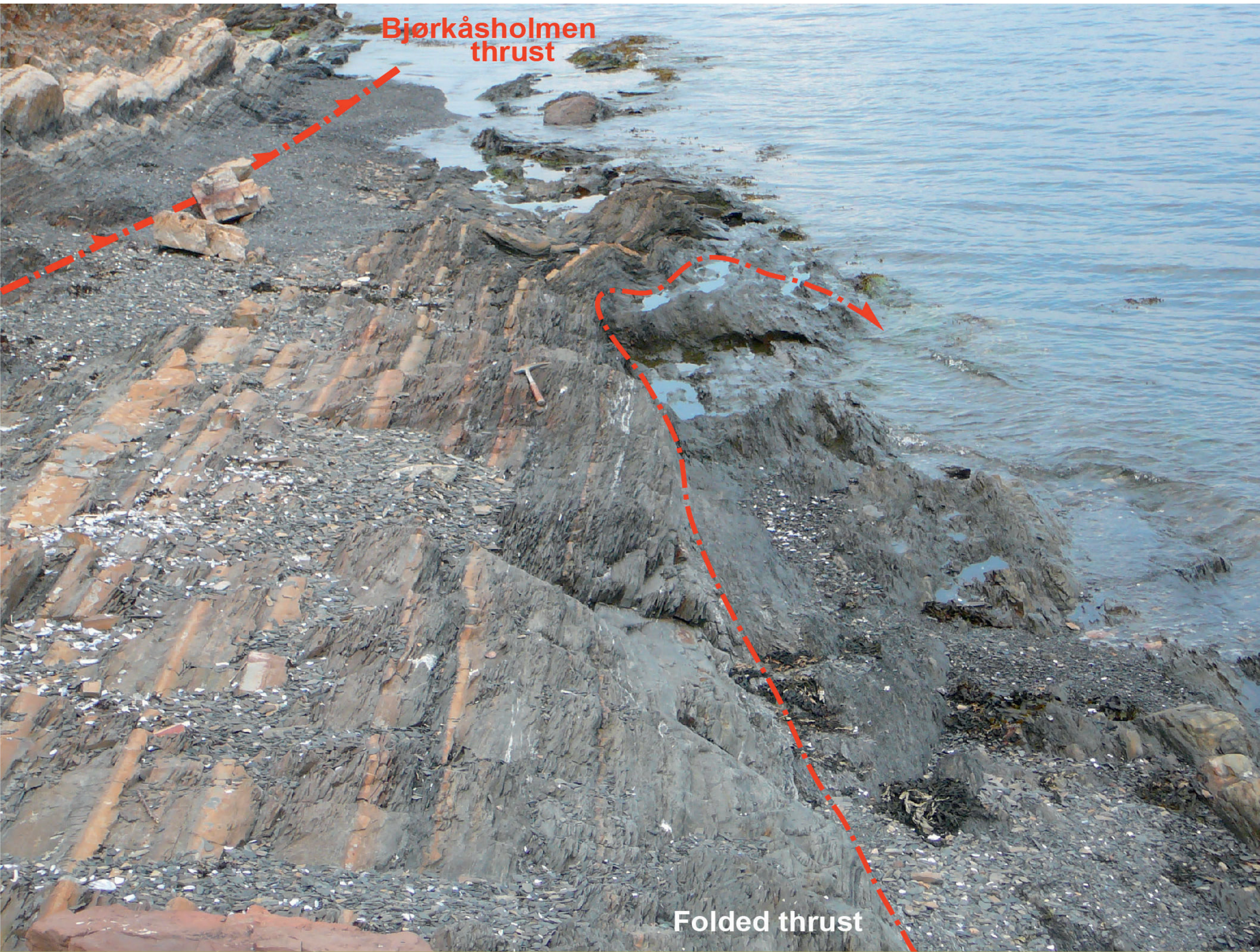
GEOLOGICAL GUIDES
5 - 2015



CALEDONIAN FORELAND THRUST TECTONICS

in the Slemmestad area, Oslo Region, South Norway: an excursion guide

By: Ole Graversen

Geological Society of Norway

ISBN: 978-82-8347-001-7

NGF Geological guides

Front cover illustration:
Ole Graversen
Bjørkåsholmen: Thrusted and folded intervals of the Alum Shale,
Bjørkåsholmen and Tøyen formations.

Levels geological guides:
The geological guides from NGF, is divided in three leves.
Level 1—Schools and the public
Level 2—Students
Level 3—Research and professional geologists

This is a level 3 guide.

Published by:
Norsk Geologisk Forening
c/o Norges Geologiske Undersøkelse
N-7491 Trondheim, Norway
E-mail: ngf@geologi.no
www.geologi.no

GEOLOGICAL SOCIETY
OF NORWAY

Caledonian foreland thrust tectonics in the Slemmestad area, Oslo Region, South Norway: an excursion guide

By

Ole Graversen

Department of Geosciences and Natural Resource Management,
University of Copenhagen, Geocenter Denmark,
Øster Voldgade 10, DK-1350 Copenhagen K, Denmark

Introduction

The Early Palaeozoic platform sediments in the foreland of the the Scandinavian Caledonides have generally been removed by erosion during postorogenic uplift of Fennoscandia during the formation of the Baltic or Fennoscandian Shield. An exception to the general picture is found in the Oslo Graben, where the Lower Palaeozoic sediments are preserved in a downfaulted position associated with the Permian graben tectonics (Fig. 1). The Cambro- Silurian of the Oslo region belongs to the Osen-Røa nappe situated at the base of the lower allochton of the Caledonian nappe complexes (Bockelie & Nystuen 1985; Morley 1986; Bruton et al. 2010). The basal decollement detachment surface forms a flat in the underlying autochton and parautochton of the Middle Cambrian Alum Shale deposited above the Precambrian crystalline basement. The Caledonian foreland deformation can be traced through the platform sediments to the southern Oslo Graben, where the orogenic deformation dies out in the Skien-Langesund area.

The thrusted and folded, lithostratigraphical succession of the Oslo Region consists of Lower Palaeozoic epicontinental platform sediments deposited on the Baltoscandian margin of Baltica. The platform sediments were deposited on the sub-Cambrian peneplain that developed subsequent to the Sveconorwegian orogeny at 1100-900 Ma and intrusion of post- orogenic granites at around 830 Ma (Graversen 1984; Graversen & Pedersen 1999; Berthelsen et al. 1996). Thrusting and folding of the Lower Palaeozoic succession culminated during the late-Caledonian, Scandian orogeny in Late Silurian time. During the evolution of the Oslo Graben, the folded, Lower Palaeozoic foreland succession was covered by thick plateau lavas and a thin cover of sedimentary rocks, and intruded by central volcanoes and batholiths during Late Carboniferous and Permian time. The Palaeozoic sedimentary rocks and the Permian lavas were stripped off from the Precambrian crystalline basement outcropping to the west and east of the graben during a later period of uplift and erosion.

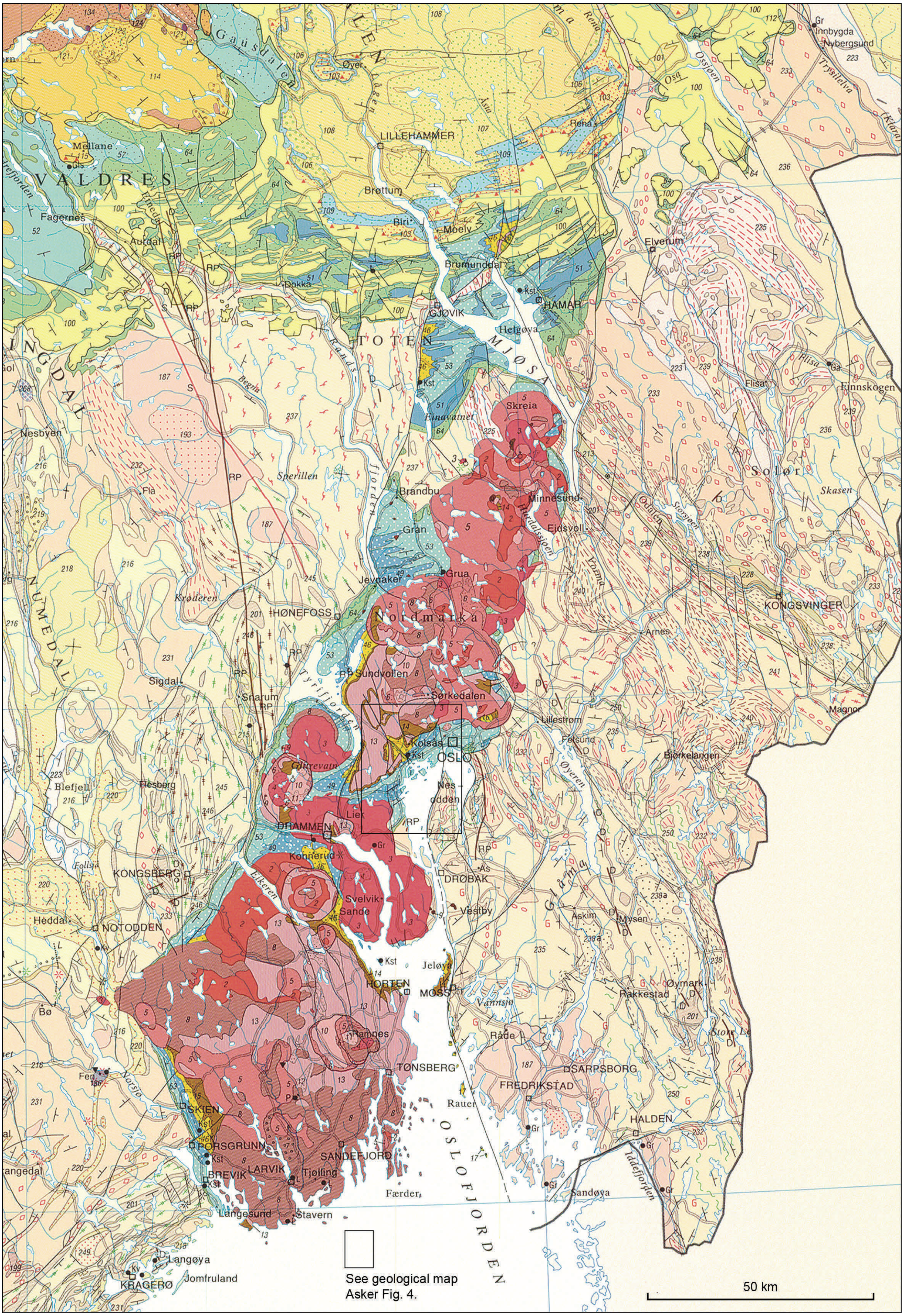


Fig. 1A. Oslo Graben Bedrock map.

Rocks of Devonian, Carboniferous and Permian age

Plutonic and hypabyssal rocks (Permian age)

- 2 — Alkali-feldspar granite (ekerite)
- 3 / 4 — Biotite granite, medium- to coarse-grained (Drammen granite) / Granite, porphyric, finegrained
- 5 / 6 — Syenite, medium- to coarse-grained (nordmarkite, Grefsen syenite, pulaskite / Syenite, porphyric, in ring-dykes and small bodies
- 7 / 8 — Foid-bearing monzozyenite (lardalite) / Monzodiorite, monzonite, syenite (Kjelsåsite, larvikite, akerite)
- 9 — Gabbro, pyroxenite, anorthosite, diorite ('Oslo-essexite')
- D / RP / S — Dolerite (D), latite porphyry (rhomb-porphyry) (RP) and syenite (S)

Extrusive and subvolcanic intrusive rocke (Permian age), sedimentary rocks (Carboniferous age)

- 10 / 11 — Rhyolite, trachyte (lava, ignimbrite and sub-volcanic intrusive rocks) / Volcanic breccia and subvolcanic intrusive breccia
- 12 / 13 — Trachyte, porphyritic lave / Latite (rhombporphyry)
- 14 / 15 — Basalt / Basalt with underlying Carboniferous sedimentary rocks

Sedimentary rocks (Permian age)

- 16 / 17 — Sandstone, mudstone / Conglomerate with pebbles (cobbles) of rhomb-porphyry

Rocks of Precambrian to Devonian age in the Caledonian mountain chain

Metamorphosed sedimentary rocks, autochtonous and allochtonous (Silurian age)

- 46 / 47 — Sandstone, subordinate limestone (Silurian, in the Oslo region also of Downtonian-Lower Devonian age) / Conglomerate with pebbles of gabbro, granite and greenstone
- 48 — Quartzite
- 49 — Limestone, shale, sandstone
- 50 — Silty shale with beds of metagreywacke, conglomerate and in places limestone

Metamorphosed sedimentary rocks, autochtononous and allochtonous (Ordovician and locally Lower Silurian age)

- 51 — Limestone
- 52 / 53 — Phyllite, mica schist / Shale, marl and lomestone

Metamorphosed sedimentary rocks, autochtonous and allochtonous (Cambrian to Lower Ordovician age; in places uncertain)

- 63 — Phyllite, partly graphitic, partly with sandy and silty layers
- 64 — Shale, alum shale, siltstone, sandstone and conglomerate

Metamorphosed sedimentary rocks, in places igneous rocks (Late Precambrian age)

- 100 — Quartzite and metasandstoen, locally tillite
- 101 — Sandstone, quartzite, shale and dolomite
- 102 / 103 — Tillite / Sandstone, quartzite with conglomerate, locally tillite
- 104 / 105 / 106 — Quartzite / Sandstone, in places conglomerate / Polymict conglomerate
- 107 / 108 — Dark sandstone, in places conglomeratic / Alternating sandstone and shale
- 109 / 110 / 111 — Limestone and shale / Dolomite / Calcareous sandstone, dolomite, phyllite

Higher legend numbers indicate rocks within higher thrust sheets (114-134) or Precambrian basement (187-267).

Geological boundaries and structural symbols

- Lithological boudary
- Fault
- Thrust boundary. (Only the major thrusts are shown. The ticks point towards the tectonostrati-graphically overlying nappe unit, irrespective of the present direction of dip of the thrust surface).
- Strike and dip of bedding or foliation
- Inverted stratigraphic sequence

Fig. 1 B Geological map of the Oslo Graben and surroundings. Extract from Sigmond et al. (1984).

Fig. 2. Thrusting of the Vollen Formation along the Bø thrust, in the southern Slemmestad area. The location is framed in Fig. 6.

