GEOLOGY OF THE HØLONDA–HULSJØEN AREA, TRONDHEIM REGION

by
Josef Chaloupský[1])

Abstract.

The geology of an area south of Trondheim is described. A new stratigraphical division of the Early Palaeozoic is proposed and its structure outlined.

The entire Early Palaeozoic sedimentary and volcanic complex has been divided into four separate groups, differing in lithology and separated by conspicuous layers of synorogenic conglomerates:

1) The oldest Støren Group (presumably of Tremadocian age), 2) The Krokstad Group (largely of Arenigian, Llanvirnian and Llandeilian age), 3) The Lower Sandå Group (of Caradocian and perhaps partly of Ashgillian age), 4) The youngest Upper Sandå Group (presumably of Silurian age). The total thickness of the Ordovician-Silurian sequence overlying the Støren volcanic complex is about 800 m. The overall structure is interpreted as a series of closely packed tight to isoclinal folds accompanied by shearing and stretching phenomena, which are grouped into extensive anticlinorial and synclinorial belts.

Introduction.

In this paper the results are presented of geological investigations and mapping of an area 45 km SSW of Trondheim, carried out during the summer of 1969. The purpose of this work was to produce a geological map of the area Hølonda–Evjeseter–Hulsjøen–Lundseter.

Mapping data were plotted onto airphotos from which a geological map on a scale of 1 : 25 000 was subsequently compiled. The area investigated is of a low mountainous topography, the lower parts of the terrain being locally covered with Recent and Pleistocene deposits of considerable thickness.

[1]) Ústredni ústav geologický, Praha 1, Malostranské nám 19, Czechoslovakia.

Fig. 1. Black square indicates location of the mapped area.

This extremely interesting sector of the Caledonides in the Trondheim region is distinguished by a very low grade of metamorphism and by the presence of thick Early Palaeozoic complexes of flysch-like character. Although the fold structure is relatively complicated, several fossiliferous horizons and distinctive marker beds, particularly conglomerates, make it possible to locate the individual members of the sequence within the Early Palaeozoic stratigraphical column with reasonable accuracy.

The interesting geology has attracted the attention of a number of geologists; among the modern ones Th. Vogt (1945) should be mentioned in particular. His division of the Early Palaeozoic complex into four series (Støren, Lower Hovin, Upper Hovin and Horg) and his dating of the early Caledonian epeirogenic phases has provided a basis for the stratigraphy of Early Palaeozoic successions in other parts of the Trondheim region Caledonides. Studies published after Vogt's detailed work, particularly those of C. W. Carstens (1951, 1952), H. Carstens (1960), Blake (1962), Chadwick et al. (1963), Chaloupský (1963) and Carter (1967) have provided a lot of new and valuable information but essentially no changes in the basic conception of the stratigraphy and structure of the area. The relevant results that modified the existing opinions were, for example, the recognition of the Hølonda porphyrite as being intrusive, and not effusive (C. W. Carstens 1951, Chadwick

