

# The structure of the Ordovician rocks of the Ringerike district: evidence of a thrust system within the Oslo Region

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The structure of the Ordovician succession in the Ringerike district is described. Two zones of differing structural styles are recognised to the north and south of a major structure, here named the Klekken Fault. The middle and upper Ordovician strata in the south are gently folded but in the north the lower Ordovician rocks dip steeply northwards and are repeated many times by high-angle strike faults. These structures are related to a thrust system which was emplaced over the younger, lesser deformed, rocks to the south. The regional implications of this structure are outlined.

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The earliest studies of the Lower Palaeozoic succession of the Oslo Region recognised the importance of extensive folding and faulting within the graben (e.g. Murchison 1847, Kjerulf 1855). Much later the effects of local thrusting were noted (e.g. Størmer 1934), but it is only recently that the presence of a major sole thrust underlying much of the region has been postulated (Nystuen 1981, Ramberg & Bockelie 1981). This suggests that contrary to conventional interpretations much of the Lower Palaeozoic sequence is at least parautochthonous.

Ramberg & Bockelie (1981, p. 81) have briefly discussed the presence and effects of a major zone of décollement within the Oslo Region and have illustrated this feature and related structures schematically (op. cit., Fig. 2). Bockelie & Nystuen (1983 in press) have discussed this model in more detail, locating the sole thrust at the top of the Cambrian Alum Shale, and moreover stated that deformation generally decreases towards higher stratigraphical levels.

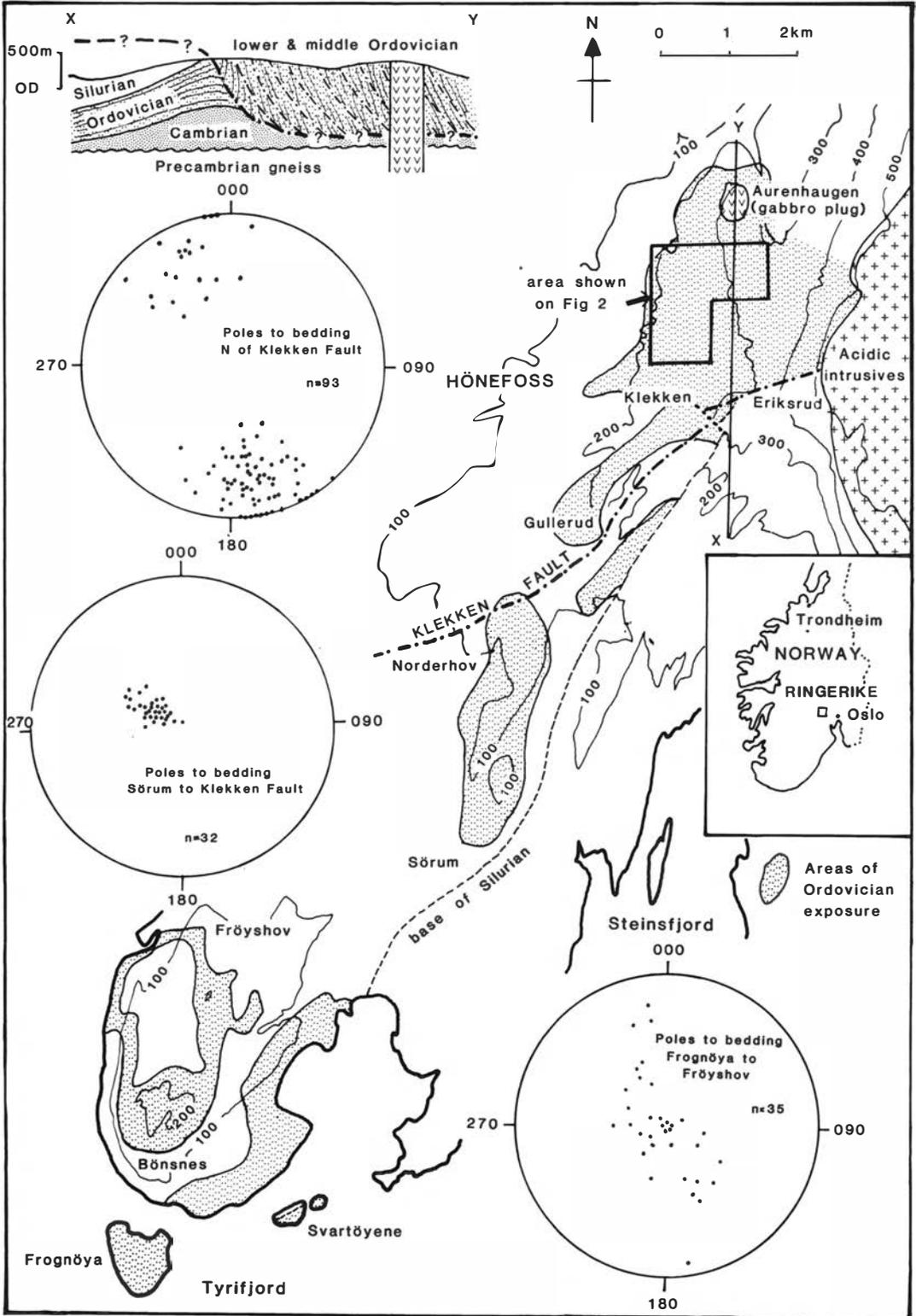
The complex structure in the Ordovician rocks of the north Ringerike district was first documented by Kjerulf (1862), who related the intense faulting to the intrusion of a small gabbroic plug at Aurenhaugen (NM 739725). The present study indicates the effect of emplacement of the plug to be negligible even locally, and herein we present evidence for a thrust system and related structures within this part of Ringerike. Størmer (1934) discussed further these intensely deformed rocks and recognised that they are separated, locally, from the lesser deformed Ordovi-