The Slemmestad area illustrates thrust faults and associated folds in an orogenic, non- metamorphic decollement foreland setting (Fig. 2). The stratigraphy of the sedimentary succession covers the Upper Cambrian through to the Middle Ordovician interval (Fig. 3) (Owen et al. 1990; Bruton et al. 2010). A field description of the sediments and fossil successions is recently published in Nakrem & Rasmussen (2013). The sequence is c. 230 metres thick and is dominated by marine black and grey shales with subordinate, bedded, lenticular and nodular limestone intervals ranging from metre to centimetre scale. A short description of the mapped units is included in Fig. 3. From a structural point of view, the carbonate-dominated Huk and Vollen formations stand out as competent levels within the otherwise shale-dominated Cambro-Ordovician interval. The contrasting lithologies resulted in a competence contrast that is outlined by the changing structural styles exerted by the different lithologies during the deformation. Hangingwall-footwall deformation and fault-fold interrelationship at different structural levels will be examined on well-exposed coastal sections and inland road cuts.

The structure of the Caledonian foreland deformation above the décollement is characterised by NE-SW to ENE-WSW-trending thrusts and folds (Figs 1 & 4). The bathymetric map of the inner Oslofjord illustrates that the foreland succession continues into the submerged, down-faulted, hangingwall blocks of the fjord area (Fig. 5). In the Oslo-Asker area to the north and west of the inner Oslofjord, the deepest section is encountered in the Slemmestad area situated to the south (Fig. 4). In that area, there is an overall younging of the succession towards the north (Fig. 4), suggesting that the general dip of the basement and the décollement surface must be in the same direction. The dominant fold vergence is towards the south associated with a predominantly northerly dip of the sedimentary rocks and the thrusts (Fig. 6); this is in accordance with a transport direction towards the orogenic front to the south. Along the analysed foreland segment of the Slemmestad area (Fig. 7) there is an overall decrease in the stratal dip, declining from 60-70° in the north down to 15-20° in the south towards the orogenic front (Fig. 8). In the central part of the segment, the Almedalen- Bjørkåsholmen duplex occurs between the Almedalen and the Djuptrekkodden thrusts.

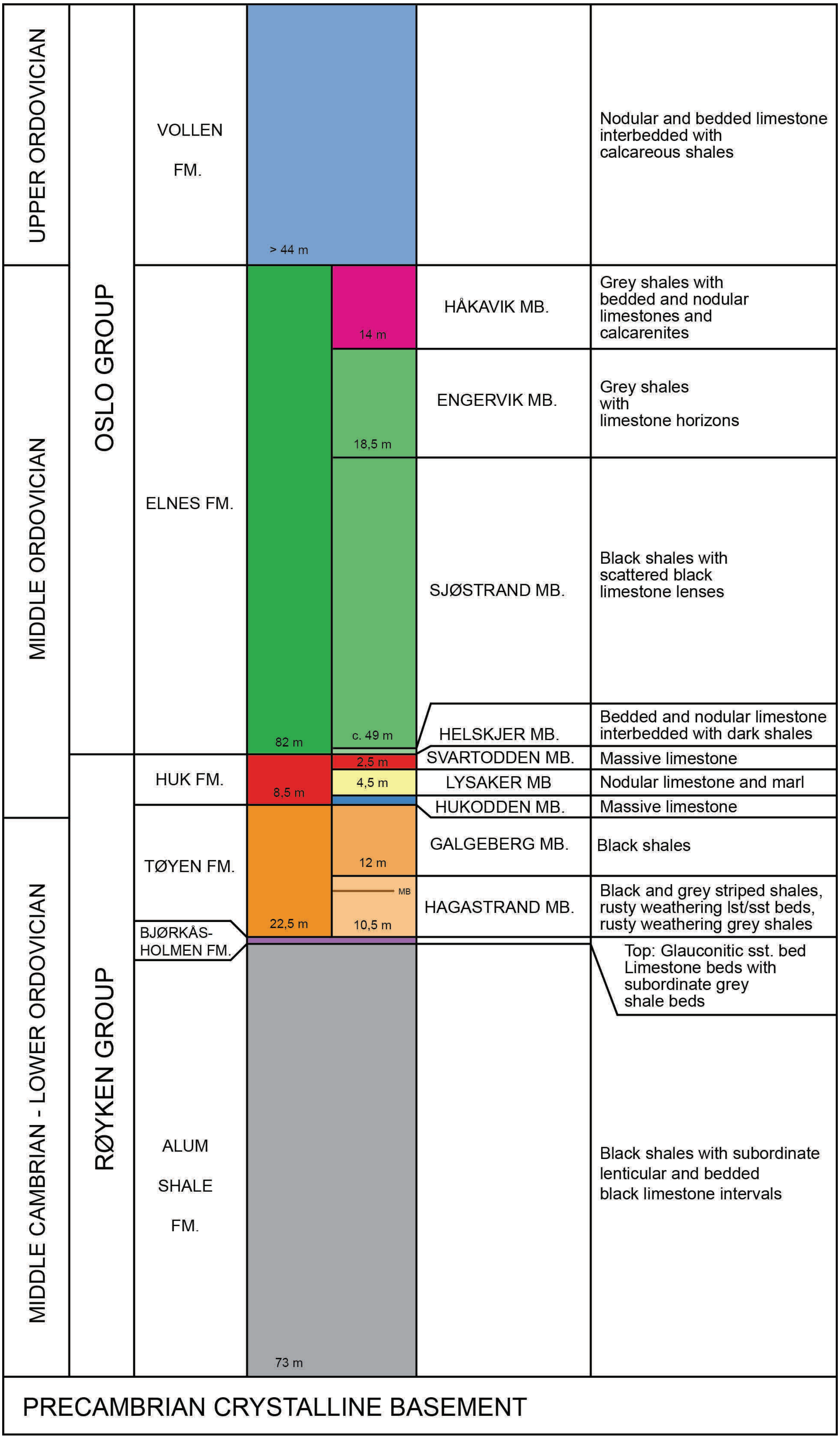


Fig. 3. Stratigraphy of the Slemmestad-Elnestangen area. Detailed descriptions may be found in Owen et al. (1990). Ages are revised according to Bruton et al. 2010.

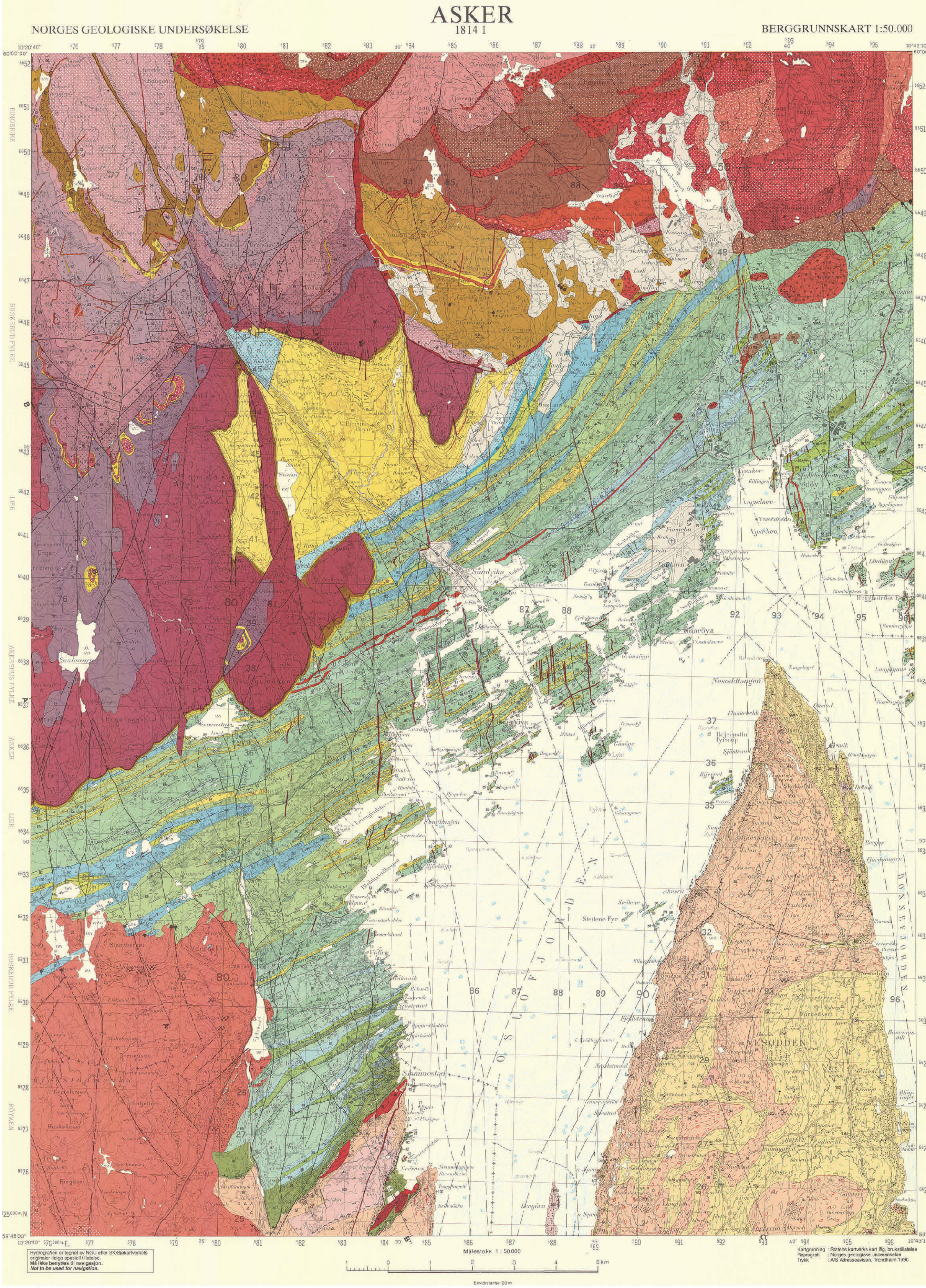


Fig. 4A. Geological map Asker. Map position indicated in Fig. 1. Reduced from Naterstad et al. (1990).

Fig. 4B. Geological map Asker: Extract of legend regarding Slemmestad and surroundings (Naterstad et al. 1990).

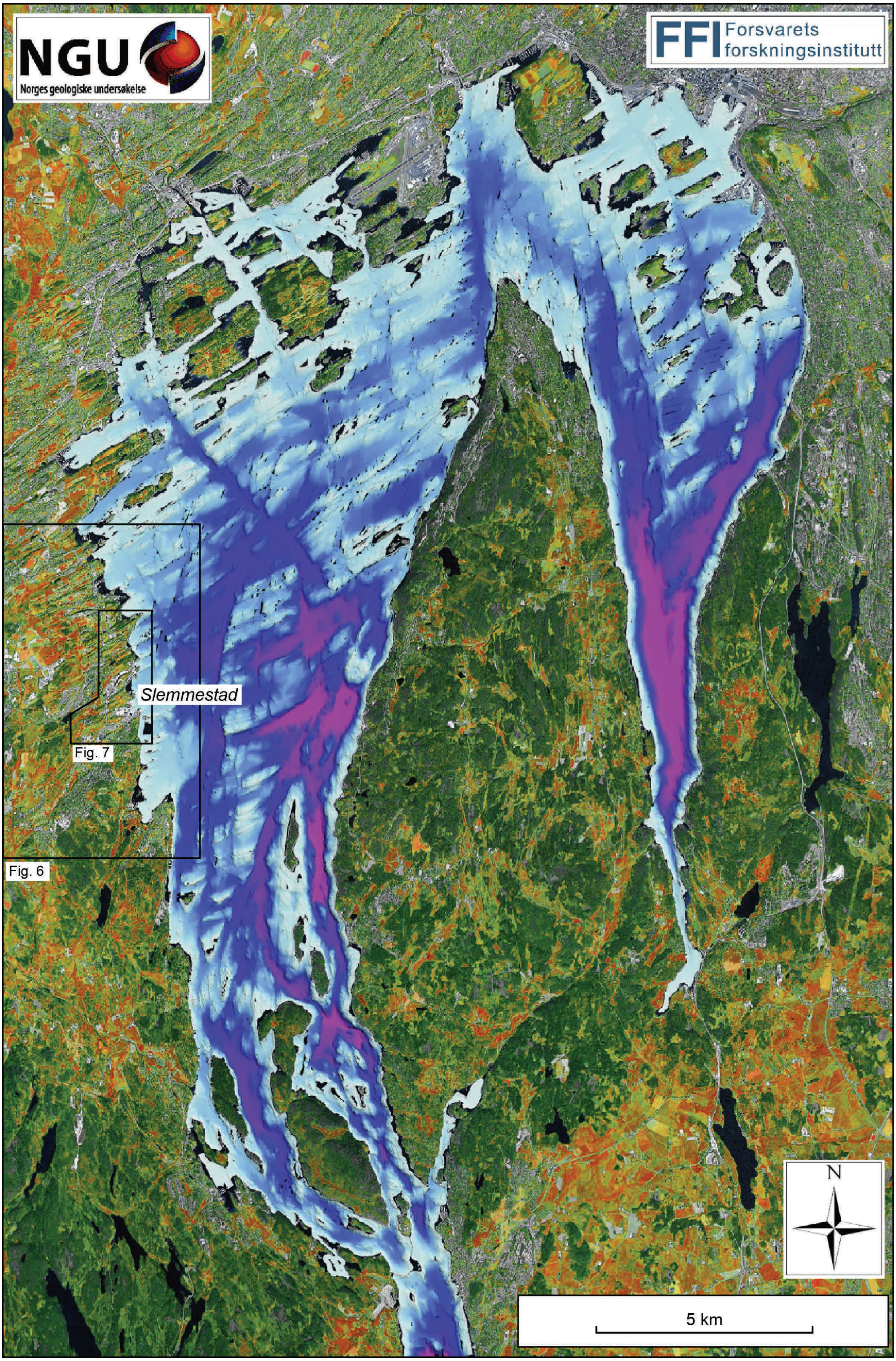


Fig. 5. Bathymetry of the inner Oslo Fjord. Courtesey Norges geologiske undersøkelse and Forsvarets forskningsinstitutt (www.ngu.no_2007).