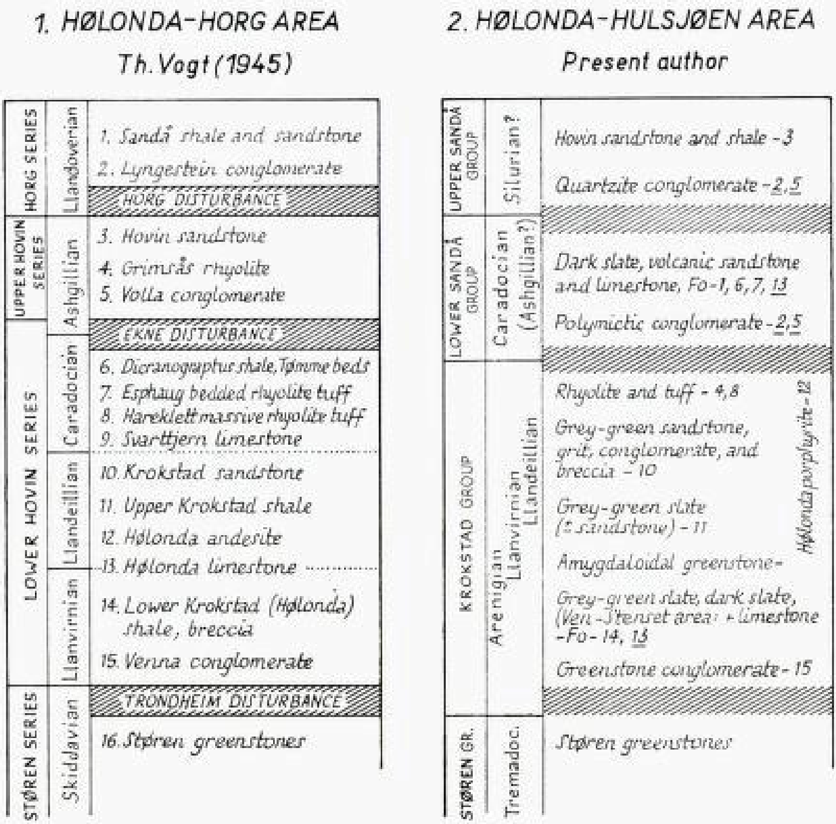

Fig. 2. Correlation of the stratigraphical schemes of Th. Vogt (1945) and the author. Numbers after the lithologies in column 2 correspond to numerals of equivalent rocks (or partly equivalent rocks when underlined) in column 1.
Fo = fossiliferous horizon.

et al. 1963); finds of graptolites in the Bogo shale, of Middle Arenigian age (Blake 1962), which allowed the boundary between the Støren and Hovin Series to be drawn more precisely; observation that the Hølonda limestone comprises more than one horizon (Chadwick et al. 1963); inclusion of the Jåren Beds in the Hovin Series (Carter 1967); incorporation of stratigraphically differentiated Sandå shale, Tømme black shale and Hareklett bedded rhyolite tuff in one complex showing tectonic repetition (Chaloupský 1963); a more precise stratigraphical positioning of some other members of the sequence (Oftedahl et al. 1969).

The stratigraphical correlation of beds from different sectors of the area studied is to be found in the various papers mentioned above. The basic stratigraphical division of the Early Palaeozoic complex, after Th. Vogt, is given in Fig. 2.

The author has mapped the area which is directly adjacent to the south-western border of that mapped by Th. Vogt. In describing the stratigraphy and structure of the area the author has made allowance for a different interpretation of some of the geological phenomena. A new stratigraphical division is put forward in the concluding chapters. Many questions, however, remain open. It would be desirable to continue the detailed and integrated investigation of the area under consideration, with particular emphasis on the composition and genesis of rocks, chiefly conglomerates, the sedimentary conditions and the newly found fossiliferous localities (their precise position is shown on aerial photos deposited in NGU, Trondheim). Only then it will be possible to make a more precise assessment of the stratigraphical position of individual members of the succession, and of the dating of volcanic activity and the extent and effects of the Caledonian deformation phases.

Acknowledgements.

I am greatly indebted to Norges geologiske undersøkelse for defraying the expenses of the investigation. My special thanks are due to Professor Chr. Oftedahl of the Technical University in Trondheim for all his assistance and interest in my work. I should like to express my special thanks to my colleague statsgeolog Fr. Chr. Wolff for his incessant help, collaboration and inspiring and friendly company during my stay in Norway. Finally, I cannot fail to mention all those Norwegian friends in NGU, Orkla Grube-Aktiebolag (Løkken Mine) and in the country who were always willing to help. The days spent among them will belong to the most cherished memories of my life.

Stratigraphy and rock characteristics.

The description of the rocks as given below is based on the stratal sequence presented in the stratigraphical column (see the map) and in Fig. 2. Although the author has endeavoured to use the generally accepted terminology,* in some cases the stratigraphical content and construction of formations and groups has had to be somewhat modified in order to fit the new geological interpretation.

* though with 'group' replacing 'series'.

Støren Group.

The volcanic complex of the Støren Group is the oldest member of the Early Palaeozoic succession occurring in the cores of the anticlinorial zones at the western and south-eastern margins of the mapped area. It is distinguished by the predominance of basic extrusive lavas accompanied by pyroclastics (agglomerates and keratophyric rocks), cherty beds and occasionally by sedimentary rocks (greyish-green or reddish slates). The lavas, which comprise massive and pillow varieties, were converted by low-grade metamorphism into typical greenstone of a characteristic mineral association: chlorite, epidote, actinolite, albite, calcite, quartz, etc.

The lack of precise palaeontological data makes the dating of the Støren Group difficult, but on correlation with other sectors of the Trondheim region it is assignable to the lowermost Ordovician, most probably to the Tremadocian.