cian and Silurian rocks of the southern part of Ringerike by a thrust. He considered this structure to extend south to Krokskogen where Ordovician rocks have been thrust over 'Downtonian sandstones' (op. cit., Fig. 1).

## Setting

The Ringerike district is the sixth of Størmer's key areas of Ordovician rocks within the Oslo Region (1953, Fig. 1) and is situated about 30 km north-west of the capital city. The Ordovician succession is complete, at least 500 m thick and comprises alternating limestones and shales with interdigitating limestone and sandstone facies in the highest part of the sequence (Hanken & Owen 1982). The Ordovician outcrop forms an elongate belt trending approximately north-east to south-west and occupies an area of some 125 square kms; the succession shows an overall younging towards the south-east. To date, only the upper Caradoc and Ashgill formations have been described in detail (Kjær 1897, Hanken 1974, 1979, Owen 1979), whilst Størmer (1953) has outlined the stratigraphy of the middle Ordovician. The entire Ordovician outcrop is currently being mapped and the succession revised in terms of a modern lithostratigraphical nomenclature (Owen & Harper in prep.).

The extensive superficial deposits in Ringerike (Østmo et al. 1978) have considerably restricted the degree of exposure of Cambrian and Ordovician rocks (Fig. 1), although the Silurian strata



and Permian igneous rocks on the higher ground to the east are much better exposed. Nevertheless the exposed outcrop of Ordovician rocks is sufficient to demonstrate both the stratigraphy and the structure.

## Description of the structure

Detailed field mapping on a scale of 1:5000 has indicated the presence of two contrasting structural zones within the Ordovician outcrop of the Ringerike district (Fig. 1). The southern part of the area is characterised by gently tilted and folded middle and upper Ordovician rocks, whilst the northern area exhibits intensely faulted and steeply dipping lower and middle Ordovician strata. The two areas are separated by a major fault, here termed the Klekken Fault, which trends essentially north-east to south-west. Along the western part of the fault, lower Ordovician strata of the north are brought against upper Ordovician rocks. But northeastwards at Eriksrud (NM 74957095) for example, lower Ordovician rocks are faulted against Silurian strata. Although the orientation of the fault is unknown it is consistent with a fairly high angle thrust from the north.

