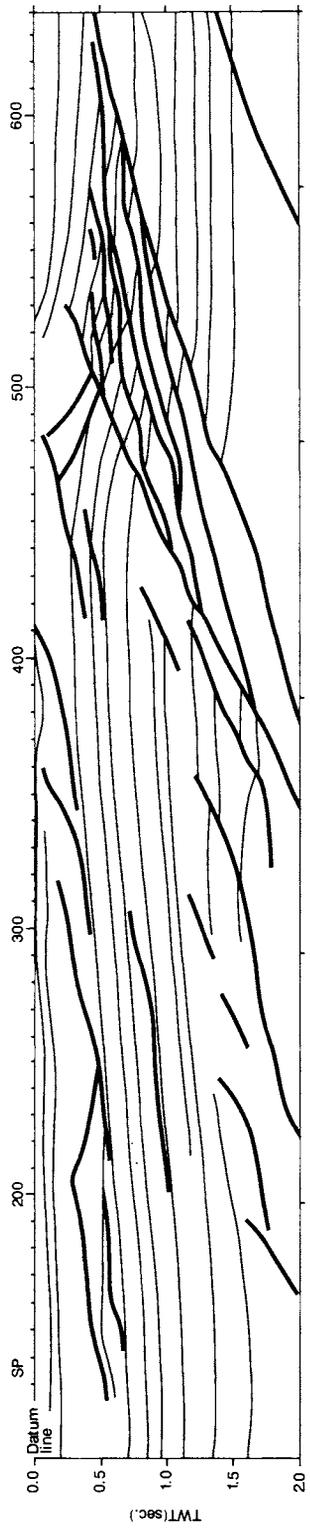
Fig. 2: Linedrawing of seismic line GR-002.

Narve Ringset & Arild Andresen

**THE GIPSHUKEN FAULT SYSTEM -
EVIDENCE FOR TERTIARY THRUSTING ALONG
THE BILLEFJORDEN FAULT ZONE.**

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The N/NW - striking Gipshuken Fault is the main tectonic
element of the Billefjorden Fault Zone at Bünsow Land
(McWhae 1953, Harland et. al. 1974). The best exposed,
upper part of this reverse fault is subvertical, off-
setting upper Carboniferous and Permian sediments. In its
southern part, at Gipshuken, it has a westerly downthrow
of 350 m. At Cowantoppen, in its northern part, the throw
of the Gipshuken Fault has decreased to about 120 m.

Part of this reduction is taken up by a NE dipping, high
angle reverse splay fault, the Cowantoppen Fault. This
fault has a W downthrow of 80 m, and diverges from the
middle part of the Gipshuken Fault with a NW strike. On
Brisingefjellet, E of the Gipshuken Fault, minor reverse
faults (back thrusts) with a composite E downthrow of 100
m occur.

Downwards, in the less competent, Middle Carboniferous
strata, these two faults appear to flatten gradually
eastwards.

A distinct asymmetric anticline, the Anservika Anticline,
forms the W limit of the studied segment of the Bille-
fjorden Fault Zone. It is interpreted as a fault pro-
pagation fold (Suppe 1985) in front of a blind thrust. As
the fold is cut by the Cowantoppen Fault, the fold
presumably is older than the fault.

A less prominent anticline in Gipsvika, just E of Gipshuken Fault, may also be a fault propagation fold, truncated by the Gipshuken Fault. It is seen only to fold Nordenskiöldbreen Fm. The overlying Gipshuken Fm. is thickened E of the Gipshuken Fault. Apparently, anhydrite beds of the Gipshuken Fm. are piled up against the Gipshuken Fault. This is due to imbricate reverse faults that merge with the main fault updip. The thickening causes rotation of the overlying Kapp Starostin Fm., which shows increasingly steep E dip towards the fault. It also implies that the throw on the Gipshuken fault must decrease downdip, so that some of the vertical displacement is transferred on a horizontal component.

The tectonic structure in the area is dominated by imbricate reverse faults. These occur on both sides of the main fault, but most frequently close to its eastern side. Some of these reverse faults have lineations plunging down-dip, indicating dip slip movement. Minor folds occur in the hanging walls of small thrusts. Neither normal faults nor indications of strike slip faults have been found.

The geometries of the Gipshuken Fault and its associated major and minor faults and folds clearly show that they formed in a compressional setting. The reverse faults are interpreted to branch out from a low angle (or bedding parallel) floor thrust, located in evaporites of the Ebbadalen Fm. As this floor thrust propagates towards W, it approaches lateral equivalent fan delta conglomerates near the western margin of the Carboniferous Billefjorden Trough. This lithological inhomogenity causes the floor thrust to ramp upwards. New reverse faults develop in the hanging walls of older ones, and the thrust system propagates towards the hinterland, forming a **trailing imbricate fan** (Boyer & Elliot 1982). The position of this thrust system at the Billefjorden Fault Zone is thus indirectly controlled by a Carboniferous structure (Fig. 1).

The timing of this thrusting event is not well constrained. The Anservika Anticline folds a dolerite sill of probable Early Cretaceous age, indicating a Cretaceous or Tertiary age of deformation. Along the Billefjorden Fault Zone south of Sassenfjorden, a phase of eastward thrusting involves Lower Cretaceous/Palaeocene rocks. These (Eocene?) thrusts appear to truncate the Flowerdalen Fault, which probably is a southerly continuation of the Gipshuken Fault. Andresen et. al. (1986) interprete the Flowerdalen fault as an Early Tertiary compressional feature, slightly older than the thrusts.
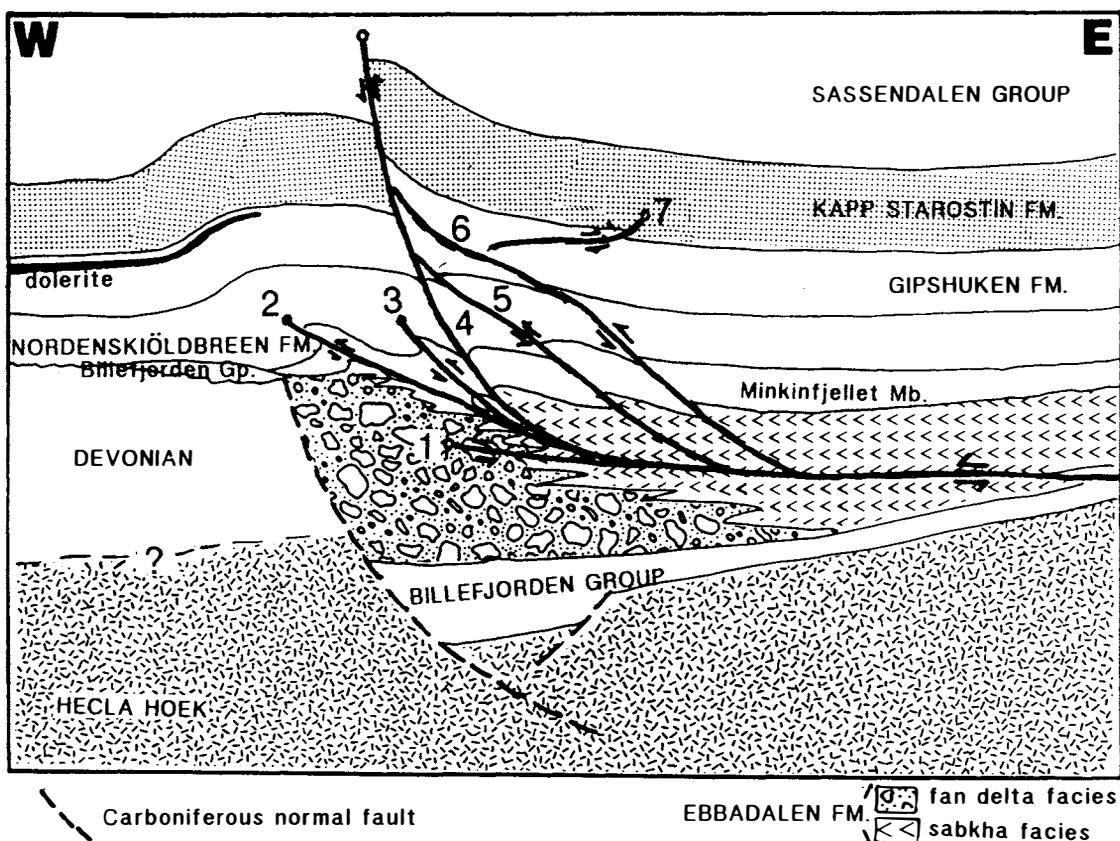
Fig.1. Interpretation of the kinematic development of the Gipshuken Fault System. Figures 1 - 7 indicate proposed sequence of reverse fault initiation, suggesting hindward succession of development.

If an Early Tertiary age is assumed for the Gipshuken/ Flowerdalen Faults, they may possibly have controlled the sedimentation of the lower part of the Tertiary succession of the Central Basin (Firkanten to Grumant Fms.). If so, an Early to Middle Paleocene age is indicated. This event may be connected to the onset of transpression along the continental De Geer transform fault. Compression along this zone may have been transferred eastwards to the Lomfjorden Fault Zone through a deep-lying décollement zone. The Gipshuken Fault system may then be interpreted as a back thrust, developed above this décollement zone.

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Pål Haremo & Arild Andresen

TERTIARY MOVEMENTS ALONG THE BILLEFJORDEN FAULT ZONE AND
ITS RELATION TO THE VEST-SPITSBERGEN OROGENIC BELT.

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Previous investigations along Billefjorden Fault Zone
(BFZ), one of Spitsbergens most prominent lineaments
(Fig.1), suggest a complex tectonic history (eg. Harland
et al.,1974). It is interpreted to have been a
tectonically active fault zone in 1)Late Devonian,
2)Early to Late Carboniferous, 3)Late Jurassic/ Early
Cretaceous and 4)Tertiary.

The Tertiary tectonic activity associated with BFZ, has
been related to the Eocen(?) transpressive Vest-
Spitsbergen Orogeny which is associated with to movement
along an intracontinental transform fault zone between

Hecla Hoek

Devonian

Carboniferous/ Permian

Triassic

Jurassic/ Cretaceous
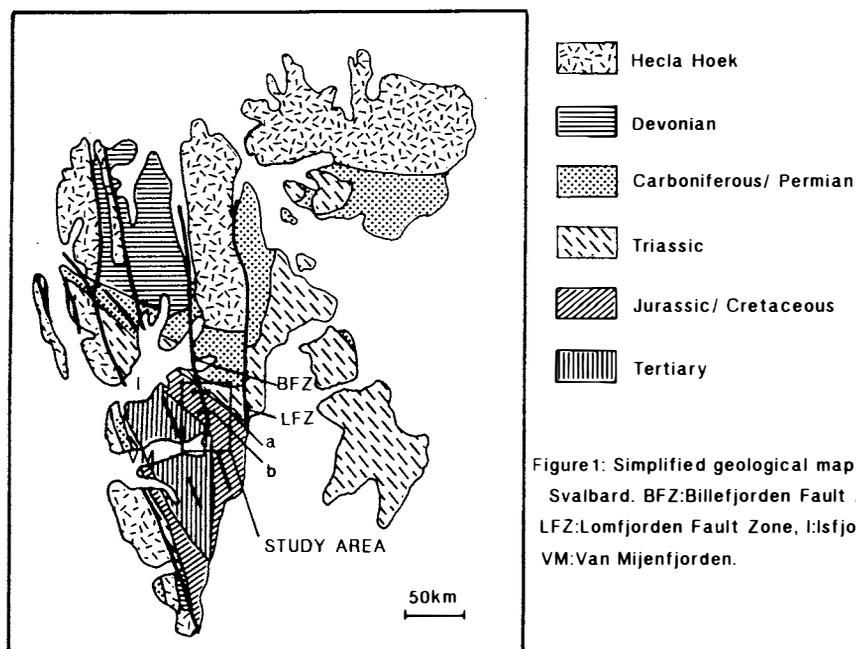
Tertiary

Figure 1: Simplified geological map of
Svalbard. BFZ:Billefjorden Fault Zone,
LFZ:Lomfjorden Fault Zone, I:Isfjorden,
VM:Van Mijenfjorden.

