Tectonic Features of an Area N.E. of Hegra, Nord-Trøndelag, and their regional Significance — Preliminary Notes

By
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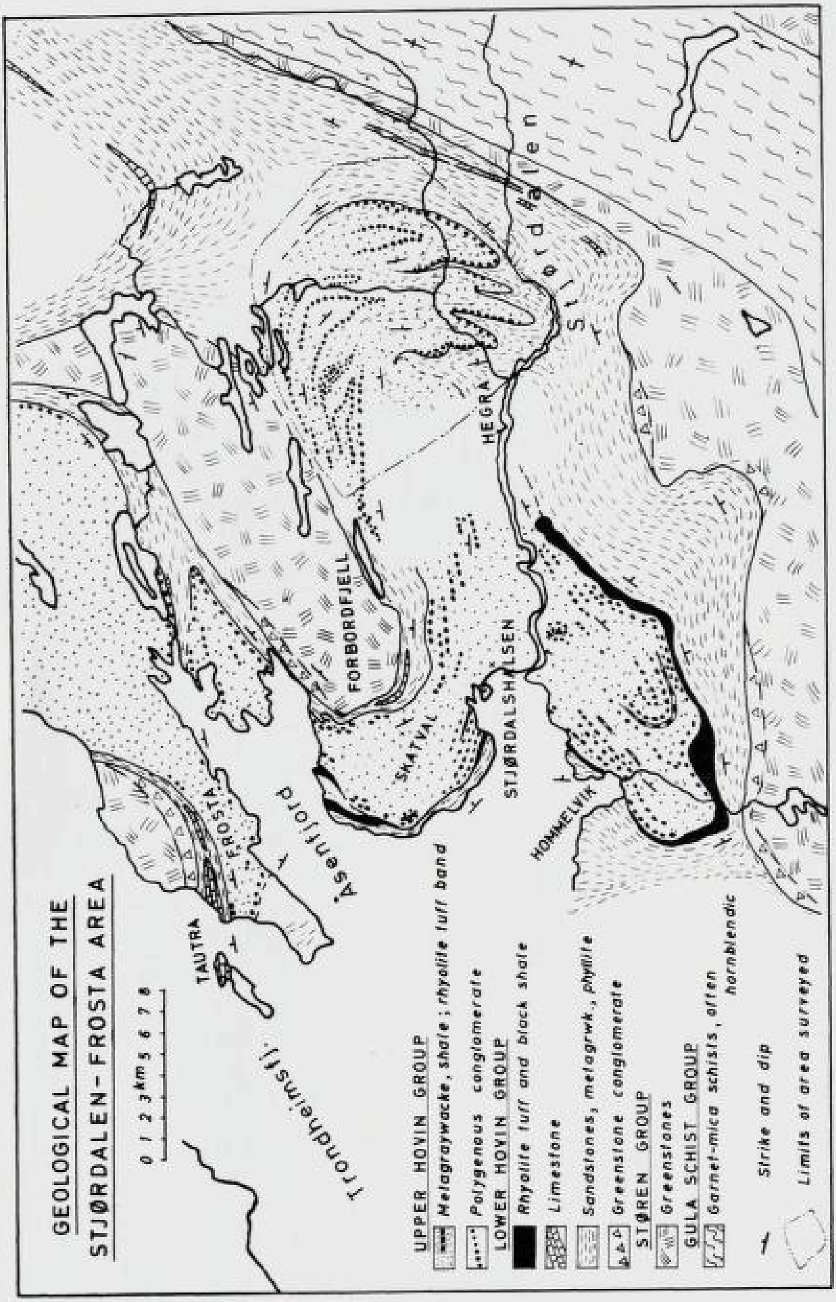
Abstract

Following brief notes on the low-grade metasediments occurring in an area near Hegra, 50 km east of Trondheim, the types of structures associated with three episodes of deformation of main Caledonian (Silurian) age are described. An outline of the suggested major structural picture is then presented. In this the principal structure is seen as a WNW-directed fold-nappe developed from the inverted western limb of the central Stjørdalen Anticline. A major eastward closing recumbent syncline underlies this nappe-like structure. These initial structures were then deformed by at least two further folding episodes. In conclusion, comparisons are noted between the ultimate fold pattern, the suggested evolution of these folds and H. Ramberg's experimentally produced orogenic structures.