To the south of the Klekken Fault, middle and upper Ordovician rocks crop out in a north-east to south-west trending belt with an essentially similar regional strike. The beds are generally inclined to the south-east at 40° or less (Fig. 1). Although there are a number of minor faults and some folding, the structure of this zone is essentially simple. The few steep dips shown on the stereonet on Fig. 1 are demonstrably associated with faults. A similar structural pattern is also seen in the overlying Silurian succession (Kjær 1908, Whitaker 1977), and the extensive normal faulting is shown in simplified form on the tectonic map of the Oslo Graben produced by Ramberg & Larsen (1978, pl. 2).

A weak cleavage is restricted to the shale units and the abundant fossils of the majority of the formations have suffered little if any deformation.

To the north of the Klekken Fault the structure is markedly different. Throughout this area the

lower Ordovician rocks commonly dip steeply northwards. Bedding plane slip is a widespread feature, and the succession is repeated by closely spaced strike faults (Fig. 2). Where exposed, e.g. in the road cutting at Klekken, these faults are near vertical. Many of the faults can be traced laterally along the east-west strike and their downthrow is almost invariably to the south. In the section between NM 732723 and NM 735713 (Fig. 2) at least 16 faults occur within a north-south transect of 1.5 km. Exposure here is particularly good and the existence of additional unmapped faults is unlikely. Assuming the resulting mean fault spacing to be typical of the district there has been a horizontal shortening of the order of 80% over the northern area.

To the immediate north of the Klekken Fault a belt of high lower Ordovician strata dips essentially southwards at angles of about 50°.

## Interpretation

Although the rocks to the north of the Klekken Fault are generally older (Cambrian to lower Caradoc) than those to the south (upper Llandeilo to Ludlow), there is sufficient overlap of both stratigraphies to suggest that the structural contrasts do not reflect an early-mid Caradoc episode of deformation. The lithostratigraphy of the Caradoc is closely comparable with that of the Oslo-Asker district (Størmer 1953) and contains no gaps. The only conglomeratic horizon is undeformed and is located within the upper Llandeilo – lowest Caradoc ‘Ampyx Limestone’ (Størmer 1953, Hamar 1964).

The distinctive structure of the northern zone of the Ringerike district is consistent with an imbricate fan or the hinterland dipping duplex system as defined by Boyer & Elliott in their recent review of thrust systems (1982). The pattern of high angle strike faults with a persistent throw to the south, together with the northward dip and younging of the strata within fault slices, strongly suggest the applicability of these models. The floor thrust probably is located within, or at the base of the Cambrian Alum Shale throughout the northern area. If the thrust system is a duplex, the floor thrust ramps up to a

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Fig. 1. Map of Ringerike summarizing the marked differences in structural style across the Klekken Fault. The schematic cross-section XY is considerably simplified. The Klekken Fault is tentatively shown as a ramp, up which the floor thrust moved to a higher stratigraphical level; possibly that seen at Stubdal, 6 km to the southeast of Klekken, where Størmer (1934) recorded Ordovician rocks thrust onto Silurian units.