BFZ
LFZ
a
b
STUDY AREA
50km

Greenland and Spitsbergen. However, neither the geometry
nor the kinematics of the Tertiary structures along BFZ,
in particular how they relate to the narrow belt of
intense deformation along Vest-Spitsbergen, have been
thouroughly described. From recent detailed structural
mapping along BFZ south of Isfjorden (Andresen et
al.,1986; Haremo et al.,1988, Fig.1) it seems clear that
Tertiary deformation is more extensive than hitherto
recognized and that Late Jurassic/ Early Cretaceous
faulting, as suggested by Parker (1966), is only minor or
non-existent in the area.

Tertiary deformation in the Mesozoic and younger strata
along BFZ south of Isfjorden is characterized by
compressional tectonics, which has led to developement of
two N-S trending thight anticlines in the Festningen
Sandstone and overlying sand/shale sequences of the
Helvetiafjellet- and Carolinefjellet formations. The
underlying shale dominated Janusfjell Subgroup (Jurassic/
Cretaceous) is thickened in the core of the two anticlines
by; reverse faulting with formation of duplexes and
imbricate fans, and folding, locally isoclinal. East-west
cross-sections illustrating the main structural features
across BFZ north of Adventdalen and north of Reindalen,
are presented in Figure 2 (for location see Figure 1).

Geometry and orientation of folds and faults indicate
tectonic transport of upper plate rocks from west towards
east, although "back-trusts" occur locally. Out of
sequence thrusts are observed and are interpreted to be
responsible for the reduced thickness of the Janusfjell
Subgroup in the inner Adventdalen area (Fig.2a). The two
anticlines are not recognized below the Janusfjell Sub-
group, suggesting that the latter acted as a major
decollement zone during compression. Construction of
detailed cross-sections show approximately 3 km of
shortening of the Festningen Sandstone across BFZ. Local
imbrication of the Triassic DeGeerdalen- and Wilhelmøya
formations indicate that another decollement zone is
present at a deeper structural and stratigraphical level.
Shortening associated with these structures are at least
0.5km. Data from outside the study area (Andresen et
al.,1988) suggests that this decollement zone is localized
to the shaly Botneheia Member of the Barentsøya
Formation.

Developement of the Tertiary structures associated with
BFZ are most likely controlled by high angle, east-dipping
reverse faults in the pre-Mesozoic basement (Fig.2). A
westward facing monocline involving the entire Mesozoic
sequence is the only indication of this proposed early
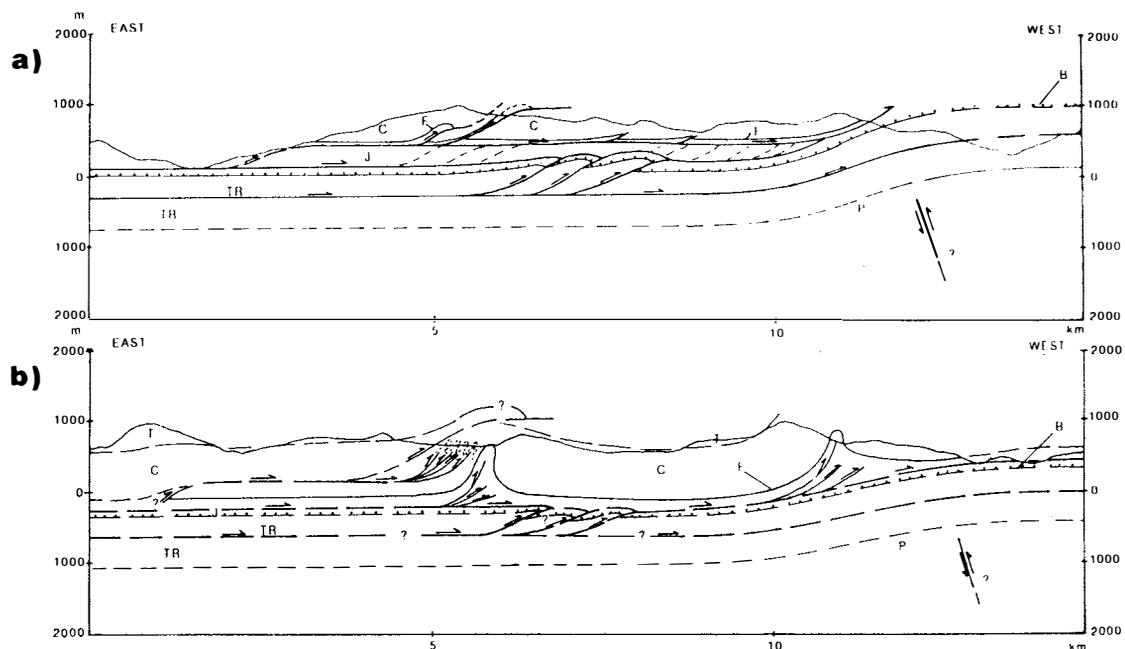
Figure 2 East-west cross sections which illustrates the main structural developement across BFZ north of Adventdalen (a) and north of Heindalen (b) For location see Figure 1. B:Brentskardhaugen Bed, F:Festningen Sandstone, P:Permian, TR:Triassic, J:Jurassic, C:Cretaceous, T:Tertiary

Tertiary faulting activity in the study area. However, eastward dipping revers faults in the Permian strata at Gipshuken (Andresen et al.,1988; Ringset & Andresen, 1988) support this interpretation.

Our own observations suggests that both decollement zones can be traced eastward to Storfjorden. They are also inferred to continue westwards and link up with the major reverse faults recognized at the same stratgraphical levels (units) around Midterhuken. The obvious thin skinned tectonic style recognized in the Mesozoic strata along BFZ south of Isfjorden, indicating a shortening of at least 3km, has to be considered when Tertiary shortening calculations, based on balanced sections across Spitsbergen, is carried out. We believe that the calculated shortening is related to decollement zones that go all the way to the west coast, and accordingly should be added to layer shortening observed further west. However, existing and new seismic data from Isfjorden and Van Mijenfjorden will hopefully prove whether this model is correct, or if the decollement zones are related to steep basement faults somewhere between BFZ and the west coast. Furthermore the lack of obvious strike slip deformational structures along the Vest-Spitsbergen Foldbelt as well as along the BFZ is indicative of two things; 1) that the main strand of the Hornsund Fault Zone was located considerably west of the present west coast of Spitsbergen and/or 2) that the Hornsund Fault Zone was a nearly frictionless interface, which caused the Tertiary

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transpressive plate motion to be decoupled into a low
stress strike slip component parallell the fault and a
high stress compressive component normal to the fault as
has been proposed for the San Andreas Fault (Mount &
Suppe,1987).

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Arild Andresen, Pål Haremo & Steffen G. Bergh

THE SOUTHERN TERMINATION OF THE LOMFJORDEN FAULT ZONE; EVIDENCE FOR TERTIARY COMPRESSION ON EAST-SPITSBERGEN.

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Lomfjorden Fault Zone (LFZ) (Flood et al. 1971) is, together with Billefjorden Fault Zone (BFZ), one of the few areas outside Vest-Spitsbergen where Tertiary deformation is inferred to have taken place. Whereas numerous papers have dealt with the tectonic history of BZF (Harland et al. 1974), considerably less is known about the geometry and kinematics of LFZ. Kellogg (1975) stated that most of the Cenozoic compression along the west coast of Spitsbergen resulted in block faulting in the central and eastern areas, and that most of the deformation took the form of folding over (reactivated (?)) basement faults.

Throughout most of its length LFZ is a down-to-the-east fault, which to the north brings Upper Paleozoic rocks in contact with pre-Caledonian rocks (Hjelle & Lauritzen 1982). Southward, where pre-Mesozoic rocks are not exposed, LFZ is seen as a prominent flexure or asymmetric anticline. In the vicinity of Agardhbukta the steep limb is locally overturned (Kellogg 1975). The details of this flexure (Eistraryggen anticline, named after a mountain north of Agardhdalen), particularly its termination south of Agardhdalen, is described herein.

In its type area the Eistraryggen anticline is seen to involve Triassic and Jurassic strata. Southward, across Agardhdalen, Lower Cretaceous sediments, including the Festingen Sst, are involved in the deformation. The structure is in this area, no longer a simple anticline as appear to be the case at Eistraryggen.