Introduction

A survey of this particular area, situated north of the valley of Stjørdalen, east from Trondheim, was begun during the 1965 field-season and progressed during parts of the summers of 1966 and 1967 in conjunction with a mapping programme led by Statsgeolog Fr. Chr. Wolff further east in this same segment of the Central Norwegian Caledonides. Further geological mapping is contemplated, the aim being to eventually complete the 1 : 100,000 sheet 'Stjørdal' (rectangle 47 C). In view of the time factor involved in the completion of this work, and the renewed interest being devoted to the geological problems of the Trondheim region (Peacey 1964, Oftedahl 1964, Wolff 1964 and 1967, Torske 1965, Siedlecka 1967, Ramberg 1967), some notes on the tectonics of the Hegra area would seem appropriate at this stage. These comments also, in effect, constitute a supplement to the writer's recent article (Roberts 1967) on the tectonics of Stjørdalen and the NE Trondheim region.

Fig. 1. A geological map of the Stjørdalen - Frosta area. Western half of the map after Carstens (1960); E and SE tract after Wolff and, in part, Roberts.


GEOLOGICAL MAP OF THE
STJØRDALEN-FROSTA AREA
0 1 2 3 km 5 6 7 8
UPPER HOVIN GROUP
Metagraywacke, shale ; rhyolite tuff band
Polygenous conglomerate
LOWER HOVIN GROUP
Rhyolite tuff and black shale
Limestone
Sandstones, metagrwk., phyllite
Greenstone conglomerate
STØREN GROUP
Greenstones
GULA SCHIST GROUP
Garnet-mica schists, often hornblendic
Strike and dip
Limits of area surveyed
TAUTRA
FROSTA
Åsenfjord
Trondheimsfj.
FORBORDFJELL
SKATVAL
STJØRDALSHALSEN
HEGRA
HOMMELVIK
Stjørdalen

Mapping (largely of a reconnaissance nature) in the western half of the 'Stjørdal' rectangle sheet has been done by H. Carstens; a version of this map appeared in the 1960 International Congress guide-book (Carstens 1960, map II). Before the present writer's investigations the eastern part of this rectangle sheet had been mapped only summarily by Fr. Chr. Wolff. The geology of this region is depicted in Fig. 1: the stratigraphical scheme shows the Gula Schist Group at the base, followed by the Støren Group and Lower and Upper Hovin Groups. Within the area considered here only the Hovin Groups are represented although the Støren Group occurs immediately to the NW and E.

Greenstone, greenschists and keratophyric rocks characterize the Støren Group: this is generally regarded as a volcanic sequence. A greenstone breccia or conglomerate locally marks the base of the Lower Hovin Group. In the Hegra area this is absent and the Lower Hovin Group comprises a lustrous grey phyllite followed by a mixed sequence of 'shale' or metasiltstone alternating fairly rapidly with metagraywacke bands. A dark grey pyritous shale occurs at the top of the group. Further west in Carstens' area a rhyolite tuff is present near the top of this group and a limestone occurs lower down. The base of the Upper Hovin Group is usually marked by a polygenous conglomerate; this may exceed 50 m in thickness with cobbles sometimes up to 40 cm across. Alternating metagraywackes, metasiltstones, shales, polygenous conglomerates and occasional quartzite conglomerates constitute the bulk of the Upper Hovin Group; thin limestones occur locally. In the SW of the 'Stjørdal' sheet a thin rhyolite tuff horizon is represented.

Primary structures are common throughout the Lower and Upper Hovin Groups and have proved an invaluable aid in the tectonic structural interpretation. Such structures include graded bedding, flame structures and load (? or flow) casts, ripple marks, shale clasts within metagraywacke beds, and sedimentary dykes. Complex slump structures, including primary folds, have been observed. Isolated pebbles (or cobbles) have also been noted in some pelitic units. Another notable feature is rapid lateral and vertical lithological variation in certain horizons, particularly of pebble content, size and distribution in some conglomerates. On the other hand some finely alternating pelite/psammite horizons are of such regular thickness as to have been quarried for roofing slate at many places within the area.