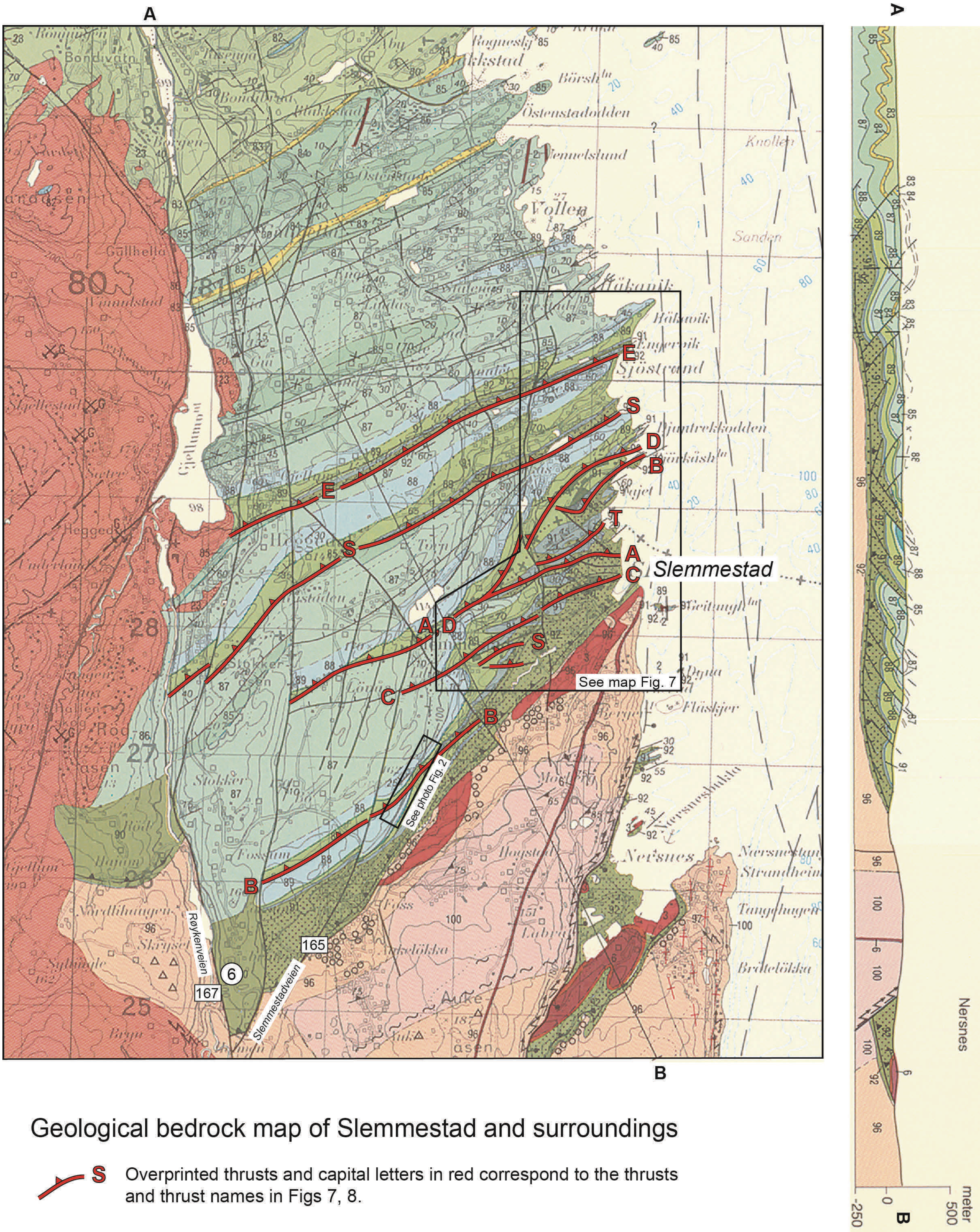


Fig. 6. Geological bedrock map of the Slemmestad area and its surroundings. Extract from Naterstad et al. (1990). The sides of the square grid are 1 km.

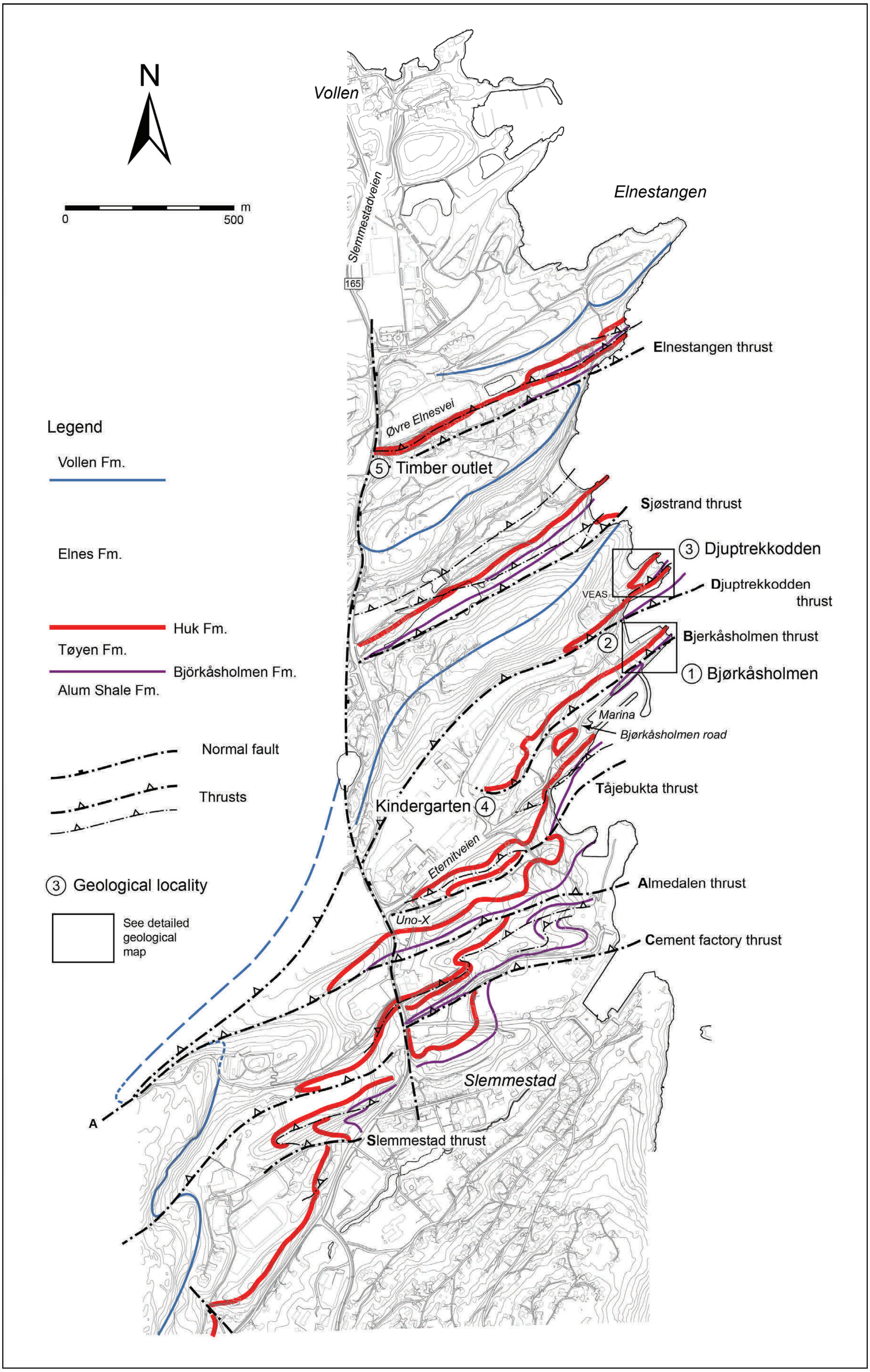


Fig. 7. Geological map of the Slemmestad-Elnestangen area. The circled numbers correspond to the stops described in the text.

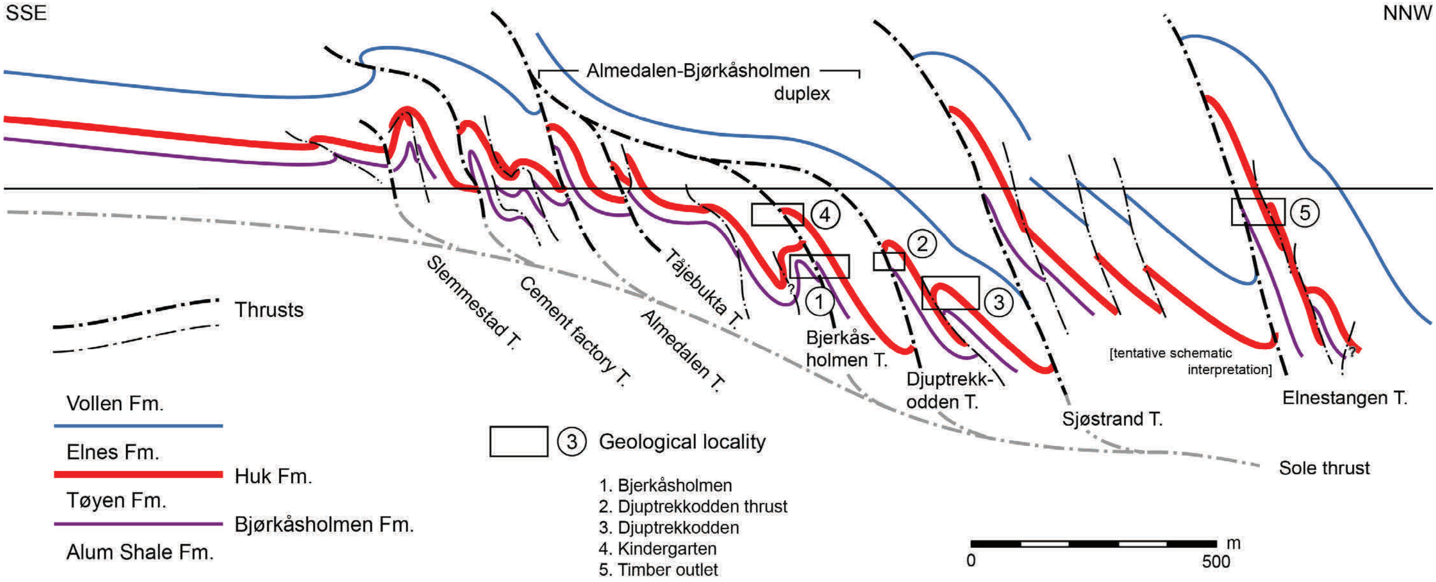


Fig. 8. Geological cross section of the Slemmestad-Elnestangen area. The circled numbers correspond to the stops described in the text; the frames correspond to the sections covered at each stop.

The excursion route

The first five stops are shown in Fig. 7 and the last stop in Fig. 6.

Stop no. 1: Bjørkåsholmen

Location

Bjørkåsholmen is a small peninsula trending NE-SW into the Oslofjord (Fig. 7). Turn northeast from Slemmestad-veien [165] and follow Eternitveien just north of the Uno-X petrol station. Continue to the northeast along the road, and you will find Bjørkåsholmen to the northeast of the marina. See map, Fig. 7. There are good parking possibilities here.

Introduction

Bjørkåsholmen is composed of a simple hangingwall block to the northwest thrusted above a complex footwall block outcropping to the southeast. The main structure of the footwall block is depicted by an anticline that includes a folded thrust indicative of a fault-fold succession. The structural position of the Bjørkåsholmen area is illustrated in Fig. 16.

Please note that the locality is protected – no hammering, no sampling!

Description

The basic stratigraphy and structure of the stops 1-5 can be introduced at the northeastern coastal section of the Bjørkåsholmen peninsula (Figs. 9 & 10). The stratigraphic section covers the Lower Ordovician through to the Middle Ordivician (Fig. 3) and ranges from the uppermost Alum Shale Formation to the Bjørkåsholmen Formation (Fig. 9D), the Hagastrand and Galgeberg members of the Tøyen Formation (Figs. 9B, C & 10), and concludes with the Hukodden, Lysaker and Svartodden members of the Huk Formation (Figs. 9A & 10). The strata dip towards the northwest, and the dip angle changes from c. 70° to the southeast to around 50° to the northwest. The lithologies show different topographical expressions of their resistance to weathering and erosion, the dark grey and black shales of the alum shale, the Galgeberg shale, and the upper Hagastrand Member forming the low areas, whereas the carbonate-impregnated Hagastrand shales and the limestone-dominated Bjørkåsholmen and Huk formations form ridges that protrude into the sea (Figs. 9 & 10). The varying limestone/shale ratio of the Lysaker Member provides a tripartite erosional profile, where a high carbonate content corresponds to the topographic highs (Fig. 9A, E).

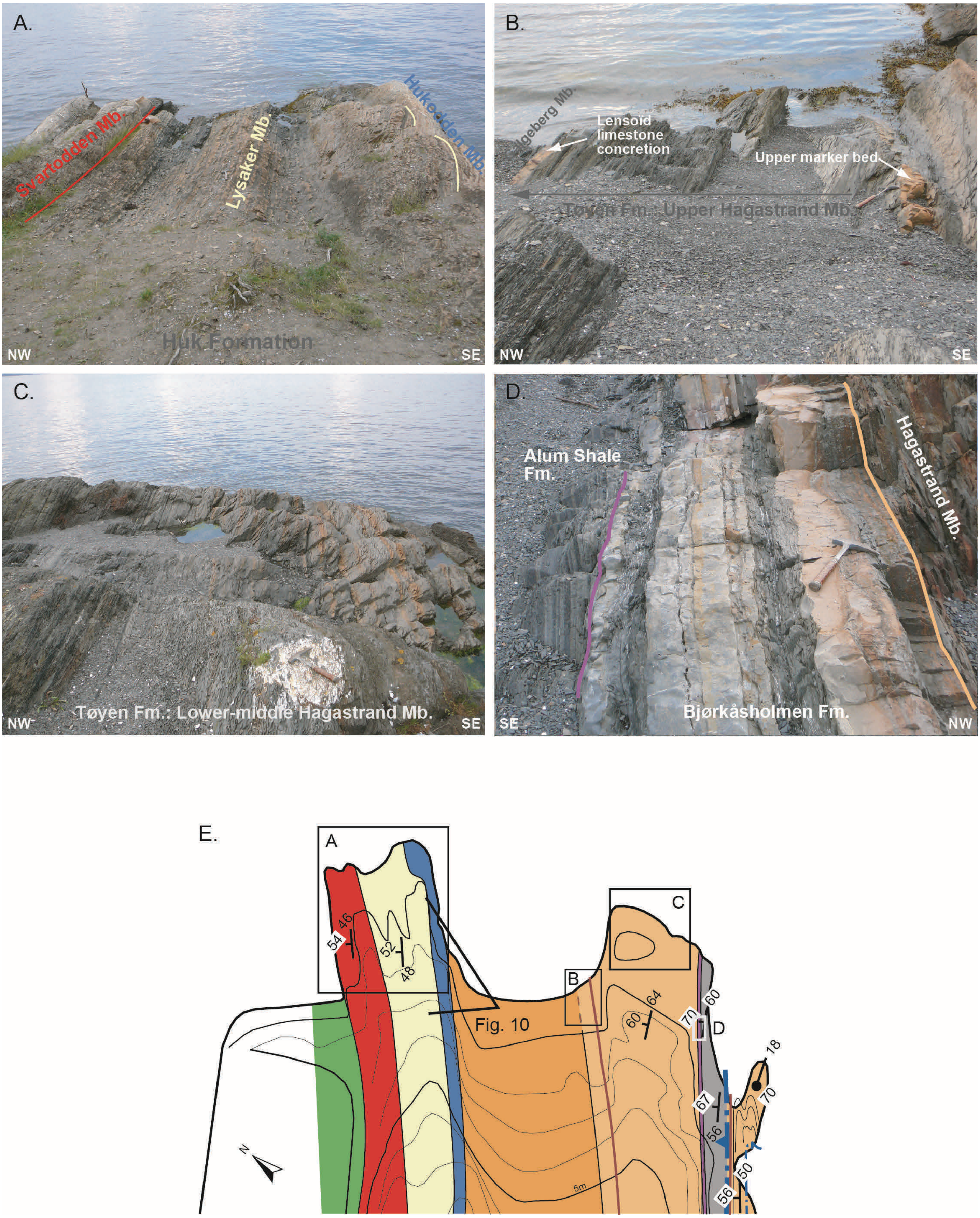

A.
Svartodden Mb.
Lysaker Mb.
Hukodden Mb.
Huk Formation
NW
SE
B.
Lensoid limestone concretion
Upper marker bed
Tøyen Fm.: Upper Hagastrand Mb.
NW
SE
C.
Tøyen Fm.: Lower-middle Hagastrand Mb.
NW
SE
D.
Alum Shale Fm.
Hagastrand Mb.
Bjørkåsholmen Fm.
SE
NW
E.
A
B
C
D
Fig. 10
54
46
52
48
64
60
60
70
67
56
18
70
50
56
5m
N