GEOLOGY OF THE KLEMENTIEVFJELLET AREA, EAST-SPITSBERGEN

Kh — Helvetiafjellet Fm

JKj — Janusfjellet Subgroup

TJw — Wilhelmøya Fm

Td — De Geerdalen Fm

Tt — Tschermakfjellet Fm

Formation boundary

Thrust

Anticline

Syncline

0   1000 m

Klementievfjellet

Agardhbukta

Rurikdalen

AA.88

Fig. 1

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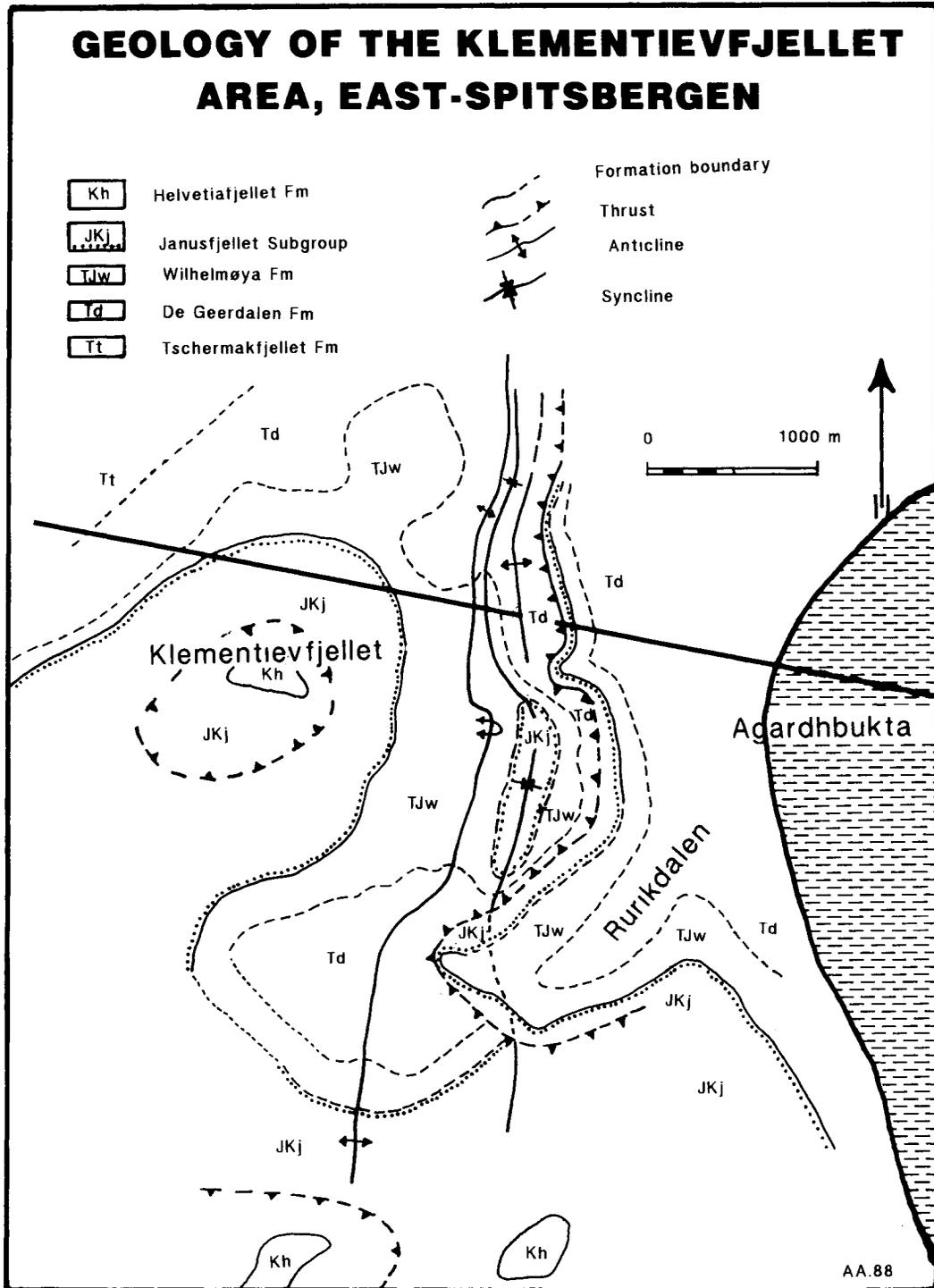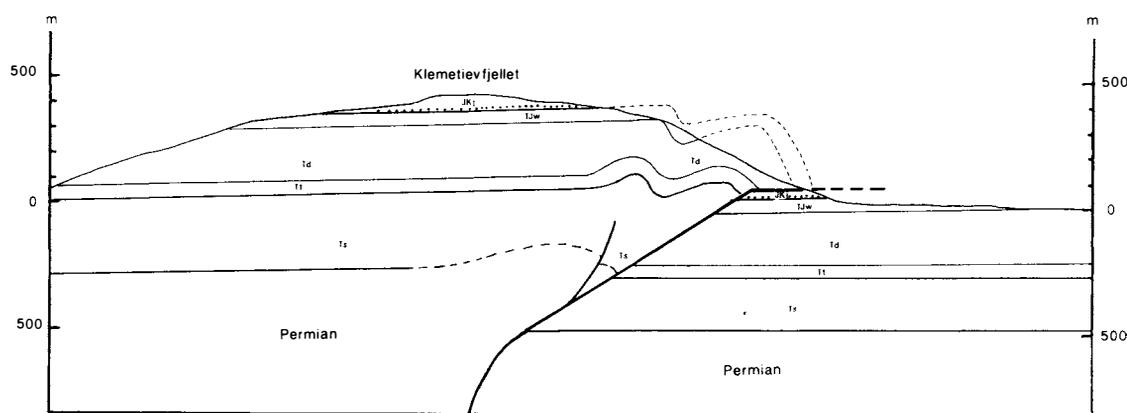
Fig. 2

Mapping of the east-facing slopes of Klementievfjellet show that two asymmetric closed, chevron-like anticlines with an intervening syncline are developed in the Mesozoic De Geerdalen-Wilhelmøya Fms (Triassic) and overlying Janusfjellet Subgroup (Fig. 1). The eastern (short) limbs of the anticlines are locally overturned; amplitude is at least 100 meters. Numerous minor revers faults, all indicating tectonic transport of the hanging wall block towards east, are developed in the core of the folds. Southward the two anticlines apparently degenerate into an open asymmetric anticline at the structural and erosional level of the Janusfjellet Subgroup (Fig. 2). Constructed foldaxes suggest that the Eistraryggen anticline around Klementievfjellet has a N-S trend with a gently southward plunge.

Structural observations along Rurikdalen (Fig. 1) shows that the folded and faulted De Geerdalen and younger formations involved in the Eistraryggen anticline at Klementievfjellet sit structurally on top of flat-lying strata of the lower part of the Agardhfjellet Formation of the Janusfjellet Subgroup (Fig. 2). A reasonable interpretation is to consider the Eistraryggen anticline as being formed above a reverse fault ramping up through the sandy competent Wilhelmøya-De Geerdalen Fms. The fault is interpreted to turn into a flat further eastward, following bedding at the base of the Agardhfjellet Formation (Fig. 2). Its geometry at depth is unclear. It may be rooted in one of the steep basement faults recognized further north towards Lomfjorden (Andresen et al. 1988). On the other hand, local duplex development in

the Botneheia Mb of the hanging-wall block at Eistraryggen indicate that it westwards may level out in a flat following the Triassic shales. Shortening calculations based on length of folded beds (Brentskardhaugen Bed) indicate a minimum shortening of 700-800 meters across the Eistraryggen anticline around Klementievfjellet.

Offset (down to the east) of the Festningen Sst within the hanging - wall block south of Rurikdalen (Fig. 1), cannot be directly linked to the folds and reverse fault discussed above, and is interpreted as a separate reverse-fault (ramp) at a higher structural level, rooted in a flat within the Janusfjellet Subgroup. Apparent offset across this reverse fault decreases southward and is interpreted to die out as a blind thrust in a fold north of Ingelfieldbukta. Although not well exposed, local development of revers-faults, all with a westerly dip, particularly at the base of Agardhbukta Formation, support this interpretation. It is tentatively suggested that this upper decollement zone continues westwards and links up with the decollement zone recognized at this stratigraphic level or a lower one along BFZ and within the Vest-Spitsbergen Orogenic belt.

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TERTIARY DEFORMATION OF SVALBARD - VARIOUS MODELS AND RECENT ADVANCES

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    Recent work has increased our understanding of and modified our
models for the Tertiary deformation on Svalbard. Seismic and field
data gathered by NORSK HYDRO/ STORE NORSKE show the need to reject a
simple strike-slip model for the West-Spitsbergen Orogenic Belt (WSOB)
(Fig. 1). A foreland fold and thrust belt model is required to account
for the increasing evidences of extensive thin-skinned thrusting
eastwards in the Central Spitsbergen Trough (CST), possibly as far
east as Edgeøya (Nøttvedt & Rasmussen, 1988; Nøttvedt & Rasmussen in
prep.). Major thrusting and asymmetric folding within the WSOB pass
eastwards, across the orogenic front, into horisontal decollement
surfaces and associated minor thrust ramps in the CST (Bergh et al.,
1988, Nøttvedt & Rasmussen, 1988).
    Similarly, previously proposed Mesozoic block faulting on the
Billefjorden Fault Zone (BFZ) and Lomfjorden Fault Zone (LFZ) have
been demonstrated to be overall unimportant. Post-Paleozoic tectonism
on these two fault zones, on east-central Spitsbergen, relates
predominantly to compression during the Tertiary (Andresen et al.,
1988; Nøttvedt et al., 1988). A sequential model of Tertiary
deformation is suggested, involving early, at least partly basement
rooted, inversion of the old Paleozoic basin element between the BFZ
and LFZ (Fig. 1)(Nøttvedt et al., 1988). These major reverse movements
are clearly overprinted by, and decoupled from, younger, shallow
rooted thrust ramps. On central Spitsbergen, the BFZ reverse fault is
interpreted to have been cut and displaced eastwards for some 4 km by
successive shallow thrusting.
    Discussions on timing of deformation have recurred frequently the
past few years. Despite speculations on a late Cretaceous phase of
compression on Svalbard, however, seismic data and field observations
of thrust ramps involving lower Tertiary stratigraphy and coal mining
notes on numerous, similar striking folds and minor reverse offsets
within the Paleocene coal-bearing strata are evidence of a Tertiary
(Eocene) age of CST foreland deformation(Fig. 2), as is the thickness
of Tertiary fill in the basin itself (cfr. Harland et al., 1976; Manum
& Throndsen, 1986). It seems logical to assign a similar age also to
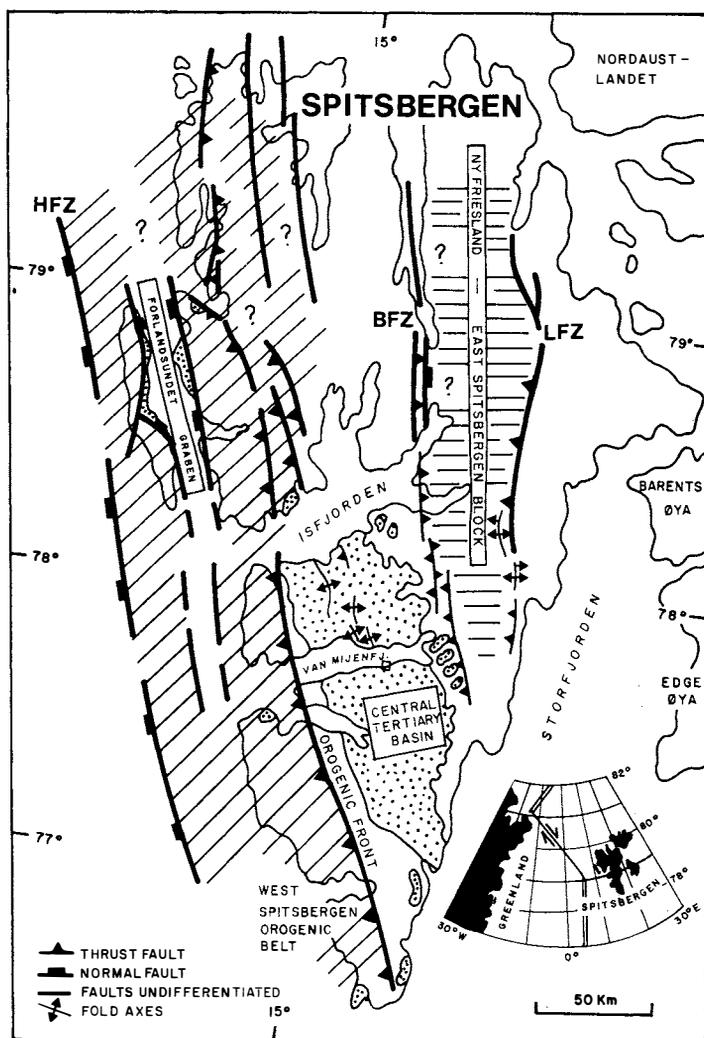
Fig. 1. Structural framework and Tertiary outcrops on Spitsbergen. Note narrowing of West Spitsbergen Orogenic Belt (WSOB) southwards across Isfjorden, due to structural plunge. Northwards continuation of structure across Kongsfjorden is highly speculative. HFZ – Hornsund Fault Zone, BFZ – Billefjorden Fault Zone, LFZ – Lomfjorden Fault Zone.

the WSOB orogenic deformation proper, though an eastward progression in the age of thrusting is expected and more westerly structures may be older.

In order to work out a tectonic model for the Tertiary deformation on Svalbard, some key issues must be resolved:

1. What is the large scale geometry of the WSOB, and how does it relat to the Greenland-Svalbard suture shear zone?
2. What are the mechanics and kinematics of foreland deformation, with special notes to the BFZ and LFZ lineaments?
3. How does our new tectonic understanding affect the model of the Central Tertiary Basin (CTB) evolution?

It is our view that a general foreland fold and thrust belt model for the Tertiary deformation on Svalbard calls for expanded thoughts and refinement. Plate tectonic evidences of early Tertiary shearing between Svalbard and Greenland are persuasive from several lines of research, and the angle of relative compression is likely to have been very low (3 - 4°) (Nøttvedt et al., in press). From such conditions a strike-slip welt is to be expected (cfr. Lowell, 1972). Yet, prolonged weak compression is believed to have caused a total crustal shortening greater than previously anticipated.