Krokstad Group.

The term Krokstad Group is used to denote a relatively monotonous sequence of greenish slates and sandstones bearing intercalations of grit, conglomerate and breccia. Beds of grey to dark-grey slates occur in the lower part of the complex. This sedimentary sequence, roughly 400 m thick, overlies the older volcanic Støren Group, being locally separated from it by basal greenstone conglomerate. Sedimentation of the group was terminated by the extrusion of rhyolite lavas and by the intrusion of porphyrites.

In addition to the greyish-green colour, the flysch-like nature and abundant sedimentary structures (lamination, graded bedding, current and glide bedding) are characteristic features of the sedimentary rocks of the Krokstad Group. The greater part of the clastic material was undoubtedly derived from the Støren volcanic complex. The succession of rocks of the Krokstad Group is shown schematically in the stratigraphical column on the geological map and in Fig. 2.

Basal greenstone conglomerate.

The conglomerates immediately overlying the greenstone complex have been described from a number of localities in neighbouring areas, under different names: Venna (Stokvola) conglomerate (Th. Vogt 1945), Greenstone conglomerate (C. W. Carstens 1951, H. Carstens

1960) and Fjeldheim conglomerate (Chadwick et al. 1963). In the present area this lithology shows the character of a coarse-grained, unsorted, polymict conglomerate, composed mainly of greenstone, keratophyre, red jasper, sandstone, slate and limestone pebbles and other rock fragments. Pebbles are generally poorly rounded so that the rock has the appearance more of a volcanic breccia than a conglomerate.

Greyish-green slates.

These rocks constitute the greater part of the lower division of the Krokstad Group and are divided by a sequence of dark-grey slates. The development and appearance of the slates in both the lower and the upper parts is similar. Petrographically, they are very fine-grained sericite slates up to metasiltstones with well-developed cleavage planes, straight or strongly warped, often transverse to the original stratification. The latter is readily observable only where the slates bear intercalations of fine-grained sandstone alternating rapidly with thin slate beds. The greyish-green colour of slates is due to the increased proportion of chlorite and epidote.

Grey to dark-grey slates.

Grey slates up to several tens of metres in thickness occur in the lower part of the Krokstad Group; their transition into the underlying and overlying greyish-green slates is gradual. On account of the petrographical similarity and local inconspicuous change in shade, the two slate types are difficult to differentiate. The darker-grey or laminated varieties abounding in pyrite can easily be confused with the dark slates of the Lower Sandå Group described below.

Greyish-green sandstone and grit.

The upper part of the sedimentary complex of the Krokstad Group in represented by greyish-green, fine-to coarse-grained sandstone with interlayers of grit, conglomerate and breccia. This unit displays beautiful examples of graded bedding and also occasionally of current and glide bedding. The larger components of the sandstone and grit are quartz, quartzite, fine-grained slates, greenstone, keratophyre, and red jasper. Sericite, calcite, epidote, albite, chlorite, ore minerals and muscovite are common. The rocks can also be designated petrographically as lithic sandstone and greywacke (Fig. 3).

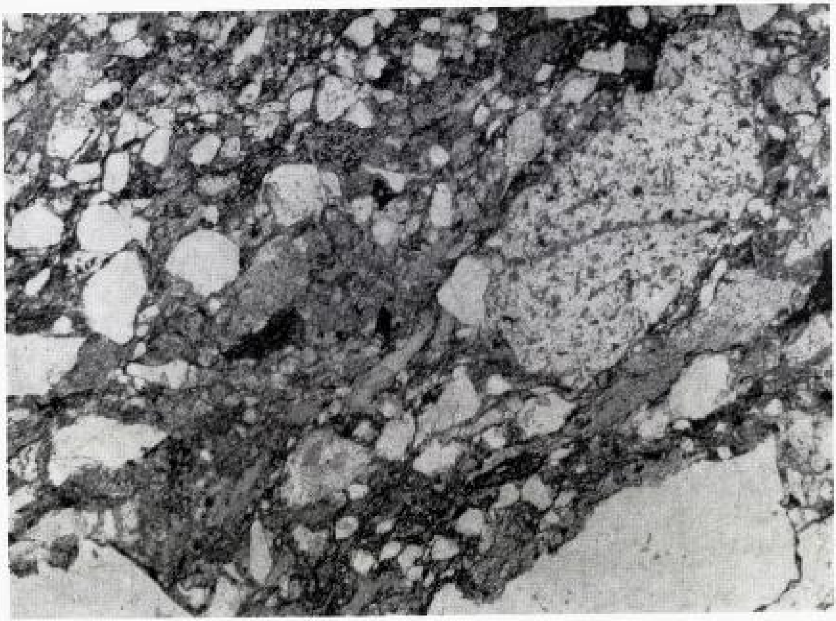

Fig. 3. Coarse-grained greyish-green sandstone of the Krokstad Group 3 km NNW of Kleivlykkja. x 22; parallel nicols.