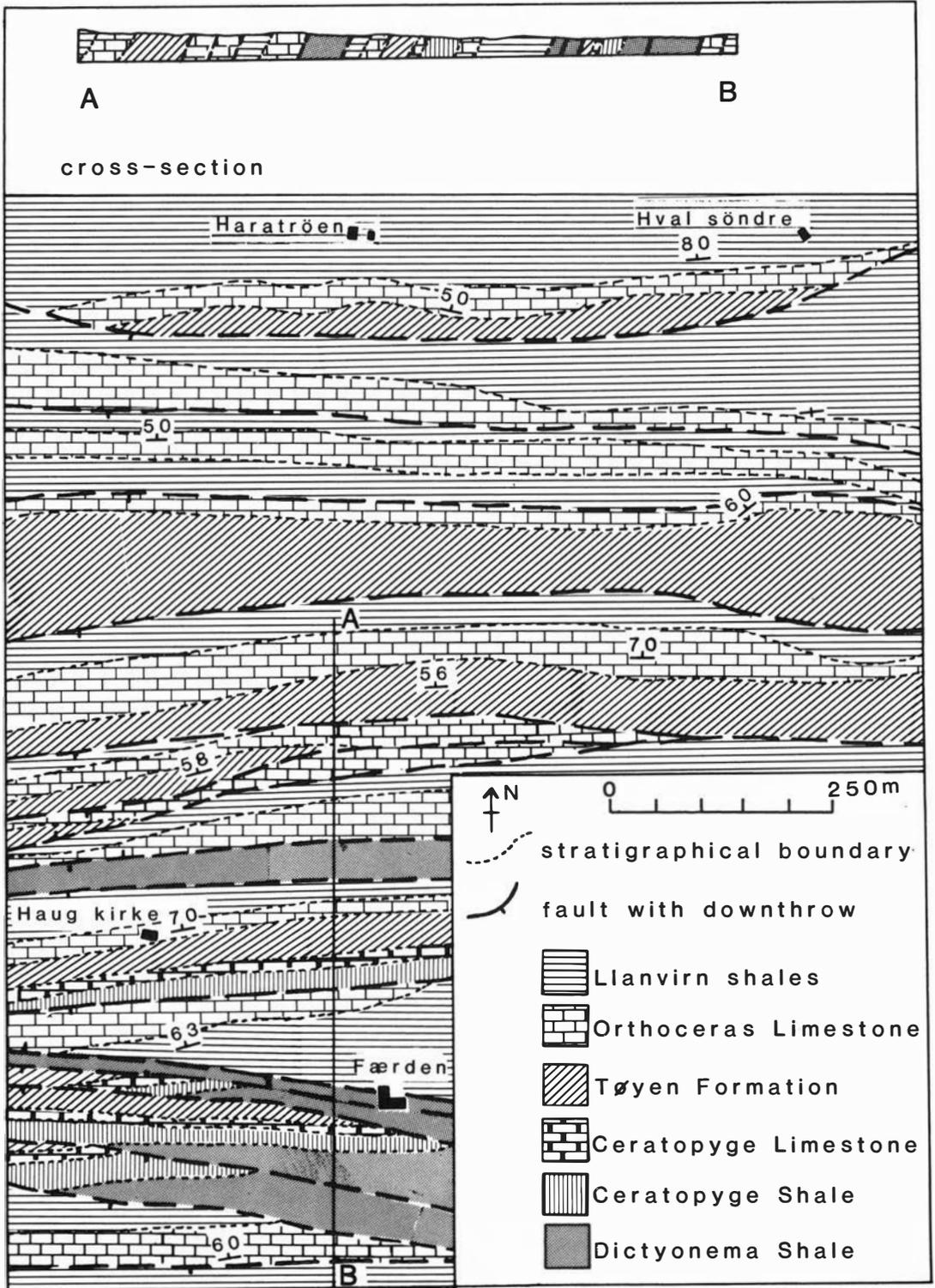


Fig. 2. Detailed geological map and cross-section of part of the northern area (see Fig. 1 for the location of this area).

much higher level along the Klekken Fault. This level may be represented in Krokskogen immediately to the east of Ringerike where Størmer (1934) documented Ordovician rocks thrust onto Silurian strata. The roof thrust of the possible duplex cannot, however, be demonstrated. Isolated outcrops to the north of the area shown on Fig. 1 have steep dips consistent with an extension of the thrusting to at least the northern end of Ringerike. North of Ringerike is the Precambrian basement on the western side of the Randsfjord fault. This marks the western edge of the folded Lower Palaeozoic succession of the Hadeland district (Owen 1978, Ramberg & Larsen 1978, pl. 1) and thus the local margin of the Oslo Graben. The parautochthonous succession within the Ringerike thrust system therefore originated to the west or even north-west of Hadeland.

There are, however, two unusual features of this system. Firstly both the imbricated strata and the faults have steeper dips than would be expected. It is possible, however, that the thrust system has undergone slight tilting to the north subsequent to its formation. Secondly the fault crops out against younger strata eastwards along its strike, suggesting that the thrusting was a late Caledonian event post-dating an episode of folding.

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