AGE	TECTONIC REGIME	TECTONIC RESPONSE			TERTIARY BASIN EVOLUTION				
		WSOB	CST	BFZ ESF LFZ ST	FG	RB/ØB	CTB (CST)	ESB	ST
OLIGOCENE	EXTENSION-RIFTING	OROGENIC RELAX-ATION: NORM. FAULTING	UPLIFT AND EXTENSIONAL FRACTURING		EXTENSIONAL GRABEN	UPLIFT			
EOCENE	COMPRES-SIONAL SHEAR	STRIKE SLIP WELT / LOW-ANGLE THRUSTING AND FOLDING	BUCKLING AND TECTONIC LOADING / DECOLLEMENT AND SHALLOW THRUSTING / REVERSE FAULTING INVERSION	LOW AMPLITUDE FOLDING ?	? ARCH-COLLAPSE GRABEN / UPLIFT		THRUST SHEET TOP BASIN / COMPRESSIO-NAL FORELAND BASIN	? ?	
PALEOCENE	EXTENSIONAL SHEAR	GENTLE WARPING			?	EXTENSIONAL BASIN INFILL		CRATONIC BASIN	

Fig. 2. Summary of Tertiary tectonics and basin evolution of Svalbard. CST - Central Spitsbergen Trough, ESB - East Spitsbergen Block, ST - Storfjorden Trough, FG - Forlandssundet Graben, RB - Renardodden Basin, ØB - Øyrlandet Basin, CTB - Central Tertiary Basin. For other abbreviations, see Fig. 1.

We believe that a strike-slip welt may have initially formed (Figs. 2, 3). But, as the welt grew larger and the amount of shortening increased, master low-angle thrust faults developed, giving rise to a compressional fold and thrust belt on the flank of the strike-slip welt. It is important in this respect that most collision zones tend to be asymmetric, with one plate overriding the other. One should therefore not be surprised that Cretaceous compressional shear on Greenland is not widely recognized on Svalbard, and that the West Spitsbergen Orogeny cannot be traced on Greenland (cfr. Håkansson & Schack Pedersen, 1982; Hanisch, 1984; Håkansson, oral. presentation - this meeting). As these large thrust nappes became also successively locked, the main strain was transmitted stratigraphically upwards and taken up in horisontal decollement planes in ductile Mesozoic shales and to some extent, in upper Paleozoic gypsum layers (Fig. 3)(Nøttvedt & Rasmussen, 1988; Andresen et al., 1988; Bergh et al., 1988; Harland et al., 1988).

This stratigraphic control on deformation style explains the curvature and narrowing of the WSOB southwards across Isfjorden (Fig. 1), as due partly to a southerly plunge of the orogenic structure. It may further be speculated if the apparent bending of the deformation front offshore Kongsfjorden (Orvin, 1940; Challinor, 1967; Harland, 1969) is a second order feature and that the fold belt proper strikes more N-S, with the possibility of Tertiary compressional overprinting also in the Hecla Hoek (- Devonian) complex of northwest Spitsbergen (Fig. 1).

Similar examples of oblique-slip deformation have been documented elsewhere. Typically, strike-slip deformation is dominant close to the shear zone and compressional deformation becomes increasingly important away from the shear zone, due to rotation of the σ stress vector across the shear zone. But, what is the position of the WSOB relative to principal suture shear zone in this general model (Fig. 3)? Assuming a paleo-suture root zone onshore West Spitsbergen (Fig.
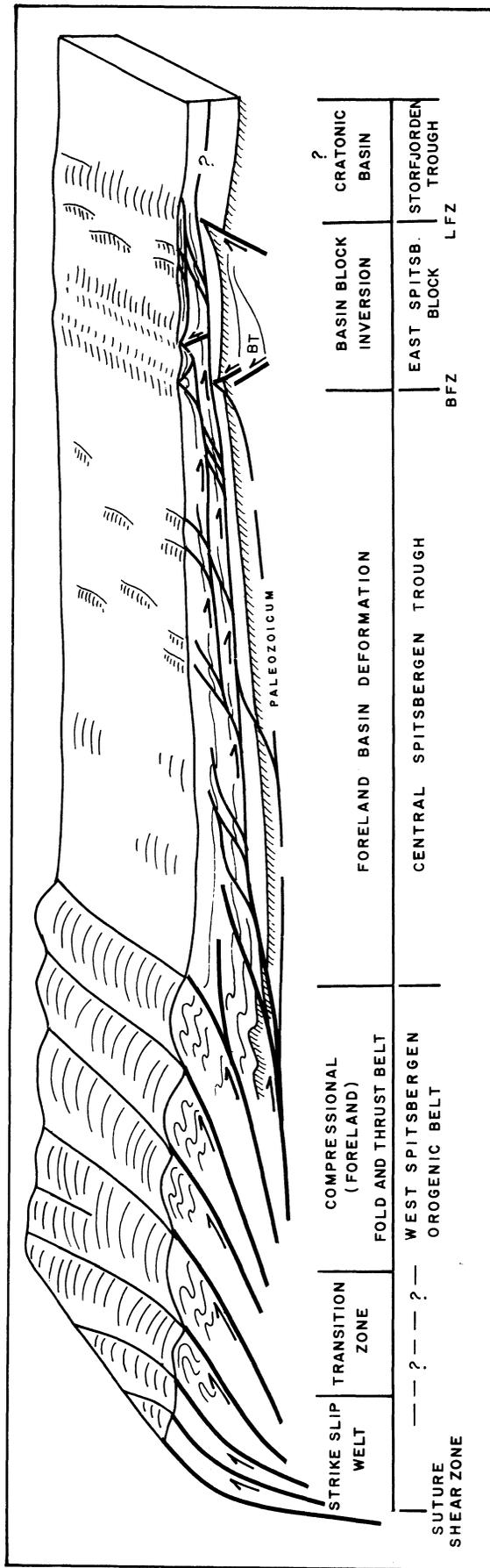
Fig. 3 Schematic model of Tertiary deformation of Svalbard. The figure is not to scale. Note asymmetry of the Central Spitsbergen Trough (CTB), due to buckling and tectonic loading by eastwards propagating orogenic belt (WSOB). Overthrust are expected to become older westwards. BT - Billefjorden Trough (Paleozoic). For other abbreviations, see Figs. 1 and 2.

1), one should expect significant evidences of obliquely striking, downward steepening thrust faults within the present fold belt. On the contrary, placing the suture shear zone along the Hornsund Fault Zone (HFZ)(Fig.1), would allow for mostly compression in the WSOB, as an eventual strike-slip welt (typically few tens of km wide) would then be expected to be buried below sea. We favour the latter, or at least an offshore location of the shear zone. In fact, previous workers nicely demonstrate the compressional aspects of the fold belt (Harland, 1969; Lowell, 1972; Kellogg, 1975; Birkenmajer, 1981; Maher et al., 1986), but mostly fail to give other than circumstantial arguments to support major strike-slip movements. Recent marine deep-seismic across the fold belt (O. Eiken, oral presentation - this meeting) points to the same conclusion.

Evidences of thin-skinned thrusting within the post-Devonian cover confirm this aspect of CST style of deformation. Yet, the inverted nature of the block element between the BFZ and LFZ on central Spitsbergen calls for basement involved mechanisms of deformation. More data is needed in order to explain the geometrical and kinematic relationships involved, but, basically, we believe there are two plausible models that should be tested, though they may augment each other:

1. The block is a pop-up structure generated by compressional block faulting, with genuine reverse vertical movements (6-800 m) on the LFZ and mainly hinging and (?) shallow rooted backthrusting (2-400 m) along the BFZ.

2. Inversion relates to basement involved, thick-skinned thrusting below the CST foreland deformation, with major ramping along the LFZ and antithetic hinging and backthrusting on the BFZ.

The integration of this new tectonic information have some important bearings on the CTB evolution. A general understanding exists, that the incipient evolution of the CTB was in response to gentle warping and weak extension on the Greenland - Svalbard shear zone (Fig. 2) (Paleocene)(Kellogg, 1975; Steel et al., 1981). Recent work further shows that with increased compressional shear (Eocene), the CTB evolved into a foreland basin, with subsidence now being controlled by isostatic loading of both thrust plates and sediment fill (Helland-Hansen, 1985; Steel et al., 1985). Tectonic models presented herein, makes it likely that the CTB passed into a third and final stage of evolution as the basin block, including its thin-skinned deformation, were caught between the upthrusted WSOB and thrust ramps along the BFZ/LFZ (Figs. 2, 3).

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Bjørn T. Larsen

TERTIARY THRUST TECTONICS IN THE EAST OF SPITSBERGEN, AND IMPLICATIONS
FOR THE PLATE-TECTONIC DEVELOPMENT OF THE NORTH-ATLANTIC

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The Tertiary tectonic development of Svalbard is analysed
based on information from three sets of data: a) marine
geophysical data and plate-tectonic analysis, b) sedi-
mentological models for the Tertiary basins, and c)
structural field-geological observations.

Talwani & Eldholm (1977) and later Myhre et al. (1982),
from plate-tectonic analysis, stated that the Greenland
Sea margins, between the Greenland-Senja and Spitsbergen
Fracture zones, evolved from a regional shear zone in
Early Tertiary times (anomaly 24/25, 56 Ma) to a rifted
passive margin in earliest Oligocene times (anomaly 13,
36Ma).
The Tertiary sediments in the Central Basin of Spitsbergen
(Van Mijenfjorden Group) are Paleocene to early Eocene in
age, and the basin is interpreted as a forland basin to
the Tertiary mobile belt (fold belt) of the western
Spitsbergen.
Knowledge of the foldbelt in Spitsbergen comes mostly from
structural observations on land, although in the last few
years reflection seismic data has also been available.

Lowell (1972), based on Harland (1965, 69 & 73) and
Harland et al. (1974), called the foldbelt of western
Svalbard a "strike-slip orogenic belt" (as distinct from a
"subduction orogenic belt"), and described it as a
Tertiary compressive dextral (transpressive) strike-slip
system. The en-echelon fold pattern, the narrow
deformation zone (5-20 km), the involvement of basement,
the pattern of the profiles ("upthrust"), the short thrust
distance, and the lack of ophiolites and of metamorphism
were the reasons Lowell used as evidence for his
interpretation.

During the 1986 field season it became clear that the
eastern part of Svalbard was also effected by Tertiary
reverse faulting. In this area only late normal faulting
had been described previously. Eastward directed reverse
faults were observed in Statoil's licence area in the
Agardh area, on both sides along the Lomfjord fault zone
(Fig. 1), and in the Sassendalen area (Fig. 2).
In the Agardh area intense reverse faulting was observed
in the Botneheia Mb. black shales of the Barentsøya Fm.
some few km west of the Lomfjord fault. The reverse
faults were easily seen in the deformation of thin more
competent sandstone beds within the shale. The strikes of
the reverse faults were about 140 - 160° and the dip about
15 - 30° W. This could indicate an eastward thrusting
with a direction about 60°. The middle and upper part of
the Botneheia Mb. acted as a flat thrust plane in a
ramp-flat geometry. Similar observations were also made
in different parts of Sassendalen. Here pronounced
monoclines also occur. In Moskushornet in the inner part
of Sassendalen a large monocline has an axial strike of
about 5-10° and an azial plunge about 10°N. In the bend
of the monocline, that occurs in Permian Kapp Starostin
Fm. beds, slickensides indicate a compression with an axis
towards the east at about 75°. East of the Lomfjord fault
zone, towards the north, clear ramp situations occur in
Kapp Starostin Fm. chert/shale/limestone approximately 10
km east of the fault zone (Fig. 1). This ramp area is as
much as 100 km to the east of the front of the fold belt
in western Spitsbergen. The reverse faults in this ramp
zone east of Lomfjorden fault zone can be followed in a
zone approximately about 2 km wide. The westward dip of
the reverse fault planes varies from 15° to 45°, generally
around 30°. The relative uplift of the flat-lying beds is
in the order of 50 m on a single fault. Several faults
can be seen in the zone and uplifts in the order of 200 m,
and shortening of 500 m or more is possible over this
exposed fault zone alone.