Breccia.

Beds of fine-to coarse-grained breccia occur particularly in the lower part of the sandstone unit. Similarly as with the basal greenstone conglomerate, the breccia is composed of angular or sub-rounded fragments of greenstone, keratophyre, red jasper, quartzite, sandstone, slate and some limestone, embedded in a sandy matrix. The beds of breccia are not limited to one horizon; they usually form several layers separated by beds of greyish-green sandstone or greenish and reddish slate.

Amygdaloidal greenstone.

Sporadic amygdaloidal rocks occupy a separate position within the Krokstad Group. They constitute thin layers (up to several metres in thickness) within the greyish-green slates, near the upper boundary of the dark-grey slate unit.

The amygdaloidal structure of these greyish-green fine-grained rocks is striking (Fig. 4). Amygdales, 1—4 mm in mean size, are filled with calcite or an aggregate of calcite, albite and chlorite grains. The ground-

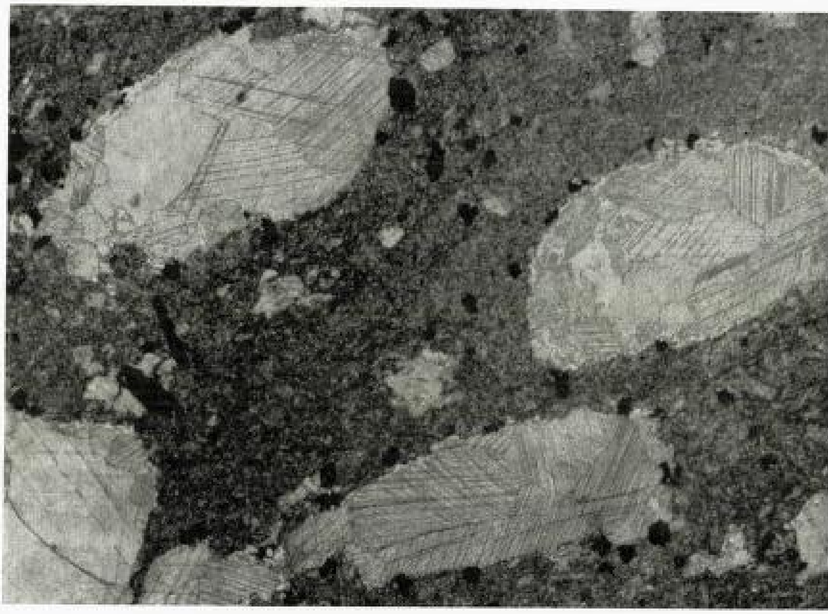

Fig. 4. Amygdaloid greenstone, Krokstad Group 1 km SE of Jonland. x 22; parallel nicols.

mass, with indications of ophitic texture, is formed of a mixture of thin laths of plagioclase-albite, chlorite and ore pigment. Quartz and apatite are usually present in accessory amounts. Regularly dispersed chlorite segregations seem to be pseudomorphs after primary mafic minerals, pyroxene or hornblende. Amygdaloidal greenstone presumably represents altered basic lavas which in their petrography are nearest to some types of the older Støren volcanic complex.

Hølonda porphyrites.

Weakly altered Hølonda porphyrites (porphyritic andesites) are found only in the northernmost part of the mapped area, and extend into the adjacent areas studied by Th. Vogt (1945), Chadwick et al. (1963) and Carter (1967). They are frequently represented by marked topographic ridges and summits of hills.