Fig. 9. Lower Ordovician lithologies in the Bjørkåsholmen section. (A) The Huk Formation with the Hukodden, Lysaker and Svartodden Members. The Hukodden and Svartodden limestones are more resistant to weathering and thus rise above the surrounding members. Two furrows are eroded down into the Lysaker Member where the limestone/shale ratio is relatively low. Note that the furrows can be identified on the 1 metre contour on the geological map in (E). (B) The upper Hagastrand Member of the Tøyen Formation is characterized by layered black and grey shales. The dark shales are sitting above the marker beds of the middle Hagastrand Member cropping out to the right. The boundary to the overlying Galgeberg Member is at the lensoïd limestone level to the left. (C) Dark layered shales of the middle Hagastrand Member with reddish weathering layers in the lower part to the right. The lower part of the Hagastrand Member is characterised by numerous pseudomorphs of calcite after (?)baryte. (D) The Bjørkåsholmen Formation between the Alum Shale Formation and the Hagastrand Member of the Tøyen Formation. The upper alum shale weathering is characterised by alternating dark and light grey shales. The lower boundary of the Bjørkåsholmen Formation is at the base of the thin nodular limestone to the left. The limestone beds of the Bjørkåsholmen Formation may be planar or exhibit an irregular thinning and thickening due to irregular concretionary growth. The upper bed of the Bjørkåsholmen Formation is a 10-15 cm-thick 'glauconitic sandstone'. (E) Geological map of the northeastern part of Bjørkåsholmen. For legend, see Fig. 11. The frames indicate the areas covered by the photos above.

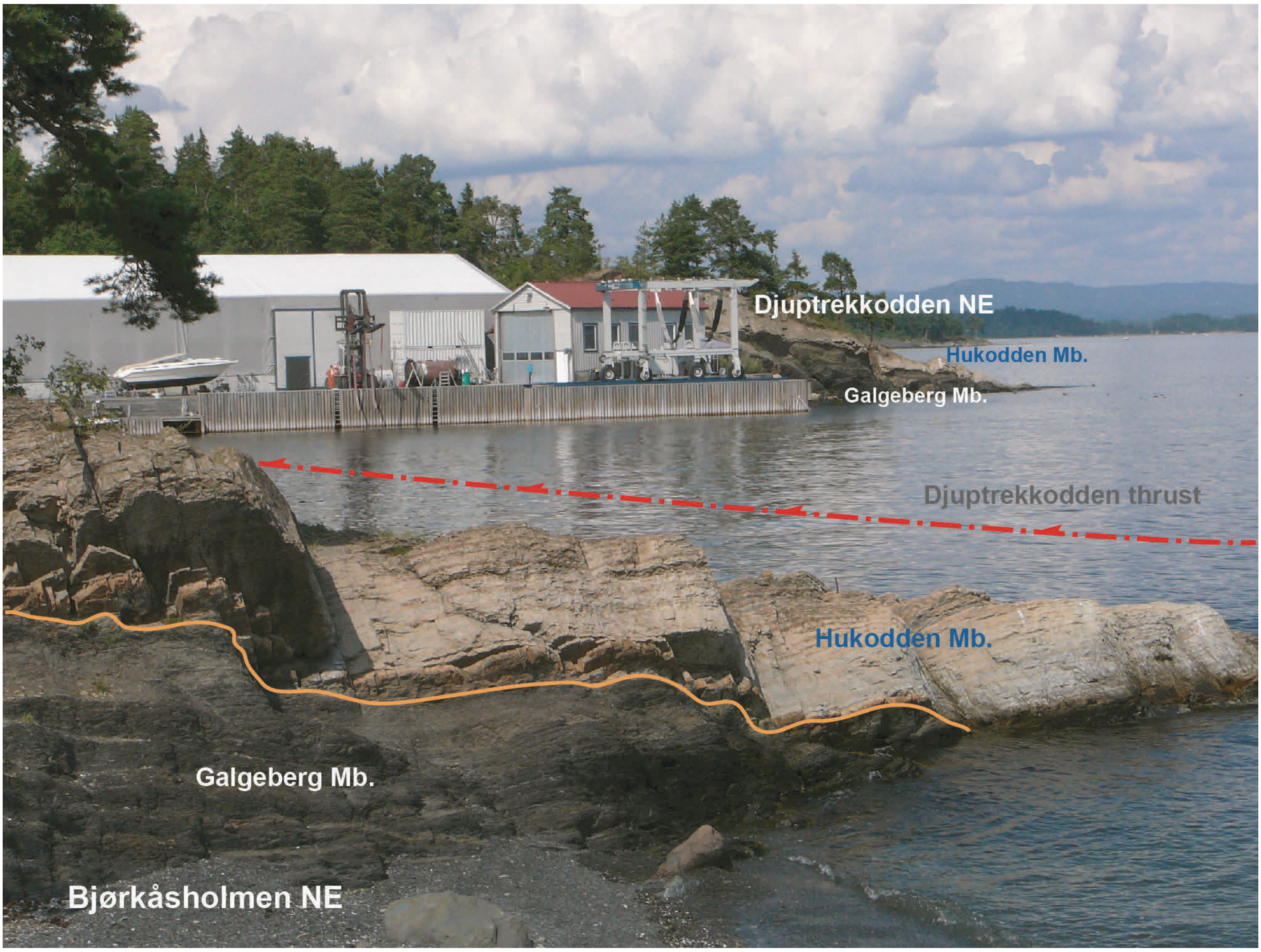


Fig. 10. The repeated lithology and orientation of the Galgeberg/Hukodden Members on Bjørkåsholmen and Djuptrekkodden illustrate the repetition due to thrusting established from the mapping.

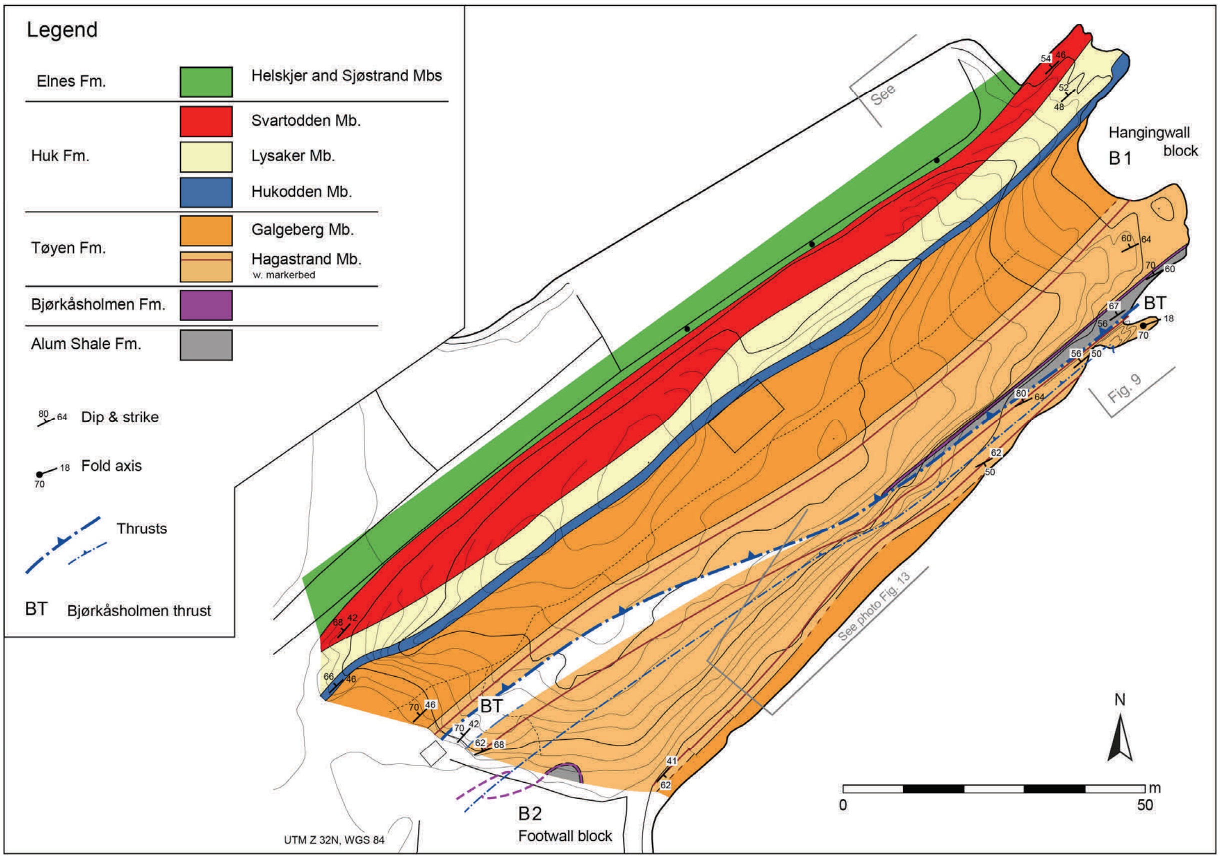


Fig. 11. Geological map of Bjørkåsholmen. The contours are drawn at 1 m intervals.

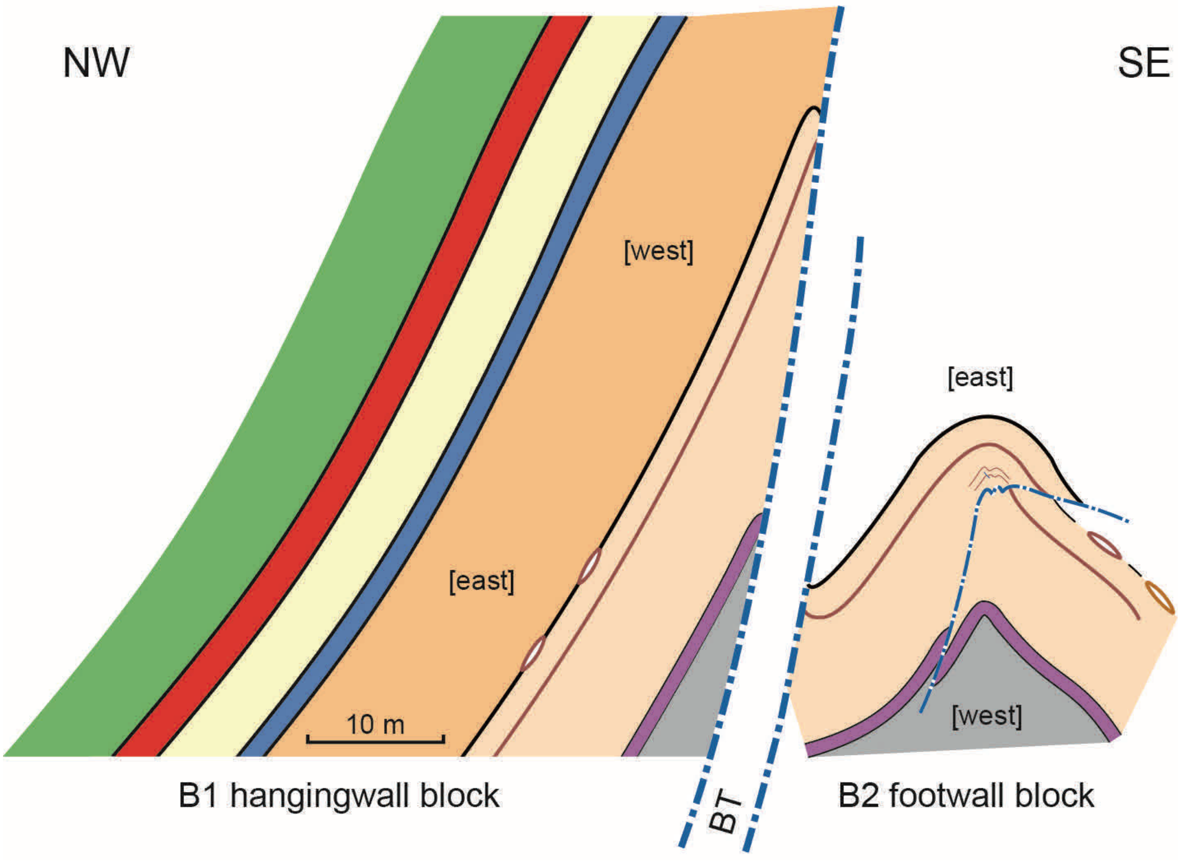


Fig. 12. Geological cross section of Bjørkåsholmen. BT: Bjørkåsholmen thrust.

Fig. 13. Structure and stratigraphy of the anticline on the southeast coast of Bjørkåsholmen. The southeastern limb is dipping towards the southeast, whereas the northwestern limb to the north of the folded thrust is dipping steeply to the northwest. BT: Bjørkåsholmen thrust.