These observations, together with a reanalysis of the fold
pattern along the mobile belt, reflection seismic data,
and field information on Bjørnøya, lead us to the
interpretation that there has been a compressional
tectonic phase on Svalbard, prior to the transpression,
transtension and spreading phases in Tertiary times. The
width of the reverse faulted zone, 100 - 200 km, and the
parallel orientation of the folds to the faults are the
two strongest arguments.

The parts of the stratigraphy that most often acts as weak
zones, where the thrusting occurs, are in the two
evaporite horizons (Ebbadalen and Gipshuken Fms.), and the
black shales of the upper part of the Sassendalen Group
(Botneheia Mb.) and Janusfjellet Fm.

It seems clear that basement is involved in the reverse faulting tectonics even as far east as Lomfjorden fault zone. This zone is today a reverse fault with the eastern block lower than the western. The faultplane has a steep dip (60 - 80°) towards the west, and is not a normal fault as marked on most maps. In this fault zone steep dipping tectonised evaporites occur in the fault plane itself.

The unanswered question as of today is exactly when the compressional phase started and ended. Most observations indicate that the Paleocene, and maybe the uppermost part of Cretaceous and the lowermost part of Eocene, was the time of compressional tectonics, a tectonic phase that merges into a transpressive phase, a phase that we have only vague evidences of on-land Svalbard.

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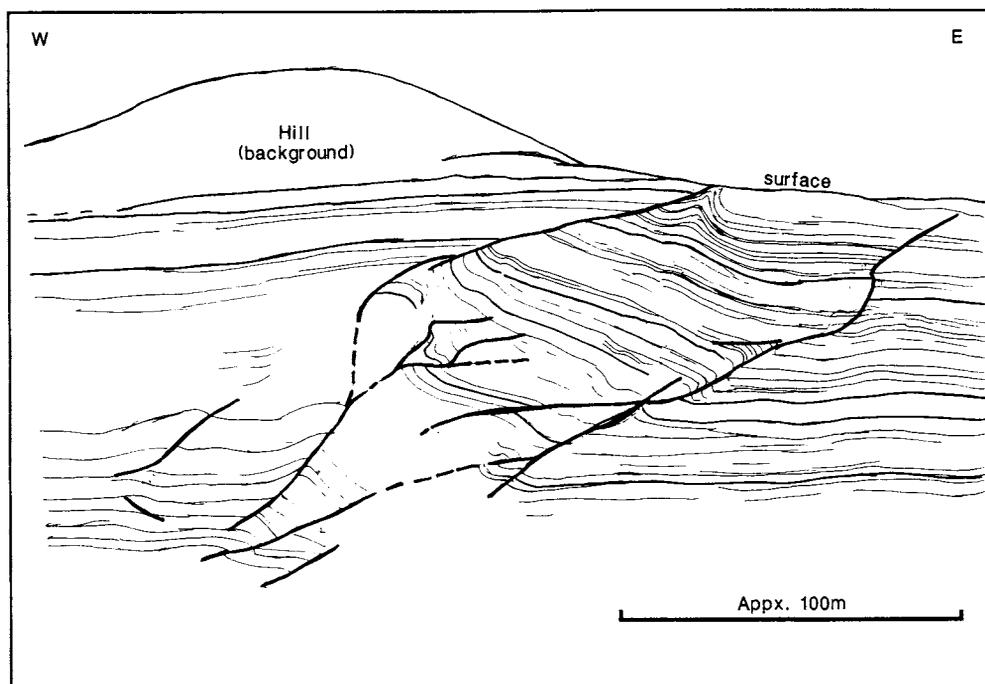
Fig. 1: Field sketch from east of the Lomfjorden Fault Zone. Ramp area
        in Kapp Starostin Fm.

Fig. 2: Field sketch from the Agardh area. Fault-bend fold and minor
        reverse faults.

A. Austegard, O. Eiken, T. Stordal & E.C. Evertsen

DEEP-SEISMIC SOUNDING AND CRUSTAL STRUCTURE IN THE WESTERN PART OF
SVALBARD

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About 2000 km of deep-crustal reflection seismic profiles (16 sec
TWT) were aquired in Svalbard waters during the "Mobil Search"
program for Norwegian Universities. 830 km of these were recorded
as two-ship operations in conjunction with University of Bergen's
"Håkon Mosby", obtaining wide-aperture reflection and refraction
profiles with particularly deep penetration. Together with the
Seismological Observatory's earlier aquired seismic data, it forms
a basis for understanding the transition from continental to
oceanic crust. The data are in an early stage of processing and
interpretation, however, some initial results are presented.

East of the Tertiary fold- and thrust-belt we observe generally a
reflective lower crust, with an abundance of diffraction hyper-
bolas. In Isfjorden a fairly horizontal and continuous reflection
at about 11 sec. TWT may originate from the crust/mantle transi-
tion or from a low-velocity layer in the upper mantle (Chan and
Mitchell 1981). This reflector gets deeper at the fold belt at the
mouth of Isfjorden, but further west the reflections are obscured
by coherent noise, and the shape of crustal thickening below the
fold belt is not established. Our interpretation disfavours the
earlier proposed block-model of the crust in central Spitsbergen
(Pajchel et. al. 1982). We do not observe deep-crustal involvment
in the Tertiary thrusting in central Spitsbergen, either.

Reflections are hart to see in the fold- and thrust belt, but from
the two-ship wide-aperture data a detailed refraction velocity
profile is obtained down to 3-4 km depth. The   belt   is
characterized by very high velocities, exceeding 7 km/s at 3-4 km
depth. Its subcrop width is narrow, since Tertiary grabens are
present immediately west of the coast line. We cannot rule out,
however, that a western aprt of the fold-and thrust belt now forms
the basement beneath these later developed grabens.

Offshore of the west coast the features are extensional: The crust is thinner, and a system of shallow (2-4 km deep) N-S trending grabens or half-grabens up to 30 km wide extends from Forlandsundet and southward at least to Hornsund. they have sedimentary infill from both sides, exhibit syn-sedimentary movements and the whole sequence is weakly compressed. These structures are interpreted mainly as extensional features, although a strike-slip model of graben-formation cannot be ruled out. The grabens are probably of late-orogenic or post-orogenic age. Based on lateral velocity variations and the thickness of post-rift sediments on the outer shelf and slope west of Spitsbergen, we assume 1-2 km of Tertiary sediments have been eroded from the offshore basins and 3 km in central Spitsbergen since the early-middle Tertiary.

The Hornsund Lineament, originally defined on basis of seismic velocities, bounds the thick basin of middle-late Tertiary sediments to the east. At deeper levels the lineament is a less prominent boundary. Extensional features are prominent. West of Isfjorden thinned continental crust with rotated basement blocks in the shelf area extend to about 35 km west of the Hornsund Lineament. However, significant structural variations occur along the margin. At 77^0, west of Hornsund, the basement seems to be downfaulted in a single fault with 6-9 km throw. North of Prins Karls Forland the basement is more gently sloping to the west. We cannot trace continental basement all the way to oceanic-type crust. A 20-30 km wide zone with thick, unpenetrated sediments is limited to the west by a prominent basement high, presumably a part of the oceanic crust, paralleling the Hornsund Lineament at about 2000 m water depth.

North of Kongsfjorden the lower-crustal reflections become shallower, suggesting a much thinner crust in NW-Spitsbergen. Possibly the trend of the fold- and thrust belt changes to a NW-SE direciton at Kongsfjorden, leaving NW-Spitsbergen more or less unaffeacted by early Tertiary compression.

We observe few signs of shear movement along the margin, in cotrast to what has been expected from plate-tectonic models. The inner-shelf grabens as well as the thinned continental crust can mostly be explained by extensional movemnts. Possibly the shear features are overprinted by later movements, or possibly the zone of major shear was situated further west.

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Fridtjof Riis & Jan Vollset

A PRELIMINARY INTERPRETATION OF THE HORNSUND FAULT COMPLEX BETWEEN SØRKAPP AND BJØRNØYA

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The term Hornsund Fault Complex is used to describe the faulted margin between oceanic crust and the relatively stable platform area of the Stappen High. The margin was strongly deformed in the Tertiary, probably with the main phase in the Oligocene. There is no evidence for strong tectonic movement in the Late Cretaceous.

The NPD is presently covering the area north of $74^{0}30'$ with a regional seismic grid, and the margin has been mapped using a small amount of new data and some reprocessed old seismic lines. As line spacing north of Bjørnøya is 10-20 km and the data quality is fair to poor, only regional mapping is possible. However, the structural development in the area west and south of Bjørnøya can be taken as a model for the northern part north to approx. 76^{0}.

The Hornsund Fault Complex is dominated by one master fault, the Knølegga Fault, defining the eastern boundary of the margin (fig. 1). The throw of this fault is greatest in the Bjørnøya area, where it separates Triassic to Permian rocks of the Stappen High from a very thick Tertiary and Mesozoic sequence to the west. The fault seems to be a listric normal fault associated with huge roll-over structures, and soling out at large depth.

In the main study area, the Knølegga Fault is also very well developed, but the roll-over geometry is not so obvious at the down-thrown side. Instead, one can define a zone of domes and rotated fault blocks west of the fault, fig.1, dome area. The dome area is separated from probable oceanic crust by a steep slope, and this boundary is associated with a strong positive gravity anomaly.

The Late Tertiary clastic wedge which was deposited across
the continent-ocean boundary can be divided in two parts.
The northern part is built up of stacked prograding
sequences and reaches thicknesses of 4 - 4.5 sec TWT. The
southern part is thinner and characterized by slumping.