The porphyrites are composed of plagioclase and pyroxene phenocrysts enclosed in a groundmass of fine albite laths, chlorite, epidote, ore minerals etc. (Fig. 5). Plagioclases are partly or completely saussuritized

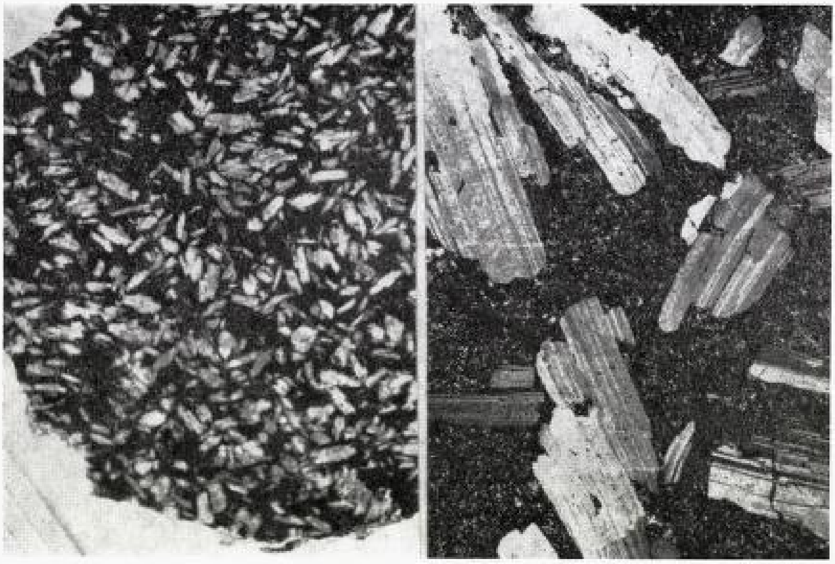

Fig. 5. Hølonda porphyrite. Road-cutting 2,3 km SSW of Hølonda church. Specimen of natural size on the left, thin-section of the same specimen on the right, x 15; crossed nicols.

and of albite composition. Pyroxene, which is colourless up to green is almost fully replaced by chlorite and uralite. Vogt (1945) differentiated two separate types of porphyrite; The Berg type, rich in plagioclase phenocrysts; and the Almås type, a little more basic and with more abundant phenocrysts of albite and altered pyroxene. Chadwick et al. (1963) observed the common occurrence of these two types within the same body.

It has not yet been decided indubitably whether the porphyrites are of intrusive or extrusive origin. Th. Vogt referred to them as lavas, and regarded the fragments of the Berg-type porphyrite in the neighbouring limestones as pyroclastic material from these lavas (Fig. 6). In contrast, C. W. Carstens (1951) considered the porphyrites to be intrusive discordant bodies. Chadwick et al. (1963) record the following criteria pointing to the intrusive character of porphyrites: lack of features distinctive of subaerial or submarine extrusive lavas, local strong baking of slates at the contact with the porphyrites, the formation of chilled and even glassy margins to the porphyrites, and occasionally the truncation of bedding in the sedimentary rocks.

Fig. 6. Fragments of porphyrite in limestone. Road-cutting, 2,3 km SSW of Hølonda church.

In the present area the porphyrites can be regarded as intrusive sill-like bodies, which were generally concordant with the bedding of the country rocks and subsequently deformed together with the sediments. Their occurrence is confined to a relatively narrow stratigraphical horizon, viz. the top part of the sandstone and slate unit of the Krokstad Group, at the contact with the overlying dark-slate and limestone beds of the Lower Sandå Group. In the vicinity of Hølonda, the limestones directly overlie the porphyrites and are not subjacent, as thought by Vogt (1935). From this it follows that the porphyrites occupy an analogous stratigraphical position to the rhyolites in the southern part of the area studied (described below). It is possible, however, that in neighbouring areas the porphyrites also occur at lower horizons in the Krokstad Group. It may be postulated that shallow intrusive porphyrite bodies were occasionally exposed during sedimentation and furnished detrital material for the sediments being deposited. Locally abundant fragments of porphyrites in the limestones in the vicinity of Hølonda are then interpreted as true pebbles and not as pyroclastic material (Fig. 6).