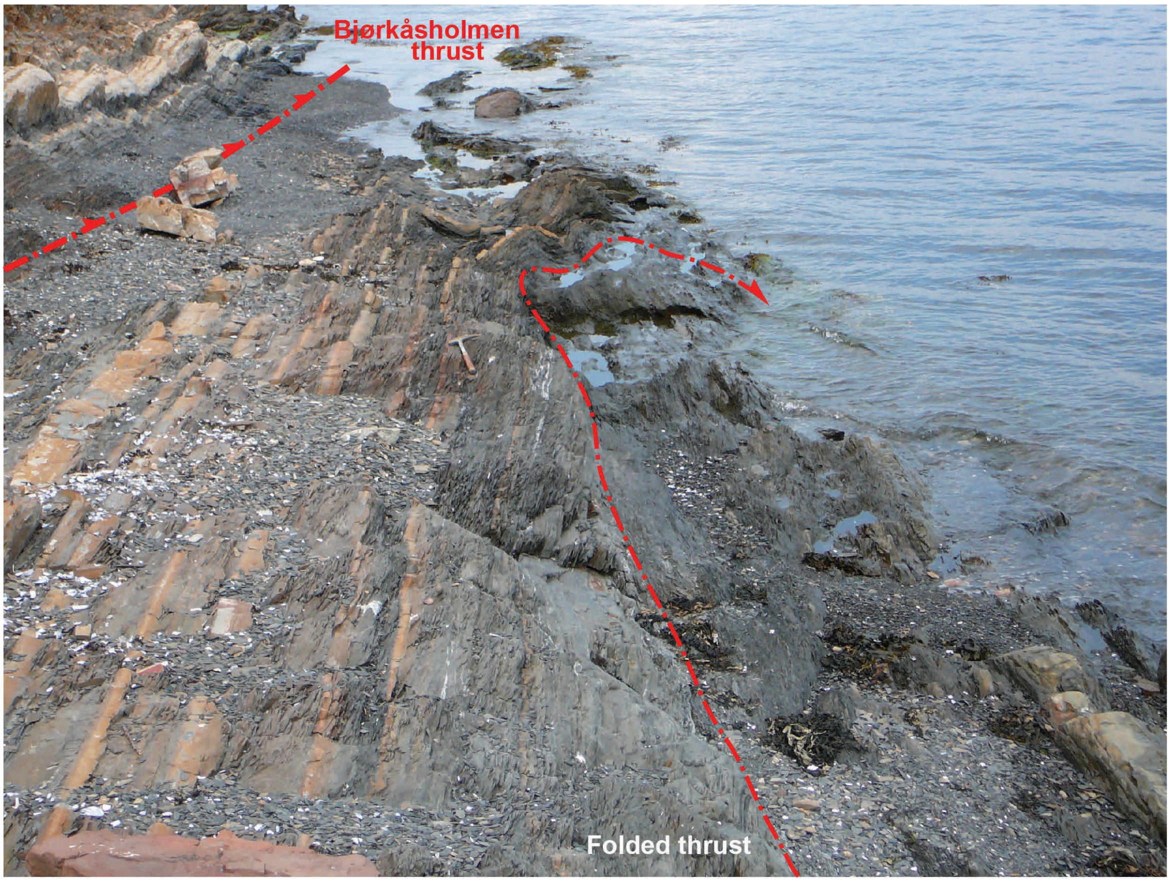
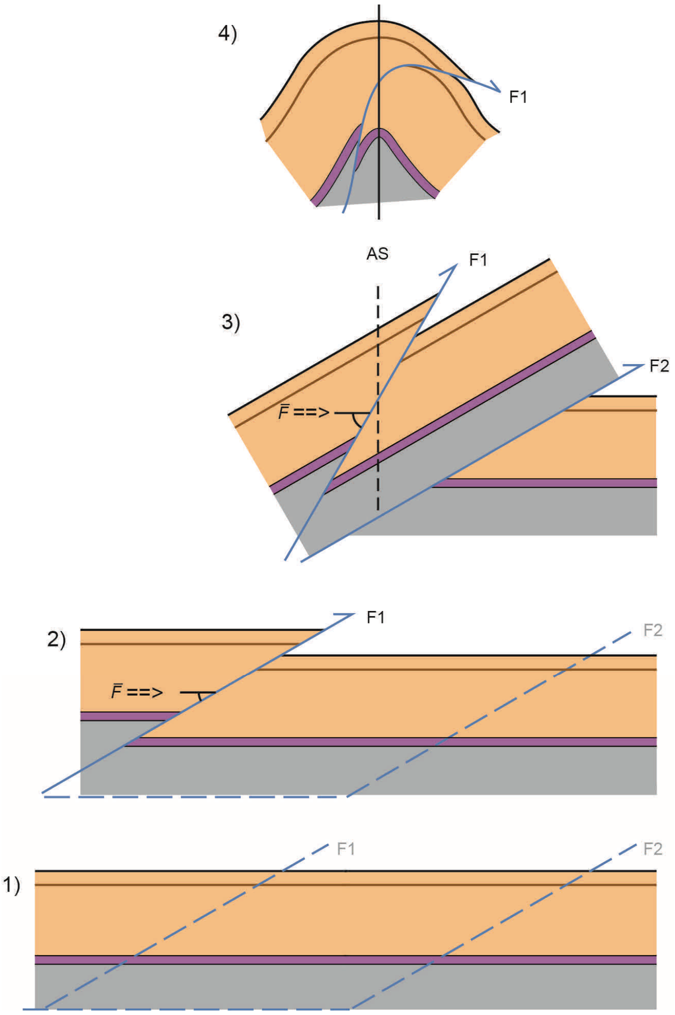


Fig. 14. Hinge zone of the Bjørkåsholmen anticline with the interpretation of the folded thrust that separates the fold limbs. The northwestern limb is dominated by the marker beds of the middle Hagastrand Member. The fold is plunging gently towards the northeast. The position of the photo is framed in Fig. 13.

The basic structure of the thrusted foreland complex can be established at the northeastern tip of Bjørkåsholmen looking north towards Djuptrekkodden (Fig. 10). The characteristic erosional profile of the northwest-dipping and easily eroded Galgeberg shale and the overlying, more resistent and overhanging Hukodden limestone on Bjørkåsholmen is repeated on Djuptrekkodden with a similar stratal dip and stratigraphic relationship. The repetition illustrates the picture established from the mapping, i.e., that the Bjørkåsholmen and Djuptrekkodden areas belong to individual tectonic segments separated by a north- dipping thrust (fig. 7).

The structure of Bjørkåsholmen is divided by a steep northwest-dipping thrust, the Bjørkåsholmen thrust, into a hangingwall block to the northwest (B1) and a footwall block to the southeast (B2) (Figs. 11 & 12). The thrust cuts up through the stratigraphic section of the hangingwall block from northeast to southwest. The B1 hangingwall block displays a simple, steeply NW-dipping segment of the stratigraphic column. By contrast, the B2 footwall block exposes an anticlinal fold and an associated folded fault; and the fold plunges gently towards the eastnortheast (Figs. 11 & 12).
The anticline of the Bjørkåsholmen footwall block is exposed at the stratigraphic level of the Tøyen Formation.



The southeastern, SE-dipping fold limb can be seen along the southeast beach of Bjørkåsholmen, where the fold structure is outlined by the upper Hagastrand and lower Galgeberg Members (Figs. 11 & 13). The fold hinge and the northwestern limb crop out along the beach to the northeast (Figs. 11 & 13-15). The detailed structure of the fold is outlined by the reddish-weathering, sandstone marker horizons of the upper Hagastrand unit. The upper (and thickest) marker bed is indicated on the geological map (Fig. 11). About midway along the southeast beach, a narrow fault zone (to the south of the Bjørkåsholmen thrust) cuts down to beach level from the higher cliffs. The fault can be traced into the hinge zone where it is folded together with the lower marker horizons (Figs. 11-14).
The occurrence of a folded thrust is interpreted to indicate that the initial faulting was superseded by folding during the structural deformation of the footwall block. A schematic dynamic model of the thrust-fold relationship is illustrated in Fig. 15. In the incipient stage of the deformation, the horizontal stratigraphic succession was cut by a low-angle thrust, F1 (Fig. 15: stage 2). As the faulted sequence moved up along a second thrust ramp (F2) in the transport direction, the rotation of the faulted sequence caused a rotation and steepening of the F1 thrust (Fig. 15: stage 3). During the rotation, the acute angle between the horizontal force F and the early thrust increased; this resulted in the growth of the normal stress vector at the expense of the shear stress along the early thrust surface (F1). Eventually, the shear movement stopped, and the faulted succession was folded during its continued forward movement (Fig. 15: stage 4). Folding of early faults has also been mapped on large-scale structures in the fault blocks above the Slemmestad and Cement factory faults (Figs. 7 & 8).

Fig. 15. Schematic model showing the inferred evolution of the folded thrust. See text for further

Stop no 2: Djuptrekkodden thrust

Location

From Bjørkåsholmen walk northwest to the Bjørkåsholmen road leading up to the VEAS administration building. The geological locality for Stop 2 is the NE-SW-oriented section to the northwest of the road. See map, Fig. 7.

Introduction

The locality exposes a first-order thrust fault between the Bjørkåsholmen and Djuptrekkodden thrust blocks.

This is a protected locality – no hammering, no sampling!

Description

The Helskjer and lower Sjøstrand Members of the Elnes Formation that were deposited above the Huk Formation are not exposed in this part of the section. The miss ing strata at this stratigraphic level is a common feature throughout the Slemmestad-Elnestangen area due to erosion below the present bedrock outcrop level. The stratigraphic column is re-entered in the upper Sjøstrand shales to the northwest of and along the lower part of the access road to the VEAS administration building. The Sjøstrand member is a black shale characterised by the presence of lens-shaped, dark, septarian limestone concretions c. 25-40 cm in length. The emergence of the Djuptrekkodden thrust block is recognised by the overlying, but older Tøyen Formation in thrust contact with the Sjøstrand shale of the Elnes Formation (Fig. 16). The thrust level can be identified at the base of the folded and overturned shales of the Hagastrand Member of the lower Tøyen Formation. The stratigraphic offset along the thrust is in the order of 50-100 m. Continuing up the road, the stratigraphic section encountered at Bjørkåsholmen is repeated as one crosses the black shales of the Galgeberg Member of the upper Tøyen Formation and passes into the more resistent Huk Formation at the top of the section.

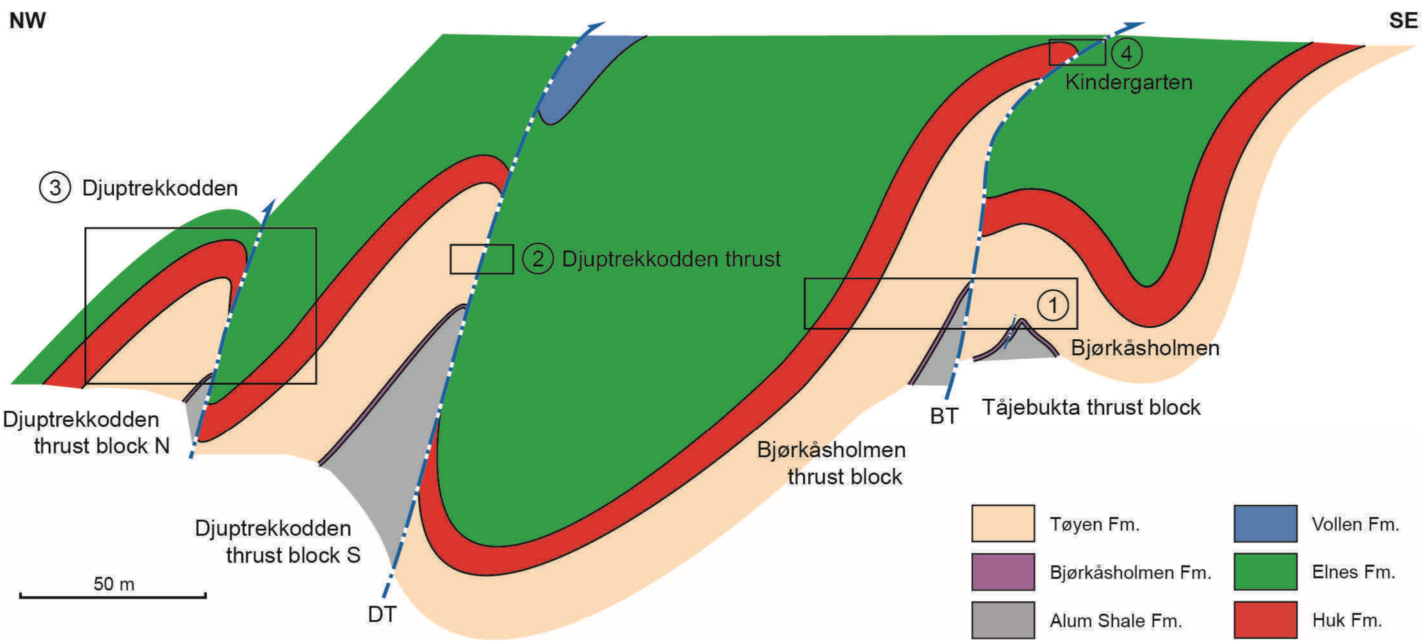


Fig. 16. Interpreted cross section of the Bjørkåsholmen thrust block and adjoining parts of the Djuptrekkodden and Tåjebukta thrust blocks to the north and south. The frames and numbers indicate the areas and the interrelationship covered by stops 1-4.

Stop no. 3: Djuptrekkodden

Location

Access to Djuptrekkodden is from 'Kyststien' (a path established along the coast starting at the SE corner of the VEAS parking area). Walk uphill to the northeast into the wood (not downhill towards the grassy field and the waterfront) and continue across the Djuptrekkodden peninsula to the northeast coast. See map, Fig. 7.

Introduction

Djuptrekkodden is underlain by a major, SE-vergent, hangingwall anticline (Figs. 17 & 18). A corresponding footwall syncline was developed in a folded thrust slab below the main thrust surface in a transgressive ramp/flat thrust system. The structural position of the Djuptrekkodden area is indicated in Fig. 16.

Once again this is a protected locality – no hammering, no sampling!