The main structural problem of the area is the transition
from the Spitsbergen folded belt to the mainly extensional
Knølegga fault. As indicated in Fig. 1, this transition
seems to take place close to Sørkapp, and it is linked to
the change in direction of the Continent - Ocean boundary.
The amount and quality of the seismic data available does
not permit any detailed structural model. However,
knowledge of the nature of this transition is important to
understand the Spitsbergen Tertiary history.
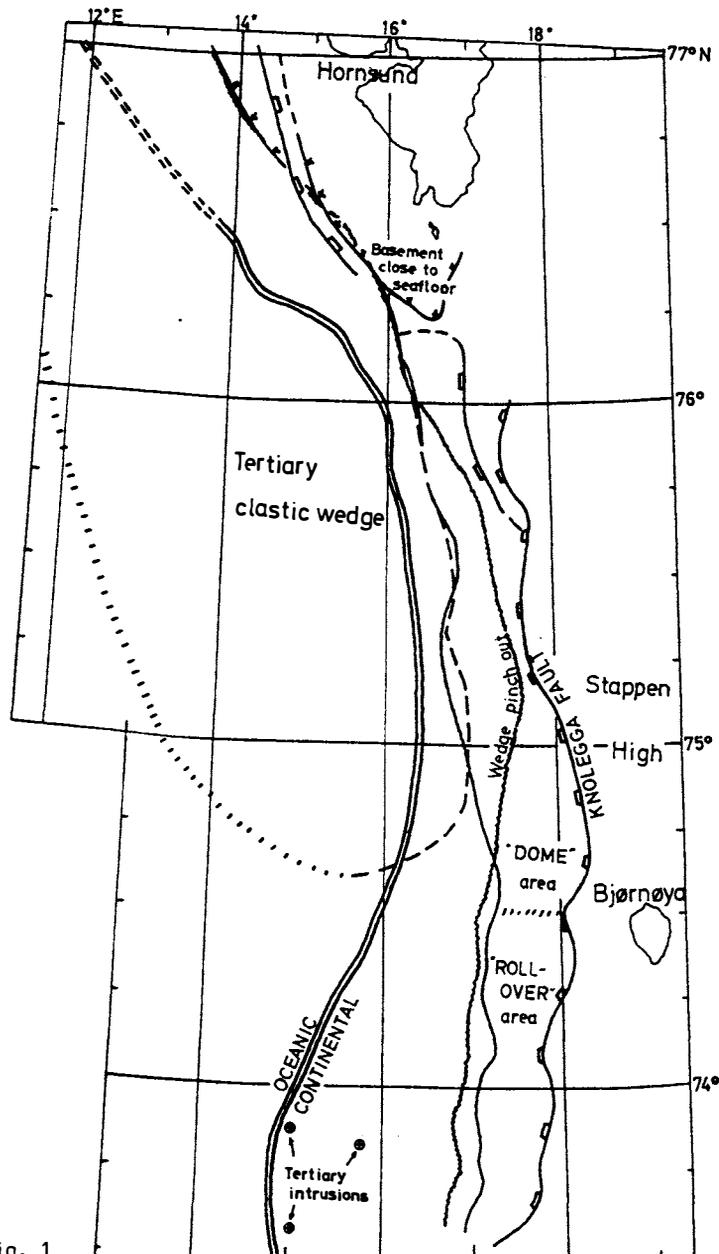
Fig. 1

Roy H. Gabrielsen & Roald B. Færseth

CRETACEOUS AND TERTIARY REACTIVATION OF MASTER FAULT ZONES OF THE
BARENTS SEA

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Structurally, the Barents Sea continental shelf is
dominated by ENE-WSW to NE-SW, NNE-SSW to NNW-SSE, and
locally WNW-ESE structural trends. In the southern part,
the ENE-WSW-trend is defined by the fault complexes
bordering the Hammerfest and Nordkapp Basins. This trend
is subparallel to a fault zone to the north defined by
the Helgøya High and the fault complexes separating the
Loppa High from the Bjørnøya Basin.

To the west and northwest the N-S-trends are dominating
(Ringvassøy-Loppa Fault Complex, Knølegga Fault, Hornsund
Fault Zone). This part of the Barents Sea have been the
tectonically most active throughout in the latest
Mesozoic and Cenozoic times. In contrast, the eastern and
northeastern parts are dominated by stable platforms with
less pronounced tectonic activity.

Few data exist on the pre-Devonian structural history of
the Barents Shelf. However, reflection seismic data
indicate that all the known main structural trends were
established by Permian times.

In the subsequent structuring of the Barents Sea area,
activity was associated with these important elements.
This led Gabrielsen (1984) to propose a classification of
faults according to their basement involvement and degree
of reactivation. In this type of model the area is
divided into separate fault blocks corresponding to the
major highs and basins, delineated by deep-seated fault
complexes. When stress is applied to this system of
blocks, a complex pattern of relative movements between
the individual blocks will take place.

Fig.1 shows the main structural features of the Barents
Sea region. In this picture, the following structures are
believed to represent the principal, deep-seated
fault lines: Troms-Finnmark, Måsøy, Thor Iversen,
Nordkinn, Kalvsundet, Ringvassøy-Loppa and Bjørnøyrenna
Fault Complexes. In addition, The Helgøy High and the
Senja Ridge are probably underlain by deep zones of
weakness.

In recent works in the area, indications of strike-slip
movements and inversion have become evident, and shear
movements have been proposed to be of importance for the
structuring in late Devonian, Permian, mid Jurassic
(Rønnevik et al. 1982, Rønnevik & Jacobsen 1984), late
Jurassic – early Cretaceous (Riis et al. 1986, Berglund
et al. 1986, Gabrielsen & Færseth in press), and Tertiary
times (Riis et al. 1986).

Of these events, the early Cretaceous deformation is best
documented. Strike-slip related deformation associated
with several of the major lineamnets has been suggested
at this point in time (Fig.1), and the most vigorous
deformation seems to have taken place along the
Bjørnøyrenna Fault Complex. The observation that the
deformation is associated with the principal fracture
systems seems to support the above principal model.

For the early Cretaceous deformation, Riis et al. (1986)
suggested sinistral shear along the Bjørnøyrenna Fault
Complex, and synthetic movements on a deep fault zone in
the central part of the Tromsø Basin. In our opinion,
this model may explain most of the structural features
observed in the Bjørnøyrenna Fault Complex, provided that
a compressional element is assumed for the strike-slip
movement (transpression). However, sinistral shear fails
to explain the compressional structures seen at the
northwestern tip of the Senja Ridge, as well as the
extension recorded in the Ringvassøy-Loppa Fault Complex
at this point in time (Fig.2a).

As an alternative model to explain inversion of the
western part of the Kalvsundet Fault Complex may be a
slight clock-wise rotation of the Hammerfest Basin fault
block (Fig.2b). This model would be in accordance with
reactivation of the Trollfjord-Komagelv trend in the
eastern part of the Hammerfest Basin, local inversion
along the easternmost segment of the Troms-Finnmark Fault
Complex (Gabrielsen & Færseth in press), and
contemporaneous extension along most of the
Ringvassøy-Loppa fault Complex.

In conclusion, several stress configurations may fit the
strain pattern as recorded in isolated parts of the area.
However, at the present stage in the exploration of the
Barents Sea region, there are difficulties in defining a

successful synergetic structural model. It is considered
likely that important pieces in this puzzle are to be
found in the structural geology of Svalbard.

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FIGURE CAPTIONS

Figure 1
Main structural elements of the Barents Sea region.
Arrows indicate late Jurassic - early Cretaceous tectonic
activity. Structural features after Gabrielsen et al. in
prep.

Figure 2
Simplified regional structural model for late Jurassic -
early Cretaceous deformation of the Barents Sea region,
implying sinistral shear along the Bjørnøyrenna Fault
Complex and clock-wise rotation of the Hammerfest Basin.
Note that the mode fails to explain inversion in the
northern part of the Senja Ridge.

Fig. 1

Fig. 2

Stig A. Schack Pedersen

MODEL OF STRUCTURAL EVENTS IN THE LATE MESOZOIC PLATFORM BREAK UP
BETWEEN GREENLAND AND SVALBARD

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Structural investigations in Kronprins Christian Land, eastern North
Greenland, form the basis for the suggested model of tectonic defor-
mations preceding the main transform dextral displacement of Svalbard
relative to North Greenland.
   Three major tectonic events of the Wandel Hav Strike-Slip Mobile
Belt are recognized. An early extensional event (the Ingeborg Event)
seems to affect Late Paleozoic carbonates and clastic sediments. The
structures comprises normal listric faults accompanied by the develop-
ment of slaty cleavage. The deformation probably took place during the
Jurassic and created depocentres, which governed the Late Jurassic -
Early Cretaceous accumulation in the order of 1,000 m or more.
   The second transtensional event (the Kilen Event) faulted the Late
Jurassic and Early Cretaceous clastic sediments. Listric normal faults
displace features related to the first event, and calcite-veins with
ankerite and siderite are often developed along the fault-surfaces.
Furthermore, mylonitic deformations affected Caledonian rocks in the
main strike-slip lineament. The deformation took place in the mid
Cretaceous and preceded deposition of between 500 m to 5 km Late Cre-
taceous clastic sediments in local, disconnected basins.
   The third event is a main compressional - transpressional tectonism
which was responsible for the structural inversion of the basins, it
is here refered to as the Kronprins Christian Land Strike-Slip Oro-
geny. Three structural phases are recognized. The first phase is an
anastomosing, penetrative shear jointing formed during initial trans-
ressional shearing. The second phase is characterized by en échelon
dome folding. Along the flanks of the domes thrust faulting appeared,
and in the third phase the domes are torn apart by dextral strike-
slip faults. The dextral faults are responsible for the final dis-
section of the area into rhomb-shaped fault blocks. Second order
sinistral faults with off-sets of a few meters are related to the
first order dextral faults. The transpressional event is dated to
Late Cretaceous - earliest Tertiary times.
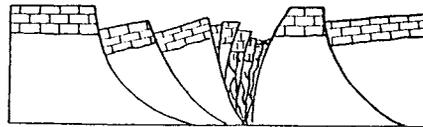
INGEBORG EVENT   transtension (?)
                                        basin subsidence
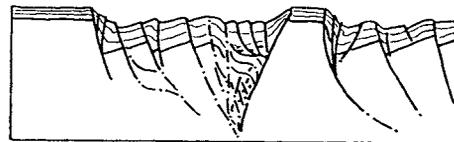
KILEN EVENT   transtension
                                        basin subsidence

KRONPRINS CHRISTIAN LAND
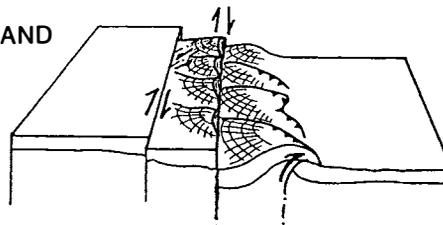
STRIKE-SLIP OROGENY   transpression
                                        basin inversion

Figure 1. Three main structural events have been recognized in the
Wandel Hav Strike-Slip Mobile Belt in eastern North Greenland. The
Jurassic Ingeborg Event affected the Late Paleozoic - Early Mesozoic
platform sediments by extensional normal listric faults leading to
sub-basin formation. In the Kilen Event superimposed extensional
faulting displace the Late Jurassic and Early Cretaceous marine
clastic sediments, and several pull-apart basins developed. Finally
the transpressional Kronprins Christian Land Strike-Slip Orogeny
resulted in the structural inversion of the sediment basins with
formation of characteristic en échelon dome folds.
For location of geographical names mentioned see Håkansson this
volume.

Eckart Håkansson

DID TERTIARY COMPRESSIONAL TECTONICS AFFECT NORTH GREENLAND?
Summary of the evidence.

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Post-Paleozoic compressional tectonics in North Greenland have been the
subject of two regional models differing somewhat in their conceptual
time frame. One model relates compression in North Greenland entirely to
Late Paleocene – Eocene events in the West Spitzbergen and Eurekan
Orogenies (1), while the alternative model, based solely on North
Greenland data, suggests that compression here is essentially Late
Cretaceous (to possibly earliest Paleocene) in age (2).

In the latter model the structural setting governing events in North
Greenland became well established some time in the late Jurassic during
the first extensional event of the Wandel Hav Strike-Slip Mobile Belt,
in the formation of the Trolle Land Fault System. Subsequently, in the
second extensional event of this mobile belt, a number of pull-apart
basins developed across North Greenland, with highly varied infill.
Finally, in the compressive culmination of the Wandel Hav Strike-Slip
Mobile Belt, these basins along with the rest of eastern North Greenland
were severely folded and thrusted. Later events are solely tensional (2,
3,4,5).

In a broader, plate tectonic context the time differences implied in
the two models are of fundamental importance; consequently this brief
review is concerned primarily with the timing of events in North
Greenland – temporarily ignoring the interesting aspects of the regional
geological implication of these events.