Tectonic structures

The deformational history of this Hegra area has followed a nearly identical pattern to that recognized from studies in other parts of the northern Trondheim region (Peacey 1964, Roberts 1967). Differences are apparent, however, not so much from the episodic aspect as in the state of preservation of major structures and their clearer relationship to the overall deformation picture. In this regard it is essential to consider the Hegra structures in a regional context, but since relatively little structural work has been done further to the west, the detailed regional structural pattern must await the results of future investigations. In the notes which follow, only the salient structural observations will therefore be commented upon.

Three generations of folds can be recognized within the Hovin Group metasediments NE of Hegra. Briefly, the earliest folds (F_1) are tight to isoclinal in style and can be observed on all scales; they deform the recognizable bedding, and the regional schistosity is axial planar to these folds. Fold axes, though locally of quite variable trend, generally plunge in a NE-E-direction: uncommon axial plunges towards N-NNW have also been recorded. Conglomerate pebbles are often elongated, a lineation which is ascribed to this first deformation episode. Second episode folds (F_2) are relatively uncommon and are best seen on a regional scale. They are less acute in style than the F_1 folds. Axial plunges are generally towards a north-easterly point.

Third generation structures (F_3) are found in virtually every outcrop, either as observable folds of variable open to tight style, or as a penetrative cleavage easily seen in the pelites but less readily apparent, and refracted, in the metagraywackes. This cleavage, moreover, is axial planar to the F_3 folds. Axes, for the most part. plunge towards a N-NNE point but locally the plunges are towards S-SW. Exceptions to the rule are indeed commonplace — west of this Hegra area F_3 axes tend to plunge more towards W or NW — and it is more than probable that the F_3 axial trend owes its variability to the fact that these small- to medium-sized folds have been superimposed on a variably dipping succession. The attitude of the F_3 axial surface cleavage is itself of interest. Although a detailed account cannot be given here, it is significant that the sense of overturning of these F_3 folds is invariably 'down-dip', the associated cleavage being of relatively gentle inclination, sometimes only a few degrees from the horizontal. Further west, in the SE Åsenfjord area, this prominent cleavage is locally deformed by an even later, but uncommon, set of minor structures (which could be termed F_4) trending NW-SE. Kink-bands and -folds deforming F_3 structures have also been observed in three localities in the Hegra area.

On a larger scale the Hegra area is dominated by a relatively open F_2 structure, here called the Hegra Antiform. This is seen to deform a series of tight or isoclinal major F_1 synforms and antiforms (Fig. 2).

Regional structural considerations

Two basic conditions must be satisfied in formulating, and in fitting the Hegra area into, an acceptable regional structural picture. These, to an extent, are mutually compatible and are briefly, (1) the inversion of the stratigraphical sequence over a large part of the 'Stjørdal' rectangle-sheet, and (2) the occurrence of a major F_1 fan-shaped anticline (the Stjørdalen Anticline) in the central part of the Trondheim region, with the higher grade rocks of the Gula Schist Group in its core (Roberts 1967).

With regard to the first point, several geologists have taken note of the situation for example on Forbordfjell (e.g., Bugge 1954, Carstens 1960). This mountain is capped by Støren Group greenstones which here structurally overlie