Description

The outcrops on Djuptrekkodden peninsula illustrate the deformation of the competent Huk Formation caused by thrusting and associated folding. The Huk Formation and the shale units above and below are separated by a compound thrust zone. Both the hangingwall block (D1) and the footwall block (D3) are cut out along a second order thrust which illustrates a ramp/ramp relationship (Figs 6.3.1, 6.3.2). A lower-order, lens-shaped, fault block, D2, is incorporated in the footwall of the fault zone. The termination of the footwall block (D3) along the fault zone is not exposed, and the structure of the footwall block is not discussed further here.

A west-plunging anticline is situated above the thrust zone in the D1 hangingwall block to the northwest (Figs. 17 & 18); the anticline is interpreted as a drag fold associated with the deformation at the base of the hangingwall block. The lower-order, lens-shaped, D2 thrust block is up to 10 m wide and c. 100 m long in map view. The thrust block is a slice of the Huk Formation, and the rocks are folded in a west-plunging syncline (Figs. 17-19). The lower boundary is defined by a composite, transgressive, fault zone composed of a ramp/flat system that cut up through the the Lysaker and Svartodden members of the Huk Formation (Fig. 19); the northwestern limb of the syncline is cut out by the overlying thrust. The D2 syncline is interpreted as a footwall syncline where the northwestern limb was overturned during the movement at the base of the main thrust zone below the D1 hangingwall block.

A reconstruction of the inferred positions of the D1-D3 fault blocks in the stratigraphic column prior to the deformation is illustrated in Fig. 20. The original positions of the fault blocks in the reconstruction imply that the D2 fault block is interpreted as a thrust slice detached from the Huk Formation and carried up along the ramp at the base of the thrust zone below the D1 hangingwall block. During the thrusting, the upper Alum Shale was carried up onto the lower Sjøstrand Member of the Elnes Formation. The stratigraphic offset is in the order of 50 metres (Figs. 16 & 20), whilst the minimum transport along the thrust zone was about 100 metres. The amount of horizontal shortening at the Huk Formation level on the Djuptrekkodden peninsula is estimated to around 50%.

Fig. 17. Geological map of Djuptrekkodden. The contours are drawn at 1 m intervals.

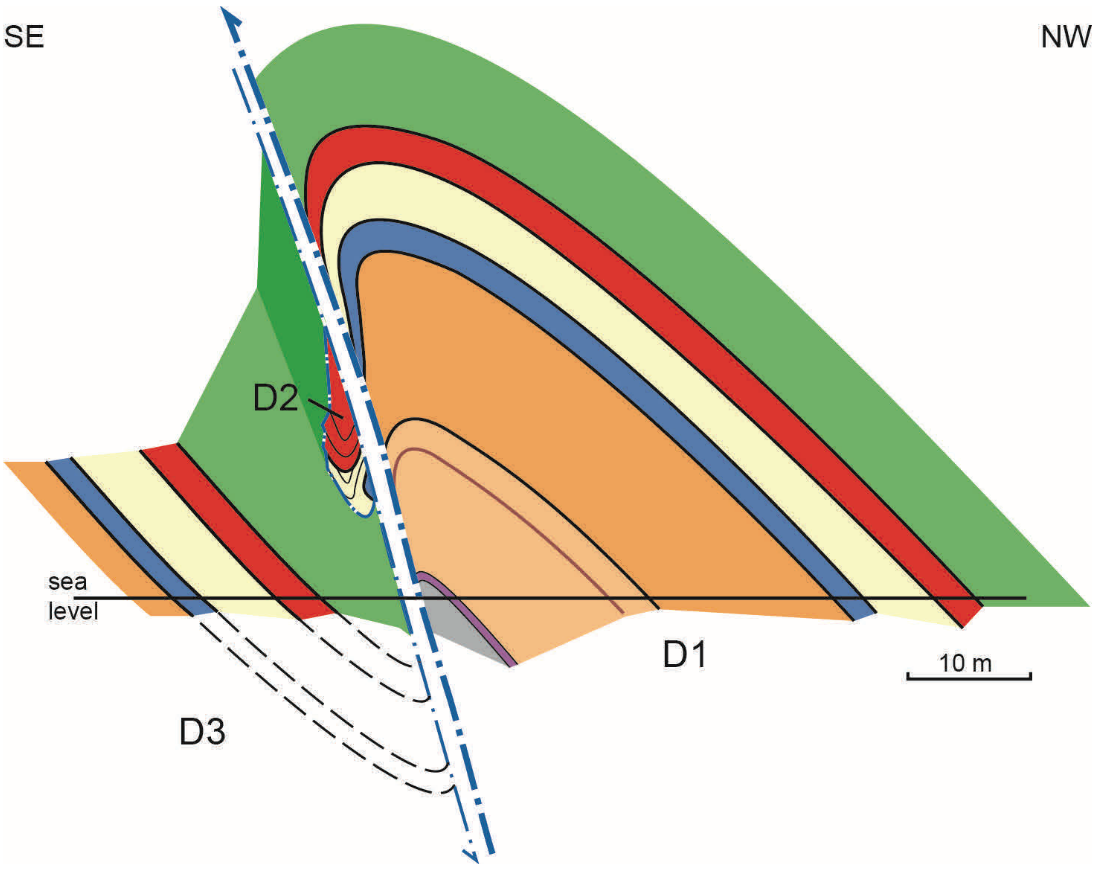


Fig. 18. Geological cross section across Djuptrekkodden. The section line is indicated in Fig. 17.

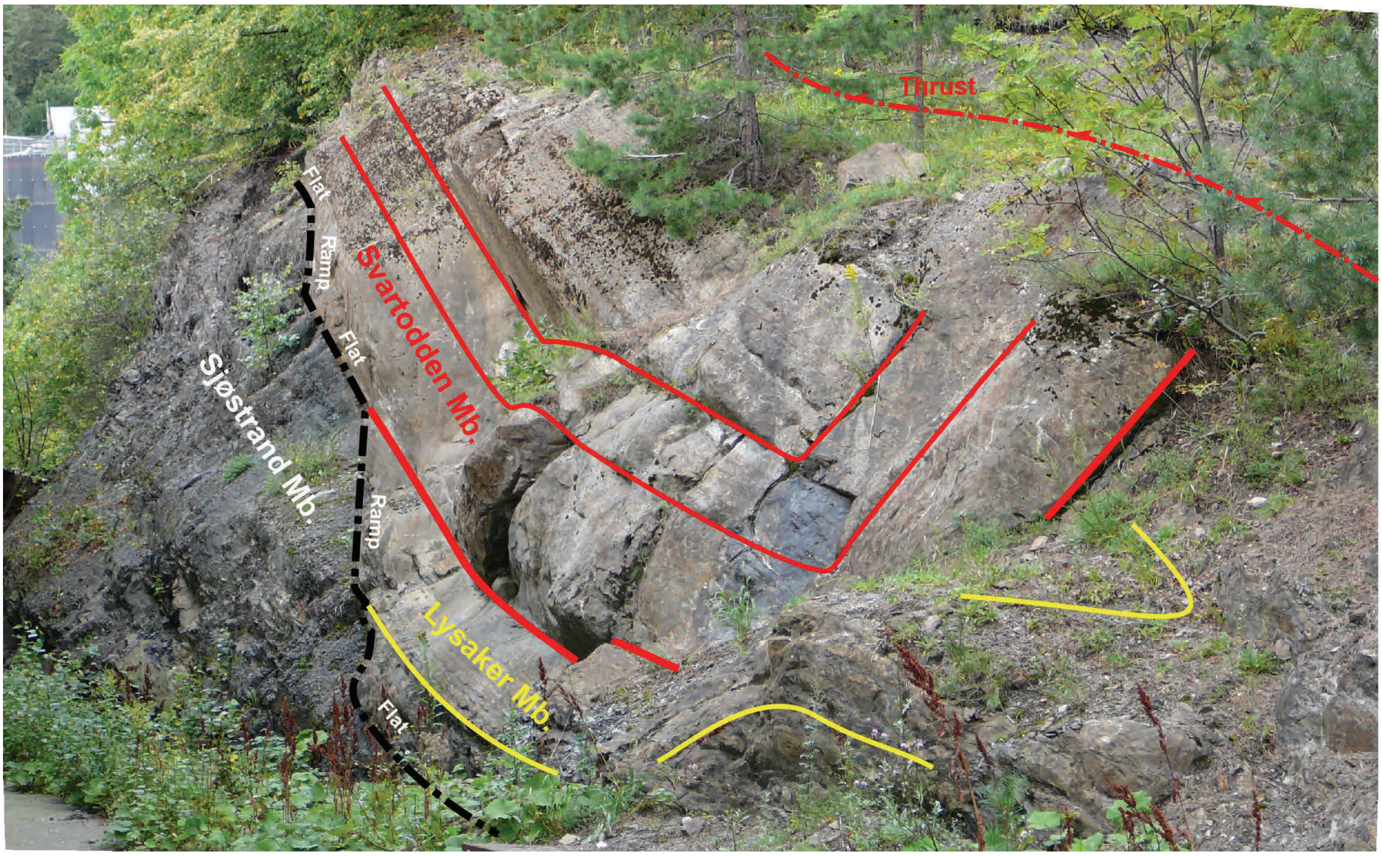


Fig. 19. Photo of the folded thrust-slab with geological interpretation.

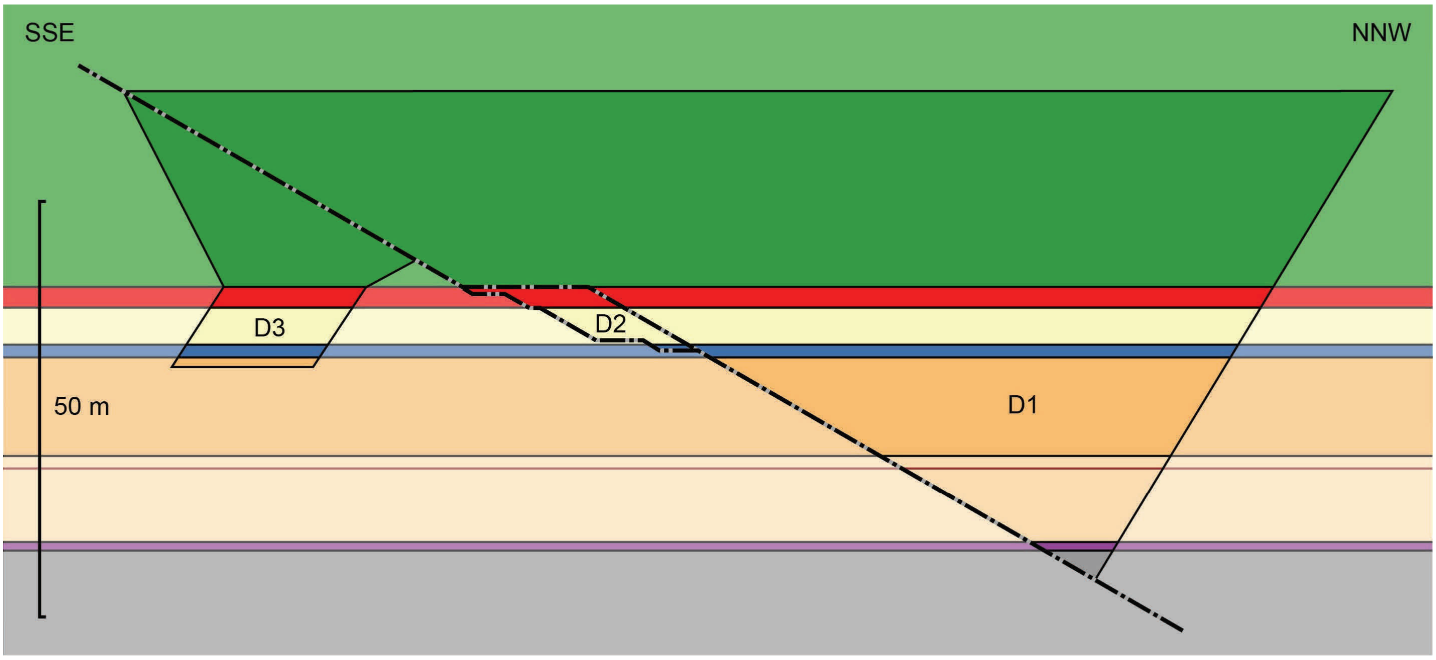


Fig. 20. Restored section of the Djuptrekkodden thrust-blocks. Legend: See Fig. 17.

Stop no. 4: The Kindergarten section, Eternitveien

Location

Drive back from Djuptrekkodden on the Bjørkåsholmen road; turn right on entering Eternitveien, and for the Kindergarten turn to your right. The geological locality is the NW- SE-oriented section northeast of the Kindergarten. See Fig. 7. There are good possibilities for parking here.

Introduction

The Kindergarten section displays a hangingwall anticline in the competent Huk Formation to the northwest (Fig. 21). Below a complex thrust zone, deformation of the incompetent Sjøstrand shales (Sjøstrand Member, Elnes Formation) is displayed in the footwall section to the southeast. The structural position of the Kindergarten section is indicated in Fig. 16 and shown in a little more detail in fig. 22.

This is also a protected locality – no hammering, no sampling!

Description

The Kindergarten section exposes the Bjørkåsholmen first-order thrust that separates the Bjørkåsholmen and Tåjebukta thrust blocks (Figs. 6, 7 & 16). At the exposure, the Bjørkåsholmen hangingwall block is represented by a hangingwall anticline deforming the Lysaker and Svartodden Members of the competent Huk Formation (Fig. 21). The Tåjebukta footwall block is here composed of the deformed shales of the upper Sjøstrand Member of the Elnes Formation. The Kindergarten section thus represents a hangingwall/footwall relationship along the Bjørkåsholmen thrust zone at a higher structural and stratigraphic level than the Bjørkåsholmen section examined at Stop 1 (Fig. 22).

At the Kindergarten section, the Bjørkåsholmen thrust exhibits a complex thrust zone with an intermediate thrust block being cut out by the BT1 and BT2 thrusts (Fig. 21); the stratigraphy of the intermediate thrust block has not been established. The BT1 thrust parallels the primary layering of the footwall block, while the layering of the intermediate hangingwall block is cut out against the basal thrust. The structures illustrate a ramp-on-flat geometry along the BT1 thrust. The BT2 thrust at the base of the hangingwall anticline block transects the intermediate thrust block and the BT1 thrust and cuts down into the Elnes Formation. The drag of the hanging wall anticline indicates that the transport direction was towards the south- southeast. The fact that the hangingwall block cuts down section in the transport direction is interpreted to indicate that the Tåjebukta footwall block was already rotated anticlockwise to dip north-northwest when the BT2 thrust cut down into the footwall block.

Below the basal BT1 thrust, the upper 3-4 m of the Sjøstrand shales in the footwall block have been affected by fracture cleavage deformation and small-scale folding.