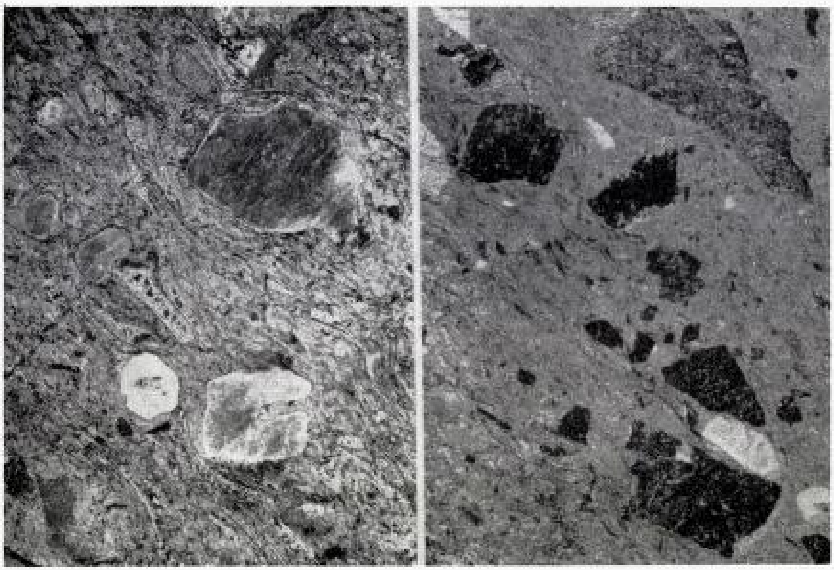

Fig. 7. Left: rhyolite showing fluidal (eutaxitic) texture. 1,5 km NW of Kleivlykkja. x 15; parallel nicols. Right: rhyolite with fragmentary texture. 3 km ENE of Evjeseter. x 22; parallel nicols.

Rhyolite and rhyolite tuff.

The rhyolites of the central part of the present area link up towards the west with two prominent bands of rock referred to by Vogt (1945) as Grimsås rhyolite and Hareklett massive rhyolite tuff. In his opinion these two rock-types are of different stratigraphical position and age. The present author, however, interprets the strips of rhyolitic rock as projections of one intensively folded layer which occupies a strictly definable stratigraphical position in the uppermost part of the Krokstad Group, directly below the basal conglomerate of the Lower Sandå Group. All rhyolites in the mapped area are of similar petrographical character.

The rhyolites are massive rocks, grey to greenish-grey in colour, without any definite traces of stratification. The groundmass is very fine-grained, composed of quartz, feldspar and sericite with an admixture of epidote, clinozoisite, sphene and magnetite, and contains quartz, albite and less frequently potassium-feldspar phenocrysts. Traces of fluidal texture and of younger recrystallization and silicification features are occasionally discernible in the groundmass (Fig. 7).

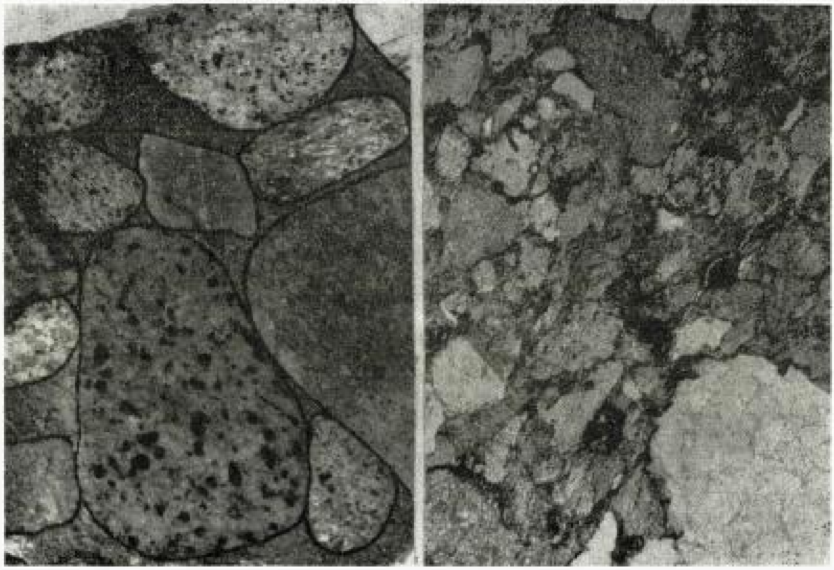

Fig. 8. Polymictic conglomerate, Lower Sandå Group. 1,5 km NW of Kleivlykkja. Specimen of natural size on the left, thin-section of the same specimen on the right. Abundant rhyolite fragments in groundmass. x 22; parallel nicols.

Types of fragmentary structure are common, this structure being particularly conspicuous on weathered rock surfaces. Rhyolite fragments are irregular, angular and several millimetres across. The abundance of fragmentary material and the structure of the rhyolites do not only provide evidence of their effusive character but suggest an origin as tuffs and agglomerates for at least a part of them. Because of folding and slight metamorphism the differentiation into lava and tuff layers is now almost impossible.