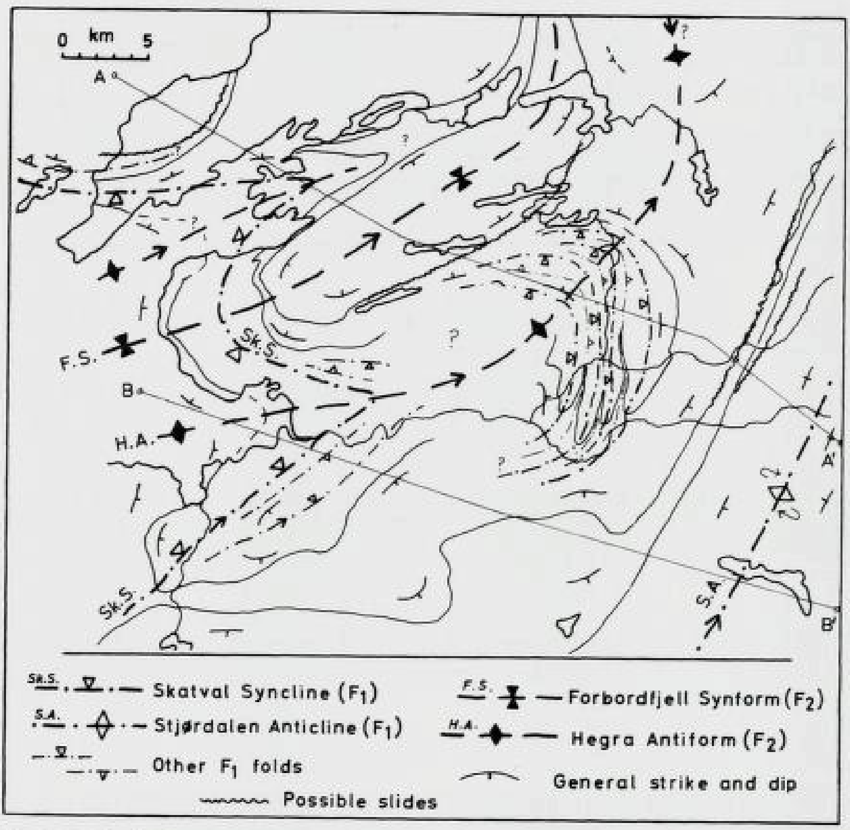


Fig. 2. Major fold axial plane traces. Main lithological boundaries as in figure 1. Fold axial plunges indicated by arrows. A-A', B-B', lines of section (see Fig. 3).

Hovin Group metasediments, the whole sequence moulded in a north-easterly plunging synform (or more properly a synformal anticline) hereafter referred to as the Forbordfjell Synform (Figs. 1 and 2).

The Stjørdalen Anticline further east is a curious structure in that both its limbs are inverted — on the eastern limb the sequence dips WNW while on the western limb dips are east-south-easterly (see e.g. Roberts 1967, Fig. 43). Considering the situation on this western limb north of the valley of Stjørdalen, the inverted sequence swings round through some 160° across the Hegra Antiform until a north-westerly dip is achieved (Fig. 1). The Støren Group greenstones then crop out again, structurally above the Hovin Groups, in the core of the Forbordfjell Synform (Fig. 2). The inference to be drawn from these observations is that the Stjørdalen Anticline is a much more complex structure than previously supposed, with its western limb of considerable dimensions and completely overturned, perhaps near-horizontal at one time in the manner of a recumbent structure. Moreover, this limb (or structure) has subsequently been deformed by the Hegra Antiform, Forbordfjell Synform and other F_2 folds in the Åsenfjord area, and then by the F_3 structures. Erosion has then helped in producing the present-day outcrop pattern. A cross-section is presented in Fig. 3a.

The question now arises as to what happens beneath the recumbent limb of this western nappe-like part of the Stjørdalen Anticline. A study of the sense of overturning of the medium- to large-scale F_1 folds in the area NE of Hegra suggests the possible presence of a major F_1 synclinal structure further to the west. On examining Carstens' map (the western part of Fig. 1), south of Hommelvik the Lower/Upper Hovin Group boundary displays a marked swing through almost 180°, the Upper Hovin rocks occurring in the core of a tight or near-isoclinal fold, the axial surface of which dips to the SE. As the axis of this fold plunges in a north-easterly direction the structure is synclinal. Following the axial plane trace north-eastwards (Fig. 2), it swings round to NW in the Stjørdalshalsen area becoming northerly around Skatval and again more NE-SW in trend on the south side of Åsenfjord. This sigmoidal curve is clearly due to the refolding of the syncline — here called the Skatval Syncline — by the major F_2 Hegra and Forbordfjell folds. The Skatval Syncline is therefore an F_1 fold of major proportions, and in the writer's opinion is to be regarded as the complementary structure to the Stjørdalen Anticline (Figs. 3b and 4).