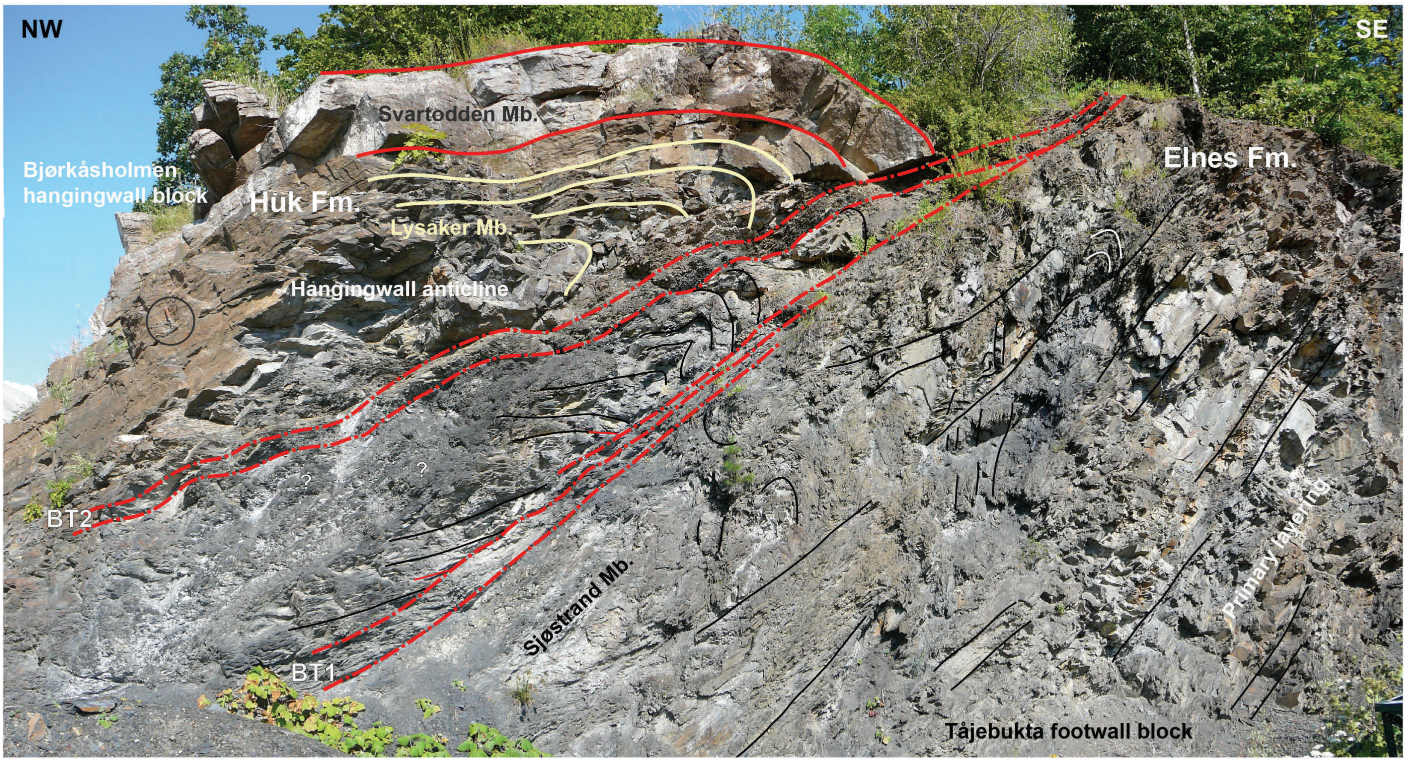


Fig. 21. Photo of the Kindergarten section with the geological interpretation. Note the encircled hammer for scale, to the left. The Bjørkåsholmen Thrust Zone is encountered between the Bjørkåsholmen thrusts, BT1 and BT2.

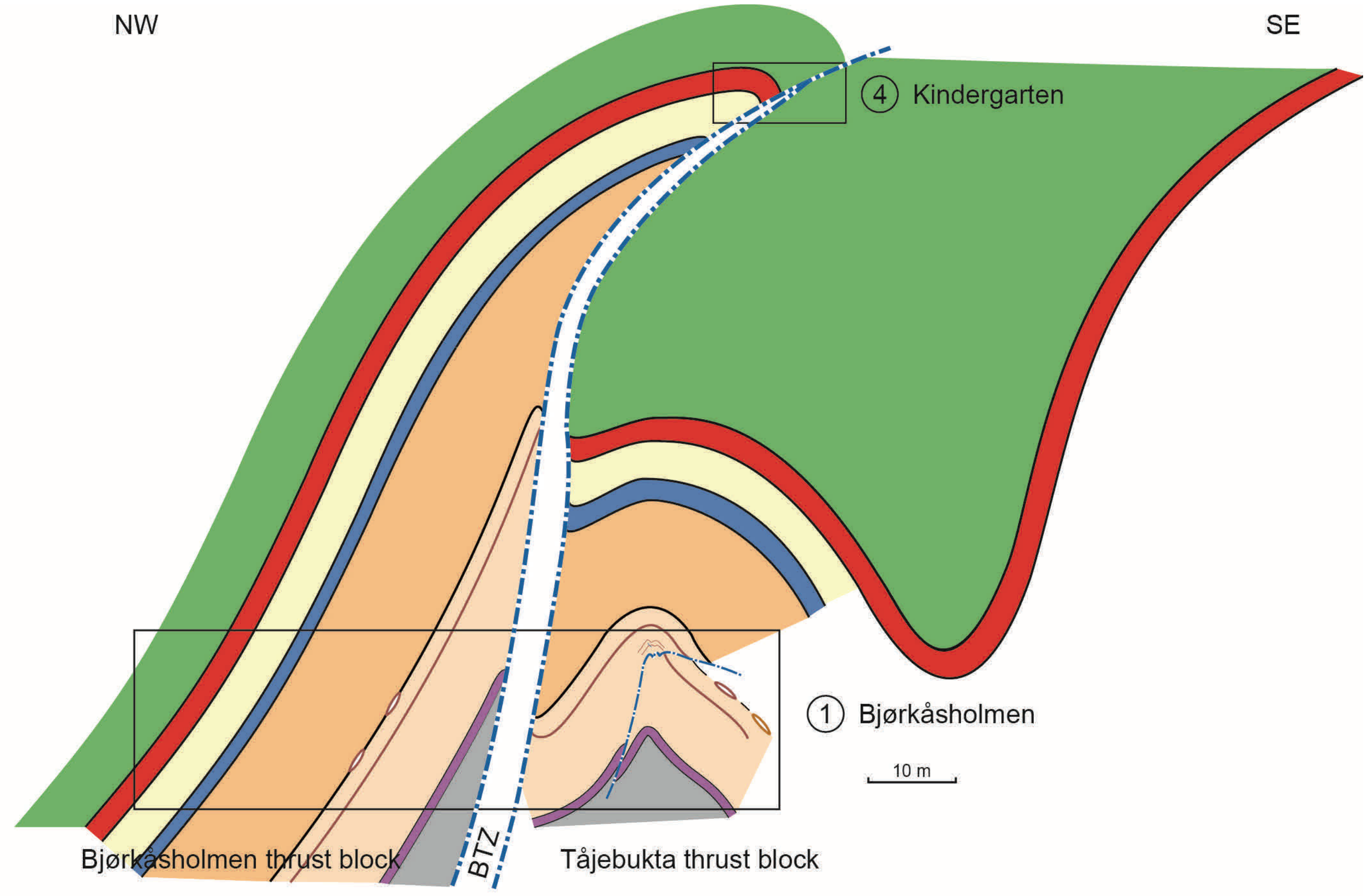


Fig. 22. Geological cross section along the Bjørkåsholmen thrust to illustrate the structural relationship between the Bjørkåsholmen and Kindergarten localities. BTZ: Bjørkåsholmen Thrust Zone.

Stop no. 5: Timber outlet, Øvre Elnesvei - Elnesknausene

Location

Øvre Elnesvei is a side road to the east of Slemmestadveien in the northern part of the Slemmestad-Elnestangen area. The geological locality is a NW-SE-oriented road section running southwards from Øvre Elnesvei close to Slemmestadveien. See Fig. 7. There are good possibilities for parking here.

Introduction

The road section exhibits a folded hangingwall ramp thrust onto a footwall flat. The thrusting is associated with a second-order thrust in the southern part of the Elnestangen first-order thrust block (Fig. 8). An additional locality occurs about 50 metres to the south of the Øvre Elnesvei road section, where 'stacked' thrust surfaces with slickensides illustrate distributed footwall deformation in the northern part of the Sjøstrand thrust block to the south of the first-order Elnestangen thrust.

Description

The geological section displays a hangingwall ramp-on-footwall flat relationship (Fig. 23). The footwall block to the southeast comprises the north-dipping upper Hagastrand and the Galgeberg members of the Tøyen Formation, the Huk Formation, and the Helskjer Member of the Elnes Formation. The hangingwall block to the northwest is defined by the Lysaker and Svartodden members of the Huk Formation. The ramp section is folded and displays a south-vergent, asymmetric, open syncline above the thrust surface with an adjacent anticline to the north. A smaller-scale, tight anticline may be observed in the Lysaker Member along the thrust surface (not visible in Fig. 23).

The anticline at the sole of the hangingwall block is interpreted to have developed by drag during the thrusting, i.e., as a small-scale, hangingwall anticline. In addition to the small- scale anticline associated with the sole thrust, a conspicuous syncline developed in the hangingwall block. The composite structure of the hangingwall block at the present locality thus contrasts with the larger-scale, hangingwall anticline that dominates the hangingwall block at the same stratigraphic level at the Kindergarten section at Stop 4. A model to explain the observed hangingwall syncline-anticline couple is illustrated in Figs. 24 & 25. The basic idea of the model is that the hangingwall, syncline-anticline couple was developed in response to thrusting and associated folding during the advance of the hangingwall block. As the hangingwall block moved up along the frontal ramp of the footwall block, the movement continued along the ramp, and a new thrust may have broken through into the base of the hangingwall block in the continuation of the footwall ramp (Fig. 25 B-C). The thrust-fold may also have overprinted the advancing hangingwall block at a more advanced stage of the break-through of the new thrust from the sole of the hangingwall block, or it may be related to a thrust splaying off and advancing from the footwall block. The steepening of the thrusted segments may relate to the break-through of new ramps in the footwall block in the transport direction (Fig. 25 D-E). As the thrust blocks were gradually tilted, the steepening of the thrust surfaces thus prevented further movement along the early thrusts as the shear stress is reduced at the expense of the normal stress.

The southern boundary of the Elnestangen thrust block is situated at the first-order Elnestangen thrust about 40 -50 metres to the south of the road section (Fig. 8). The main thrust is not exposed, but the uppermost layers of the Sjøstrand footwall block to the south belonging to the Arnestad Formation are exposed in an ENE-WSW-oriented and c. 2 m-high road section. The Arnestad Formation is dominated by dark shales with subordinate limestone horizons. In the road section, the Arnestad Formation is truncated by a number of small-scale parallel thrust surfaces identified by slickensides and numerous calcite growth lenses (Fig. 26). The thrusts are encountered over a couple of metres across the strike, and the thrust separation is c. 50 cm. The stratigraphic offset is in the order of 200 m, corresponding to thrusting along intersecting ramps in excess of 450 m. The closely spaced, lower-order thrusts are interpreted to illustrate that the footwall deformation below the main thrust was distributed between discrete thrust surfaces.

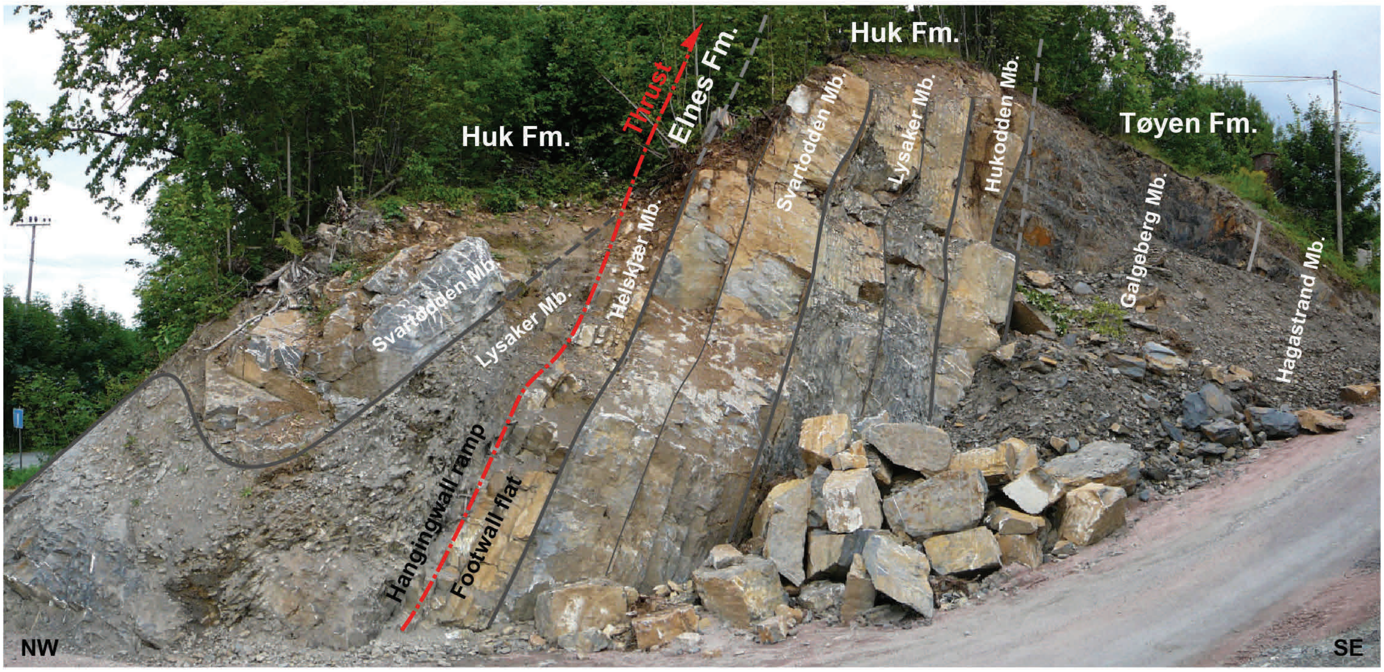


Fig. 23. Photo of the road section at Øvre Elnesveien with the geological interpretation.