Three structural entities in particular hold information pertinent
to the assessment of the timing of the compressional regime in North
Greenland.

A.   In northern Peary Land the Kap Cannon Thrust Zone is an imbricate
thrust fault fan with wedges containing a.o. all known occurrences of
the Kap Washington Group. The thrust zone further affects a dense, N-S
oriented dyke swarm. Dating of the dominantly volcanic Kap Washington
Group is based on mixed paleontological and radiometric data: Partly
intrabasaltic sediments from near the base have yielded poor macroplants
indicative of Late Cretaceous ages (6), intrabasaltic sediments some

3 km above the base contain a restricted Campanian or Maastrichtian flora (6), while rhyolithic lavas at the top yield Rb/Sr-ages of 64±3 ma (7). The dyke swarm is most likely of (?)Late Cretaceous age; previously reported K/Ar-dates of dykes and retrograded micaschists from this area must be considered unreliable at this point (8).

B.   The Harder Fjord Fault Zone in central Peary Land is a long-lived E-W oriented linear feature containing, along with older strata, variously disturbed sediments of Late Permian to possibly Paleogene age in an up to 5 km wide tectonic melange.

Centrally in the zone Inoceramus bearing Late Santonian strata were intruded by somewhat irregular basic dykes prior to upthrusting into the present vertical position. Associated with the compression, both magmatic and sedimentary rocks were subject to severe thermal alteration. Subsequently the entire disturbed sequence was intruded by a generation of N-S oriented basic dykes, which have undergone no thermal alteration.

Further to the east a tilted, unfolded sequence of fluvio-deltaic origin referred to the Herlufsholm Strand Formation has been thrusted over strongly deformed rocks of the Franklinian Fold Belt; no direct age determination has been possible due to a complete thermal degradation of all organic-walled microfossils. A very limited occurrence of continental strata with a very restricted pollen flora suggesting a Paleogene age has also been reported from this part of the fault zone (9). The orientation of these strata is unknown, but the fact that they do contain reasonably preserved microfossils in spite of their location in the middle of the fault zone, is taken to indicate, that the two sequences were separated in time by the thrusting event.

Volcanic necks and breccia pipes previously referred to the same magmatic provenance as the Cretaceous dykes and Kap Washington Group volcanics were deformed in the mid-Paleozoic Vølvedal Orogeny (2,10).

C.   The Trolle Land Fault System is a complex of largely parallel, NW-SE oriented faults with anastomosing E-W oriented, second order faults which strech across eastern North Greenland from Peary Land to Kronprins Christian Land. A great variety of data has been gathered along this system.

In East Peary Land a sequence of Carboniferous through Middle Triassic sediments were deformed in the first Wandel Hav Strike-Slip Mobile Belt event, in what was here most likely a sinistral strike-slip regime. The resulting block mosaic was transgressed in the Middle Oxfordian, and, after an interval of continental deposition starting in the Valanginian, marine conditions were reestablished in the Aptian-Albian period. Subsequent to this, fluvio-deltaic sediments of the Herlufsholm Strand Formation accumulated in a basin close to the junction between the Harder Fjord and Trolle Land Fault Zones. This area was later subjected to fairly strong domal folding in an event which probably also led to the complete thermal degradation of the microflora. Apart from the presence of deciduous leaves and wood indicating a Late Cretaceous or Early Tertiary origin (11), no age determination has been possible in this basin, neither regarding the sedimentation nor the deformation. However, by comparison with the neighboring basin in the Harder Fjord Fault Zone and the overall structural frame, a Late Cretaceous age is considered most likely.

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On the north coast of Kronprins Christian Land very gently folded marine sediments are found containing a fairly divers bivalve fauna indicative of a Late Cretaceous age. Locally extensional faults of probable Tertiary age are abundant with associated, quartz filled tension gashes giving evidence of a substantial increase in heat flow. Throughout the area organic walled microfossils are lost completely in this late episode, and neomorphic envelopes are typically developed around all non-quartzose sediment grains.

On the east coast of Kronprins Christian Land, at Kilen, a Late Jurassic to Albian marine sequence of substantial magnitude is developed somewhat parallel to the sequence in east Peary Land. This sequence is disturbed by normal listric faults of the second extensional event in the Wandel Hav Strike-Slip Mobile Belt prior to a Turonian transgression. Marine sediments with abundant ammonites and inoceramids continued to accumulate into the Coniacian, but a significant portion of later Cretaceous sediments at the top of the sequence has so far not been more precisely dated. In the final compressional culmination of the Wandel Hav Strike-Slip Mobile Belt the entire sequence at Kilen was severely disturbed in a series of domal folds and thrusts.

On the west coast of Kronprins Christian Land Permian sediments as well as Caledonian nappes were strongly faulted and folded in several episodes prior to the deposition of a clastic sequence in an alluvial fan to coastal plain setting. The macroflora from these sediments is associable with the Early Tertiary floras of Svalbard and the Sverdrup Basin, and from microfloral evidence a (?Late) Paleocene age can be assumed for the North Greenland strata. The Paleocene cover sequence is unfolded and cut by extensional faults only. Together with older strata the Paleocene sediments have been affected by the late episode of strong heat flow increase centered on the north coast of Kronprins Christian Land.

Summing up the evidence, I find it reasonable to maintain that post-Paleozoic compression in North Greenland may well have been concluded entirely within the Late Cretaceous period. The inviting parallel to the West Spitzbergen Orogeny in Svalbard therefore becomes very intricate, since compression here is mostly agreed to be of Paleocene age. Whether this discrepancy reflects an actual difference in the plate tectonic significance of the two orogenic belts, or whether it merely reflects difficulties in dating events and strata in Svalbard, has yet to be established.

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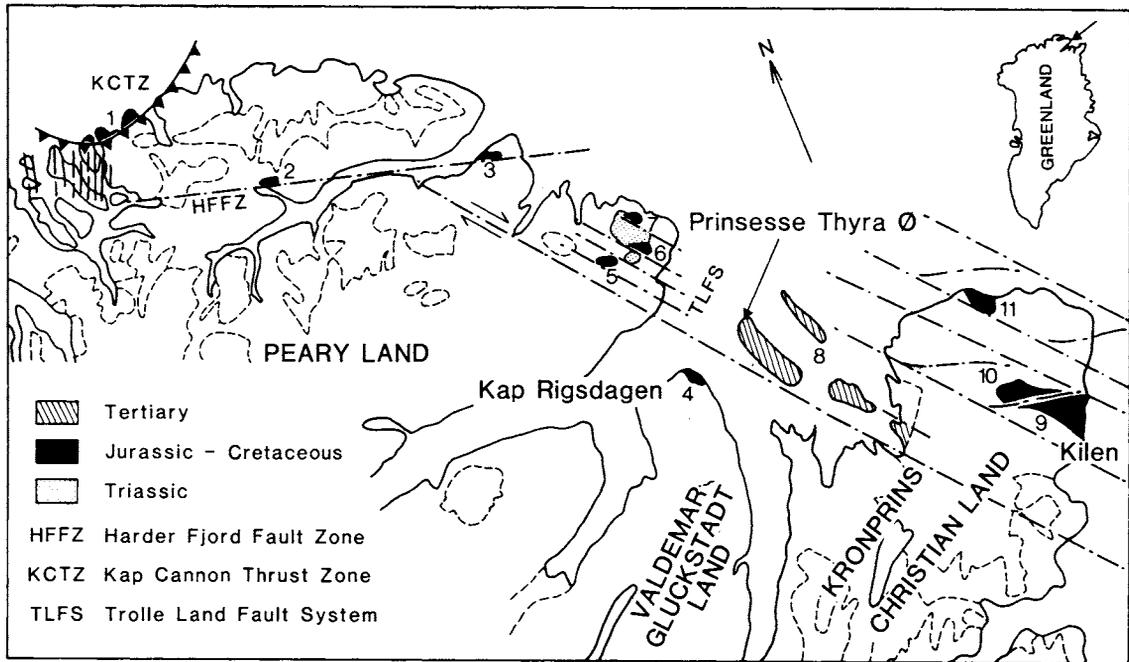
Structural and depositional elements in the Wandel Hav Strike-Slip Mobile Belt.
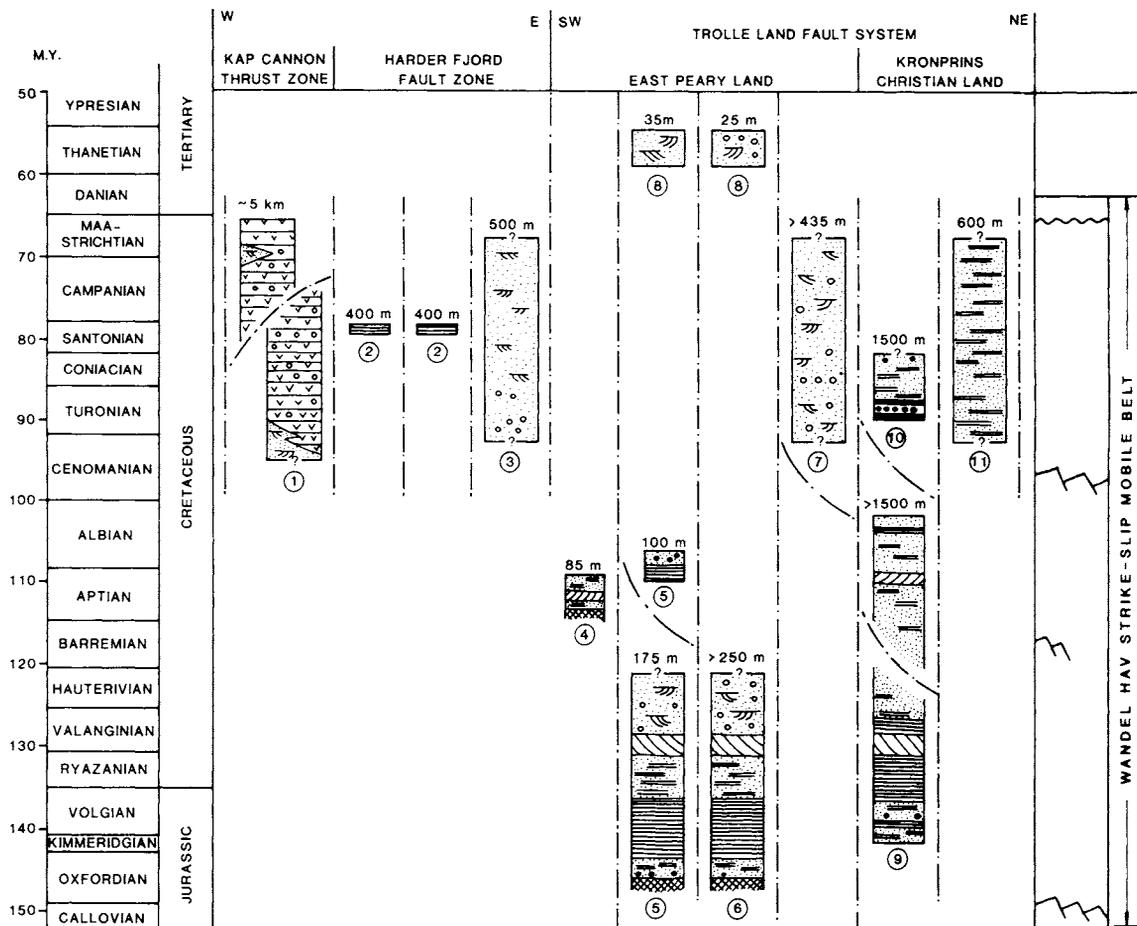
Stratigraphy of the Wandel Hav Strike-Slip Mobile Belt.