In the Åsenfjord area an accurate tracing of this early syncline is rather difficult, but in all probability it swings westwards across yet another major

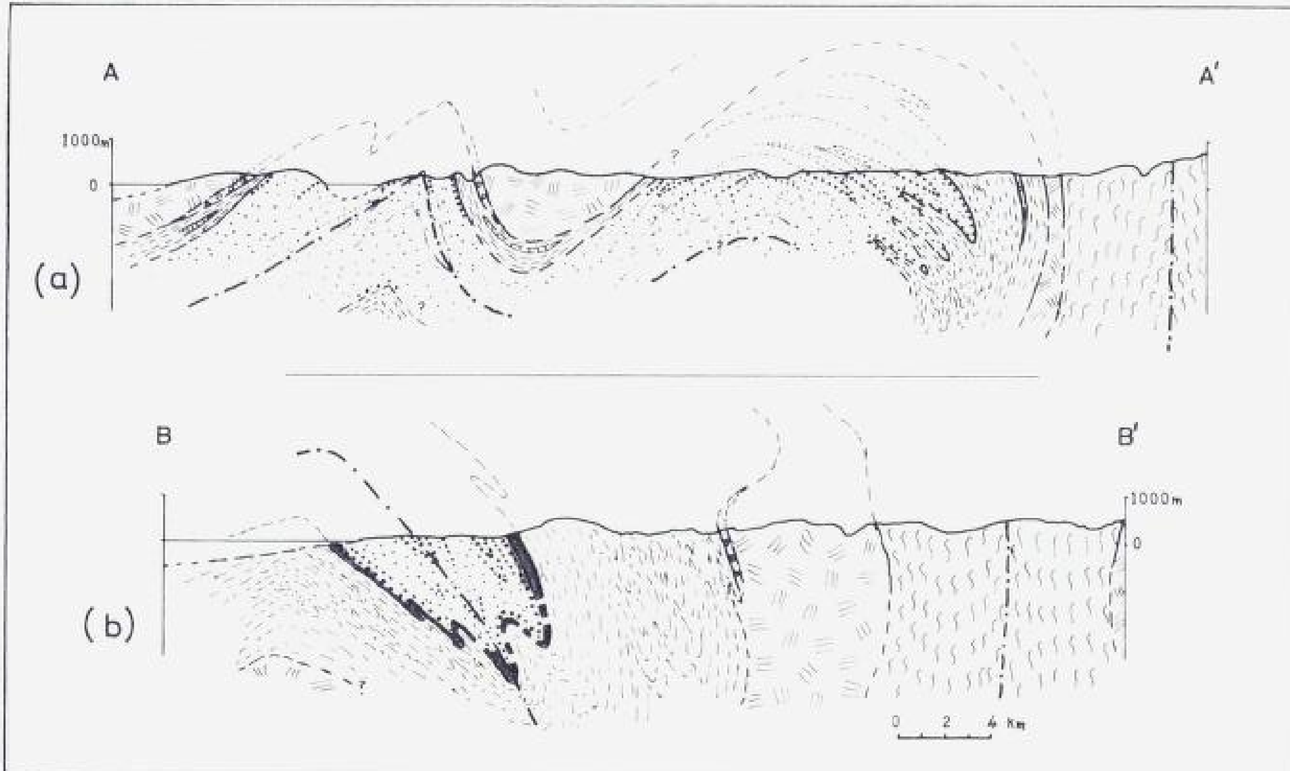


Fig. 3. Sections across the area. Lines A-A' and B-B' are indicated in figure 2. Symbols as in figures 1 and 2.

F_2 structure into the southern part of the Frosta peninsula, and then north-westwards beneath Trondheimsfjord. Further north one can but speculate at this stage, but it is quite possible that the tight synclinal fold present on the SE and S flanks of the Tømmerås Anticline (Wolff, 1960) and then disappearing beneath the fjord to the west is the same structure as the Skatval Syncline. This has been suggested quite independently by both Dr. J. S. Peacey and Professor John Rodgers (personal communications): at this point the writer wishes to express his gratitude to Dr. Peacey for providing much information and inspiration prior to and during the course of his studies in the Trondheim region.