The age of the Krokstad Group can be estimated from the palaeontological finds recovered from equivalent horizons in adjacent areas. From the basal part of the Krokstad Group (the Fjeldheim Beds of Chadwick et al. 1963), Blake (1962) has described numerous graptolites of Middle Arenig age from the dark Bogo shale. Dark Bjørgen roofing slate bearing Upper Arenigian fauna (Størmer, 1932) also corresponds to the lower part of the Krokstad Group. Another significant fossiliferous formation is the limestone with intercalated dark-grey slate occurring in the more easterly Ven-Stenset area. These rocks were dated as either Upper Llanvirnian up to the Lower Llandeilian (Vogt 1945) or Llandeilian (Strand

Fig. 9. Polymictic conglomerate, Lower Sandå Group. 3 km ENE of Evjeseter.

1949): the limestones are analogous in stratigraphical position to the dark-grey slates in the lower part of the Krokstad Group in the present area. In the author's opinion, the entire Krokstad Group underlies the Lower Sandå Group, the Caradocian age of which has been confidently established. Consequently the sedimentary complex of the Krokstad Group, volcanics included, can be placed within the period embracing the Arenigian, Llanvirnian and Llandeilian.

Lower Sandå Group.

The Lower Sandå Group comprises about 250 m of dark slates with intercalations of grey fine-grained sandstone and locally of limestone. Polymictic conglomerates form the basal unit of the group.

Polymictic conglomerate.

Basal polymictic conglomerates are of only limited distribution. They overlie the greyish-green sandstones and slates, rhyolites and rhyolite tuffs, which are the youngest members of the Krokstad Group. The largest proportion of the pebble material is of light-coloured quartzite; fine- to medium-grained granitic to dioritic rocks, rhyolite, felsitic

Fig. 10. Dark banded slate, Lower Sandå Group. 750 km NW of Kleivlykkja. Flaggy parting on the left, splintery disintegration on the right.

porphyry, sandstone, slate and more rarely greenstone, limestone etc. are present in variable amounts. Pebbles are several centimetres across on the average, well worn, densely packed or scattered in a matrix of greywacke type. The matrix is occasionally composed almost exclusively of minute fragments of rhyolite rocks (Figs. 8, 9).

Dark slate.

Dark-grey to black slates constitute the main part of the Lower Sandå Group. They disintegrate into splinters mostly along false-cleavage surfaces (Fig. 10). Rusty weathered grains of pyrite and pyrrhotite occur in abundance. Locally a prominent banding or lamination is produced by the alternation of thin grey silty laminae or bands with black slate. The boundaries between the slates and the silty laminae are generally sharp on one side and diffuse on the other. As well at these indications of graded bedding, flame structures have also been observed. The banded slates are most common within the main occurrence of rhyolite and rhyolite tuffs in the central part of the area, where they contain in addition numerous layers of fine-grained *volcanic sandstone* (Figs. 11 and 12). These are up to several metres thick, dark-grey and partly

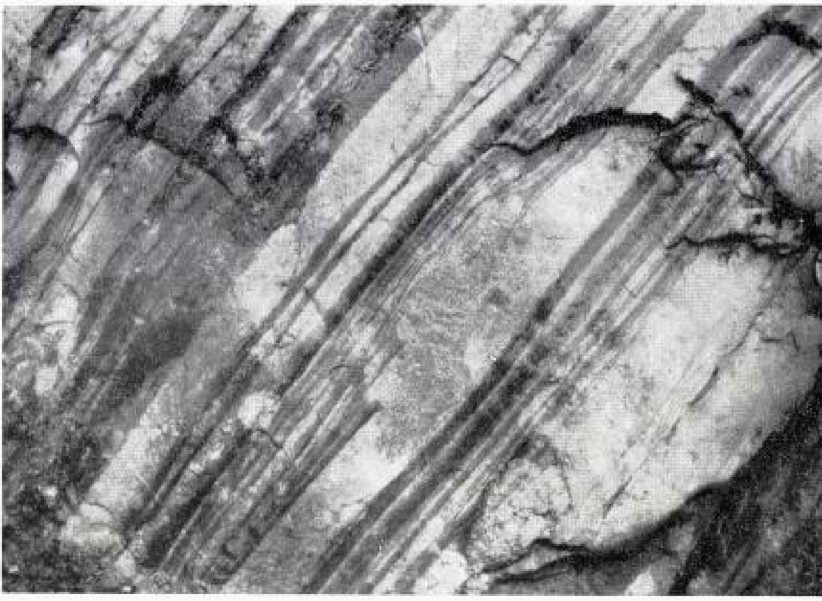

Fig. 11. Interbanded grey sandstone and dark slates, Lower Sandå Group; the sequence is here inverted as denoted by the prominent load cast near the centre of the picture. Graded bedding and current ripple lamination are also present. Road-cutting near Sjursmoen, west of Hovin. Photo, Dr. M. R. Wilson.