Erling Vågnes, Per Arild Reksnes, Jan Inge Faleide and Steinar Thor Gudlaugsson:

PLATE TECTONIC CONSTRAINTS ON THE FORMATION OF THE SPITSBERGEN FOLD AND THRUST BELT

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The formation of the Spitsbergen fold and thrust belt was related to the breakup of the North-American, Greenland, and Eurasian plates at the Yermak triple junction, and the subsequent ~550 km of dextral strike-slip along the Hornsund Transform in the Eocene. It is generally accepted that the fold and thrust belt resulted from transpression (e.g. Harland 1969; Lowell 1972). However, dating problems, and uncertainties regarding the exact geometry of the plate tectonic evolution of the Greenland Sea, have made exact correlation between geologic observations and plate tectonic predictions problematic. New evidence eliminates   earlier discrepancies and enables an integrated discussion of structural geology and plate tectonics. It also opens the possibility of an alternative interpretation of the earliest part of the orogeny.

Models for the plate tectonic movements between Greenland and Eurasia are converging (Talwani & Eldholm 1977; Reksnes & Vågnes 1985; Srivastava & Tapscott 1985). Generally the model of evolution of the Norwegian-Greenland Sea put forward by Talwani & Eldholm (1977) is confirmed. In particular the direction of movement between Greenland and Eurasia from late Paleocene to early Oligocene was constant, thus excluding shifts in the direction of plate movement as an explanation for the Tertiary orogeny on Spitsbergen. The poles of rotation obtained by Reksnes & Vågnes (1985) are the starting point for the following analysis.

The dating of the orogeny now seems well constrained; onset in the latest Paleocene is indicated by the shift from an easterly to a westerly source area in the Central Basin (Steel et al. 1985; Manum & Throndsen 1986). The orogeny must have continued at least until deposition of the syn-orogenic Eocene formations. The latest Paleocene

onset of the orogeny may predate the onset of sea-floor spreading in the Norwegian Greenland Sea in the earliest Eocene, but the discrepancy is near the limit of resolution of the datings available, and may be an artefact. On the other hand part of the orogeny may have been a response to movements pre-dating the breakup of continents.

Late Cretaceous to early Paleocene(?) dextral strike-slip movements are reported from the Trolle Land Fault Zone in the Wandel Sea Basin (Håkansson & Pedersen 1982). Major Late Cretaceous subsidence and deposition is observed in the basins off central Norway. This is in striking contrast to the southwestern Barents Sea where little coeval deposition is observed. In reconstructed positions the Trolle Land Fault Zone and the Senja Fracture Zone are aligned. We suggest that the Late Cretaceous extension to the south was taken up as dextral strike-slip movements along the "Trolle Land-Senja Fault Zone", thus shielding the southwestern Barents Sea from Late Cretaceous extension. These movements caused no deformation on Spitsbergen (Faleide et al. this volume).

A latest Paleocene/earliest Eocene rifting episode formed a major Tertiary basin along the Senja Margin in the southwestern Barents Sea (Faleide et al. in prep.). The onset of the Spitsbergen Orogeny was a part of the same tectonic episode, a result of pre-drift movement between Greenland and Eurasia. Along the Harder Fjord Fault Zone (HFFZ) ~20 km Tertiary dextral strike-slip has been reported (Higgins 1985). Furthermore, when Eurasia and Greenland are reconstructed to their late Paleocene positions the trend of the HFFZ intersects the Svalbard margin at the southern termination of the Spitsbergen fold and thrust belt. The HFFZ also had a more westerly azimuth than the post-breakup direction of movement between Greenland and Eurasia (~20 deg.). These observations are consistent with a model in which a wedge of crust, limited to the south by the HFFZ, became squeezed between the Greenland plate to the south and the Eurasian to the north. This resulted in transpression along the HFFZ. At this time the Spitsbergen Orogeny may be seen as the southeasternmost part of the Eurekan Orogeny (Fig. 1a).

Increasing movement forced a break between Greenland and Eurasia, initiating large scale strike-slip (~2 cm/yr) between Eurasia and Greenland and producing the post-breakup part of the orogeny. The geometry of the initial plate boundary was probably a compromise between the direction of plate motion and the HFFZ trend. The larger the impact of the Harder Fjord trend on the initial plate boundary, the more transpression on Spitsbergen. An average of 30 km of shortening along the fold and thrust belt may easily be accommodated in such a model (Fig. 1b).

The fold and thrust belt does not cover the full length of the paleo-transform. A trend-shift in the plate boundary off Kongsfjorden would explain its northward termination. Evidence for such a northward shift in the azimuth of the present ocean-continent boundary has been reported (Eiken & Austegard 1988).
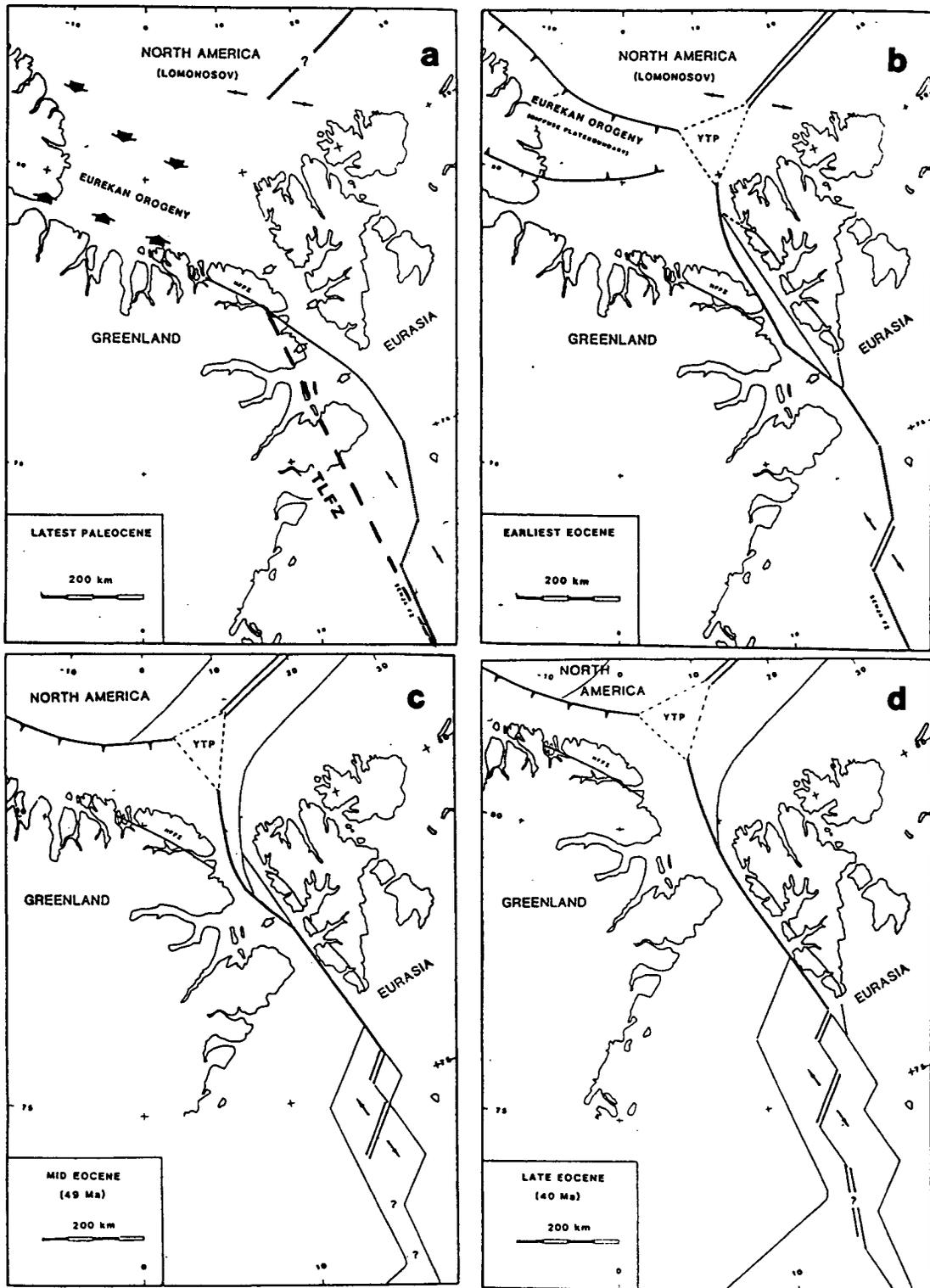
Figure 1. Schematic illustration of the interaction between plate movement and the plate boundary during Tertiary orogenesis on Spitsbergen. (YTP= Yermak Triple Junction, HFFZ= Harder Fjord Fault Zone).

Major orogenic activity ended in late Eocene (~40 Ma) when Greenland had slid past Svalbard a distance equal to the length of the fold and thrust belt (~375 km). At that time the plate boundary had become parallel to flow-lines along the whole Spitsbergen fold and thrust belt. The pre-Oligocene Hornsund trend was thus a product of transpression (Fig. 1d).

In earliest Oligocene the Greenland plate became part of the North-American plate. The Yermak Triple Junction became extinct and extension became dominant between Spitsbergen and Northeast Greenland, probably overprinting some of the compressive structures. The present lineaments along the Hornsund trend and the Forlandsundet Graben are likely a result of post-orogenic extension, which may have commenced in the late Eocene. Important information regarding the orogeny, particularly the position of the main transform fault, was probably erased by this event.

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TERTIARY DEFORMATION OF SVALBARD: REGIONAL RELATIONSHIPS, CRITICAL
AREAS, ALTERNATIVE MODELS

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Tertiary deformation of Svalbard includes: (1) reciprocal
formation of the West Spitsbergen Uplift and the Central Basin on
a fold-thrust boundary structure in the Early Tertiary;
(2) formation of the Forlandsundet and Outer Shelf basins in the
Middle and Later Tertiary; (3) Some reactivation of older more
easterly fault zones, especially the Lomfjorden fault; (4) south-
ward regional tilting; (5) regional uplift; (6) a small pullapart
under a volcano.

The cross-sectional geometry of the West Spitsbergen Uplift is
best displayed at its north end where it plunges southward into
the ground. Alternatives are considered for both the map-view and
cross sectional configuration of the northern end of the uplift.
The Thrust Belt east of the basement exposure is made up of
thin-skinned imbrications forced ahead of the basement thrust.
Southward termination of these imbrications does not occur at
Isfjorden, rather they are likely to plunge southward under the
Central Basin. The en echelon map pattern of the imbricated zone
is more related to this southward plunge than to an en echelon
pattern imposed by the strikeslip component.

Plunges are important to deciphering deformed belts and end-member
possibilities are presented. The southward plunge at the north
end of the uplift reverses itself in the area of Bellsund, but
becomes southward again at inner Hornsund. The outcrop of lower
Hecla Hoak north of outer Hornsund contrasts with that of
Carboniferous and Triassic south of it, indicating a large
transverse ramp as the cause. There are two alternatives,
depending on whether or not these exposures ride on the same
thrust plate and whether plunges are northward or southward.
Bear Island's faulted central basement uplift plunges north and
seems to be a smaller scale replica of the West Spitsbergen
uplift. A significant part of its development seems to be
Tertiary.

Several additional points are covered including: (1) Alternative causes for the Forlandsundet Basin; (2) smaller-scale deformation along the thrust front and out into the Central Basin; (3) possible reactivation of older faults; (4) the causes of the vertical history of the area; and (5) some aspects of the plate setting.