Concluding remarks

Taking into consideration the results of the mapping near Hegra and the structural disposition of litho-stratigraphical groups in the eastern Trondheimsfjord region, the central major F_1 structure — the Stjørdalen Anticline — in this part of the Trondheim basin would seem to be far from simple. As well as being inverted in the present-day Stjørdalen profile, it is clear that the western limb was at one time more or less recumbent, rather complex, and of great magnitude forming part of a fold nappe or *Überfaltungsdecke* structure. The Skatval Syncline is essentially a complementary fold to this western sub-structure of the main central anticline. Fig. 4 depicts the generalized picture in the form of a schematic profile across the region contained by figure 1. Basically this shows the main overfolding in this western part of the northern Trondheim region to have been in a WNW-NW direction, the mirror image of that found further east in the Norwegian/Swedish Caledonides. The overall picture recalls C. Bugge's diagrammatic profile (1954, Fig. 11) across the mountain chain and also bears appreciable similarity to structures depicted in some of the illustrations of centrifuged model experiments carried out by Ramberg (1966).

In a more recent paper Ramberg (1967) has compared the structural evolution of these dynamic models with structures present in the Scandinavian Caledonides. Of particular interest here are Ramberg's remarks concerning small- and medium-scale folds in the eastern Trondheimsfjord area, these folds being the F_3 structures of the present study. Ramberg (1967, p. 49) states that, "It seems not unlikely, particularly in view of the apparent inversion of the Støren-Hovin groups at Forbordfjell and Foldsjø (Carstens, 1960), that these smaller folds are second-order folds on a huge recumbent nappe-like structure. The nearly horizontal axial plane schistosity signifies a compression in vertical direction such as would happen when a large recumbent fold spreads under