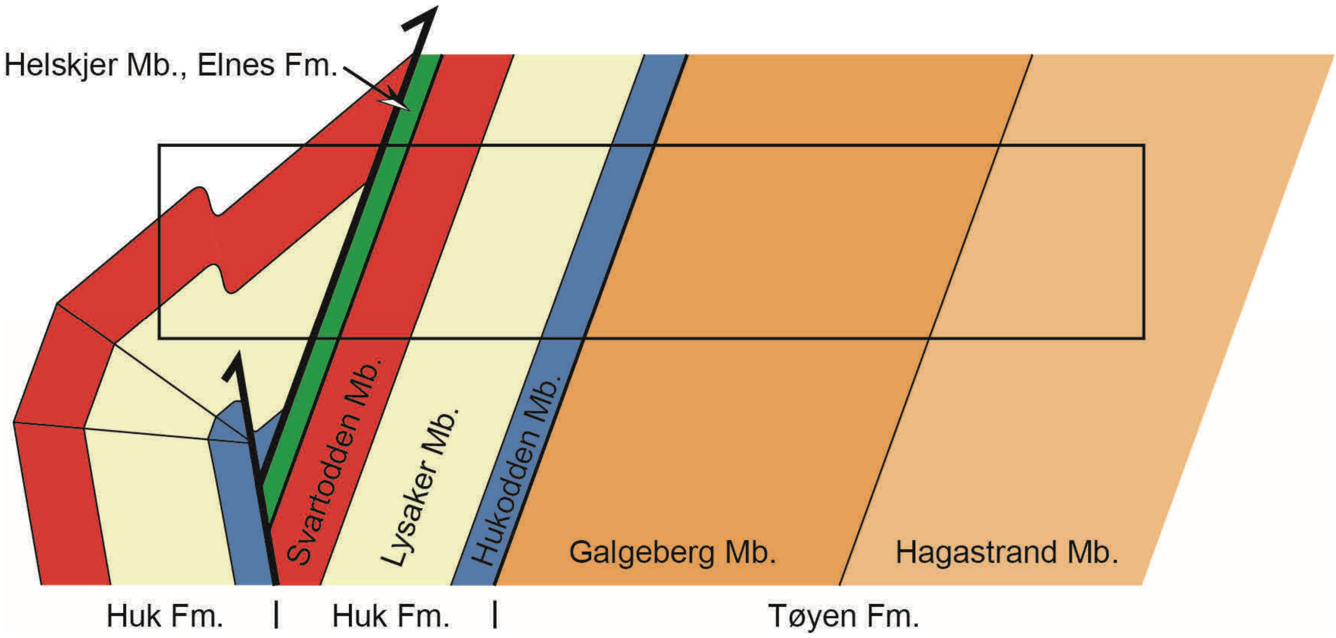


Fig. 24. Geological model of the road section at Øvre Elnesveien. The frame indicates the position of the exposed section in Fig. 23.

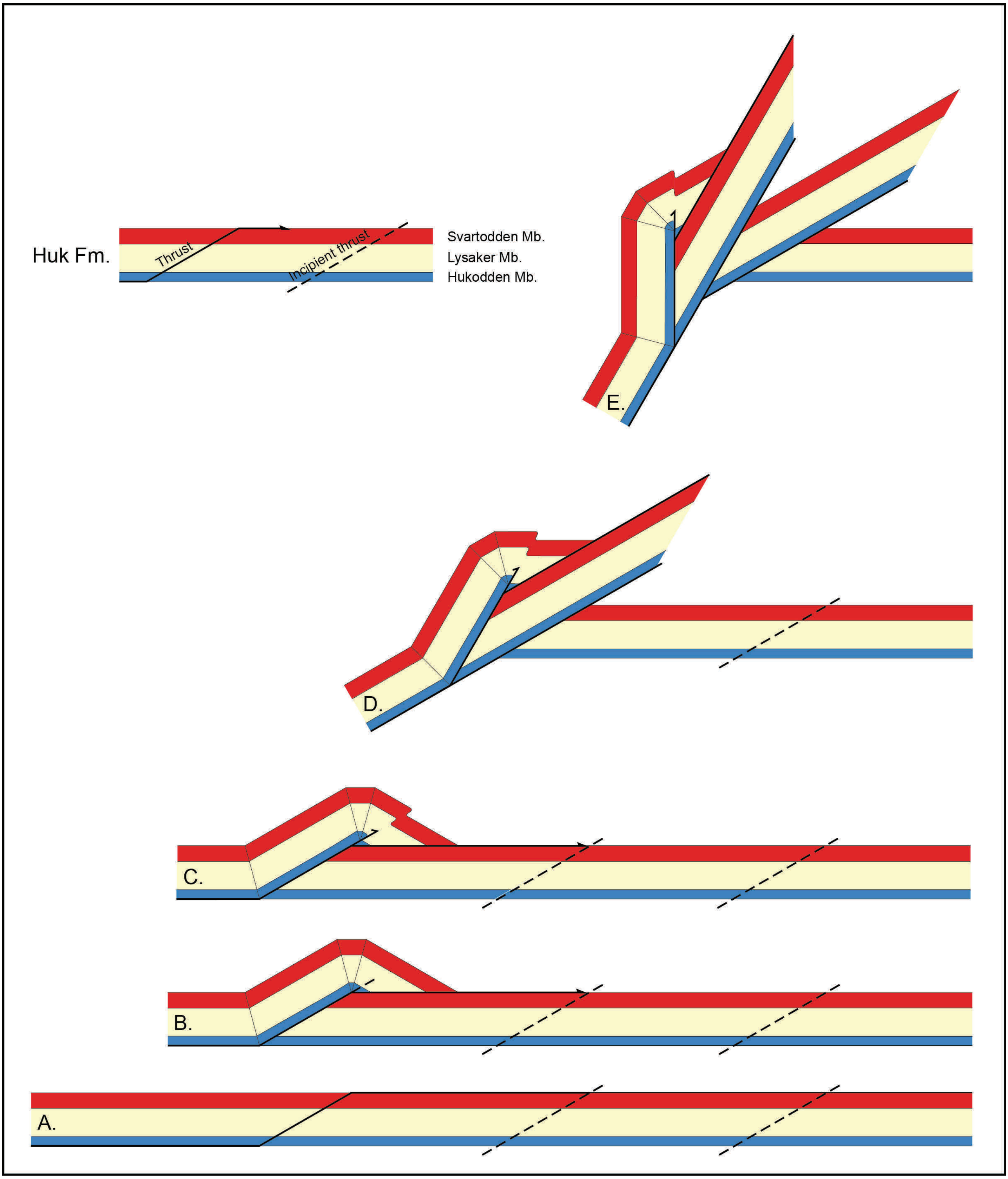


Fig. 25. Ramp-flat model to show the inferred evolution of the Huk Formation at Øvre Elnesveien.

Fig. 26. Photo of the Arnestad Formation cut by minor thrust surfaces with slickensides and calcite growth lenses. The layers are dipping steeply towards the north-northwest.

Stop no. 6: Road section, Røykenveien RV 167

Location

Road section along the east side of Røykenveien (RV 167); start from Slemmestadveien (RV 165) to the south and walk north. See map Fig. 6. Some views may be restricted due to vegetation. Restricted parking possibilities.

Warning: Take care – there is heavy traffic on Røykenveien!

Introduction

The locality is a N-S-oriented, c. 700 m long road section with continuous exposure of thrust- fold structures ranging from the Alum Shale to the south and up through the Lower-Middle Ordovician interval into the Sjøstrand Member of the Elnes Formation.

Description

The road section shows a wide variety of thrusts and associated fold structures including tight, upright, symmetrical folds as well as asymmetrical, overturned folds and complex chevron folds (Figs. 27-30). In the Alum Shales to the south, the competent limestone horizons are relatively thin, i.e. c. 20-30 cm, and the wavelength and the amplitude of the folds are in the order of 5-10 metres. Moving north, higher stratigraphic levels are encountered; the Huk Formation and the overlying Helskjer Member at the base of the Elnes Formation are composed of massive and nodular limestone beds, and this sequence forms the competent backbone unit between the Tøyen and Sjøstrand shale units. The limestone succession is c. 10 m thick, and the wavelength of the thrust-fold structures at this level are in the order of 50-100 metres or larger. The increase in fold size on moving up in the stratigraphy thus seems to be directly related to the increased thickness of the competent units involved.

Fig. 27. Tight, upright, flexural-slip folds; a syncline flanked by anticlines. Røykenveien section, east side, southern part.

Fig. 28. Asymmetrical, overturned, flexural-slip folds, Alum Shale Formation. Røykenveien east side, southern part.

Fig. 29. Complex folding and thrusting of a layered limestone-shale sequence in the Alum Shale Formation. Røykenveien east side, southern part.

Fig. 30. Complex chevron folds, Vollen Formation(?). Røykenveien east side, northern part.

Fold duplex. At the Alum Shale level, shale-limestone fold arrays formed by tight upright to overturned folds are arranged in symmetrical bundles topped by a thicker, more competent level (probably formed by the calcareous upper Alum Shale) forming larger-scale, low-amplitude, open anticlines (Fig. 31). The two incongruent structural levels must be separated by a low-angle thrust. In addition, the Alum Shale fold arrays must also be floored by a décollement zone below the present observation level in order to compensate for the strong compression and shortening that must be involved to create the tight to isoclinal folds. In conclusion, the fold arrays are thus interpreted to be sandwiched between a subhorizontal floor thrust and a broad anticlinal roof thrust. By analogy with fault duplexes formed by horses stacked in thrust slab sequences, I suggest that such a fold array confined by thrusts is termed a 'fold duplex'. In contrast to a 'thrust duplex' comprising thrust slabs, a fold duplex may develop when an incompetent shale unit is thrusted and folded between two enclosing thrusts.

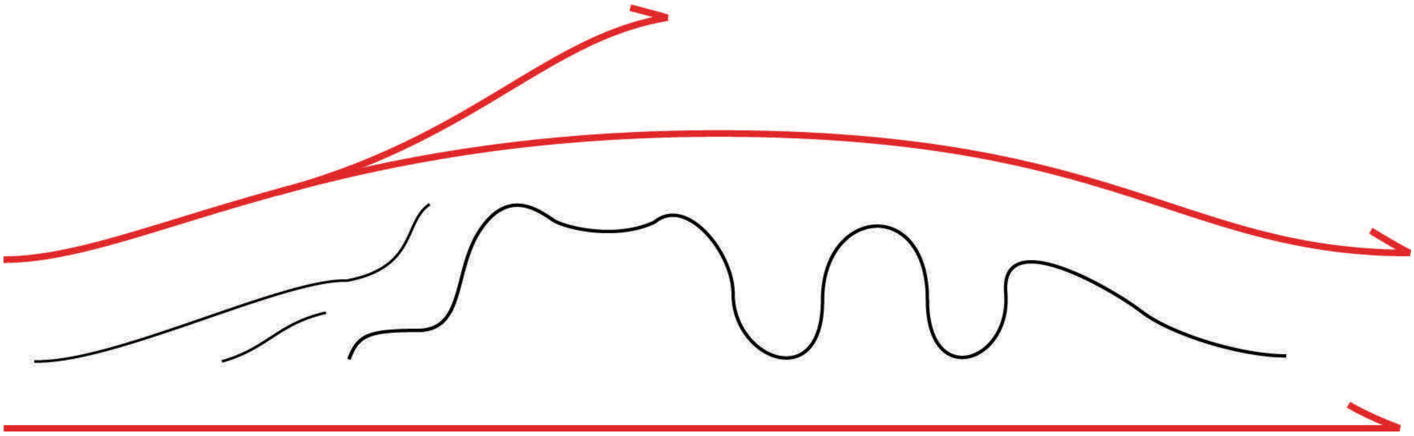


Fig. 31. Sketch of the fold duplex described in the text, Røykenveien east side, southern part.

Acknowledgment

I thank David Roberts for constructive review and correction of the English language that improved the manuscript.

References

Berthelsen, A., Olerud, S. & Sigmond, E. .O. 1996: Geologisk kart over Norge, berggrunnskart Oslo 1:250000. *Norges Geologiske Undersøkelse.*

Bruton, D. L., Gabrielsen, R. H. & Larsen, B. T. 2010: The Caledonides of the Oslo Region, Norway – stratigraphy and structural elements. *Norwegian Journal of Geology 90*, 93-121.

Graversen, O. 1984: Geology and structural evolution of the Precambrian rocks of the Oslofjord-Øyeren area, Southeast Norway. *Norges geologiske undersøkelse Bulletin 398*, 1-50.

Graversen, O. & Pedersen, S. 1999: Timing of Gothian structural evolution in SE Norway: A Rb/Sr whole rock age study. *Norsk Geologisk Tidsskrift 79*, 47-56.

Morley, C.K. 1986: Vertical strain variations in the Osen-Røa thrust sheet, North-western Oslo Fjord, *Norway. Journal of Structural Geology 8*, 621-632.

Morley, C.K. 1986: The Caledonian thrust front and palin spastic restorations in the southern Norwegian Cale donides. *Journal of Structural Geology 8*, 753-765.

Morley, C.K. 1987: Lateral and vertical changes of deformation style in the Osen-Røa thrust sheet, Oslo Region. *Journal of Structural Geology 9*, 331-343.

Morley, C.K. 1994: Fold-generated imbricates: examples from the Caledonides of Southern Norway. *Journal of Struc tural Geology 16*, 619-931.

Nakrem, H.A. & Rasmussen, J.A. 2013: Oslo district, Norway *in* Calner, M., Ahlberg, P., Lehnert, O. & Erlström, M. (*eds.*): The Lower Palaeozoic of southern Sweden and the Oslo Region, Norway. Field Guide for the 3rd Annual Meeting of the IGCP project 591. *Sveriges geologiska undersökning, Rapporter och meddelanden 133*, 58-85 (+ references).

Naterstad, J., Bockelie, J.F., Bockelie, T., Graversen, O., Hjelmeland, H., Larsen, B.T. & Nilsen, O. 1990: Asker 1814 I, Geological bedrock map Scale 1:50 000. *Norges geologiske undersøkelse.*

Owen, A.W., Bruton, D.L., Bockelie, J.F. & Bockelie, T. 1990: The Ordovician successions of the Oslo Region, Norway. *Norges geologiske undersøkelse Special Publication 4*, 1-54.

Sigmond, E.M.O., Gustavson, M. & Roberts, D. 1984: Geological bedrock map of Norway, Scale 1:1 million. *Norges geologiske undersøkelse.*

NGF
Geological Guides

Number 5, 2015

NORSK
GEOLOGISK
FORENING