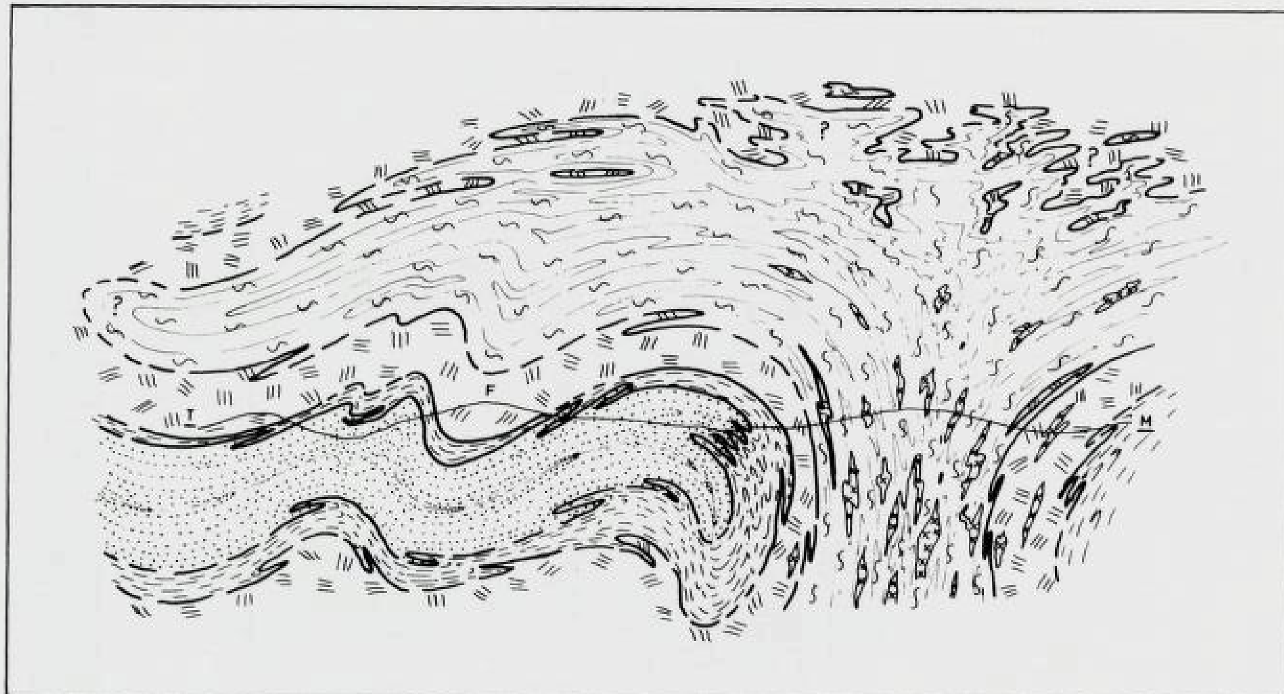


Fig. 4. Schematic reconstruction of the major structures occurring between Meråker (M) and Trondheimsfjord (T) — ca. ESE-WNW profile through Forbordfjell (F). Line TFM, present-day erosion surface. Symbols as in figure 1: xx - trondhjemite bodies. Profile not drawn to scale.

its own weight". This explanation for the development of these folds is essentially similar to that advocated by the present writer for an area further to the east (Roberts 1967, p. 105), and observations in the Hegra area have tended to support these views. With regard to the geometry and development of the principal (earliest) structures, it is tempting to go along with Ramberg's suggestion that these structures probably evolved along similar lines to those produced in his experiments, i.e., propelled by the body force of gravity. Gravitational gliding has almost certainly contributed towards lateral movement of these vast recumbent folds: the question of their actual *inception* is unfortunately too complex a topic to be discussed in these short notes, but Ramberg's experimentally-backed views are worthy of careful consideration by all concerned with Scandinavian Caledonian deformation.

That the main Caledonian deformation sequence in this region can be dated to a Silurian age has been discussed elsewhere (e.g. Vogt 1945, Strand 1961). A division of the orogenic movement into fold episodes is justifiable in terms of fold superposition although it is questionable as to whether any marked time gap occurred between the development of the respective folds. The writer has previously remarked that the F_1 and F_2 sets may preferably be looked upon as "the product of a broadly continuous deformation" (Roberts 1967, p. 102) and it is indeed possible that some of the major F_2 structures were initiated during the closing stages of the emplacement of the vast F_1 recumbent folds. In this connection it seems not unlikely that large parts of the Støren/Lower Hovin boundary are tectonic with slides possibly present within the sequence: this appears to be the case, e.g. directly north of Hegra and again on the Frosta peninsula. With some isoclinal folds being affected by slides, Hovin Group strata directly adjacent to Støren greenstones may locally appear to young towards the latter. Sliding was most probably initiated during the F_1 deformaion and continued into the F_2 episode. Some minor thrusting occurred towards the end of this latter episode. On the SE side of the Forbordfjell Synform it is quite possible that Upper Hovin rocks may locally structurally underlie the Støren Group, the Lower Hovin having been completely excised during Caledonian movements. It is of interest here to note observations reported by other workers in the western Trondheim region, in whose areas the Støren-Hovin boundary has been regarded as a 'fault' (Chadwick et al. 1963, Torske 1965).

Another interesting point concerning the Hegra Antiform is whether or not this structure overlies a primary upwarp in the basement. Tracing this fold northwards it appears as if it might possibly connect with the small 'dome' of (?) basement rocks just SE of Levanger (Carstens 1960), and then link up with the Tømmerås Anticline which is considered to have developed upon a primary ridge in the basement (Peacey 1964, p. 63). Alternatively, this Hegra fold and other large F_2 anticlinal structures could be associated with basal culminations developed actually during the Caledonian orogeny. But as Ramberg's model experiments suggest, any primary bulges present in the basement were probably strongly activated, producing domal rises, during the main Caledonian orogeny (Ramberg 1967, p. 47).

Much more structural information is required from this western Trondheimsfjord region before a fully satisfactory tectonic picture can emerge, but the general pattern of events now appears somewhat more comprehensible than was the case a decade ago. An interesting exercise now would be to investigate the south-westward continuation of the major structures described above — F_1 recumbent folds or nappes deformed by tight or open F_2 folds — into the classical Hølonda-Horg district (Vogt 1945) and further west into the Surnadal region.

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