greenish in colour. The greenish-grey sandstones are difficult to distinguish from the strongly folded greyish-green sandstones of the older Krokstad Group, and it cannot be excluded that they were partly confused even during the mapping. The sandstones consist essentially of angular or more or less rounded quartz grains and felsite fragments which contain strongly decomposed plagioclase and resemble closely the underlying rhyolite rocks. Calcite, albite, epidote, fragmentary flakes of muscovite, chlorite, ore pigment, fragments of shale, sandstone, and rarely tourmaline and apatite occur in subordinate or accessory amounts. The admixture in dark banded slates shows a similar composition. Fragments of volcanics suggest that pyroclastic material is possibly present. It is, however, more plausible that it represents redeposited material of older volcanic rocks, viz. rhyolites and rhyolite tuffs.

Dark slates with sandstone intercalations make up a uniform unit, stratigraphically equivalent to the following rocks in the area mapped by Th. Vogt: the Dicranograptus shale, the Tømme black shale and

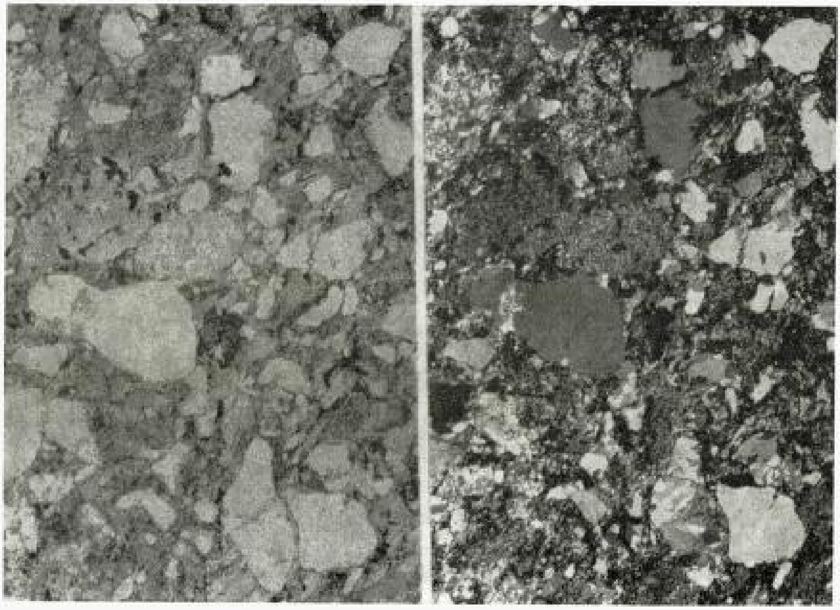

Fig. 12. Volcanic sandstone, Lower Sandå Group. 3 km W of Kleivlykkja. x 22; parallel nicols on the left, crossed nicols on the right.

mudstone, the Esphaug bedded rhyolite tuff, the Sandå shale with the associated Lundamo tuff (Oftedahl et al. 1969) and part of the Hølonda shale (Skjegstad shale). The first three of these formations have yielded fossils of Caradocian age. The author has also found poorly preserved graptolites in the dark slates, north of the Hulsjøen Lake. Dr. I Chlupáč of the Geological Survey, Prague, identified them as monoserial graptolites, but neither generic nor specific determination was possible: both a Silurian and an Ordovician age can be considered.

Limestone.

The Lower Sandå Group also contains limestones occurring in the lower part of the dark slates, west of Kleivlykkja and close to Hølonda. They are light- to dark-grey, generally fine-grained and partly of crystalline texture. In places they are nodular and contain intercalations of dark slates. Their mean true thickness is a few metres. West of Kleivlykkja fossils have been found at several localities in the limestones. The localities are plotted on the geological map and their precise positions

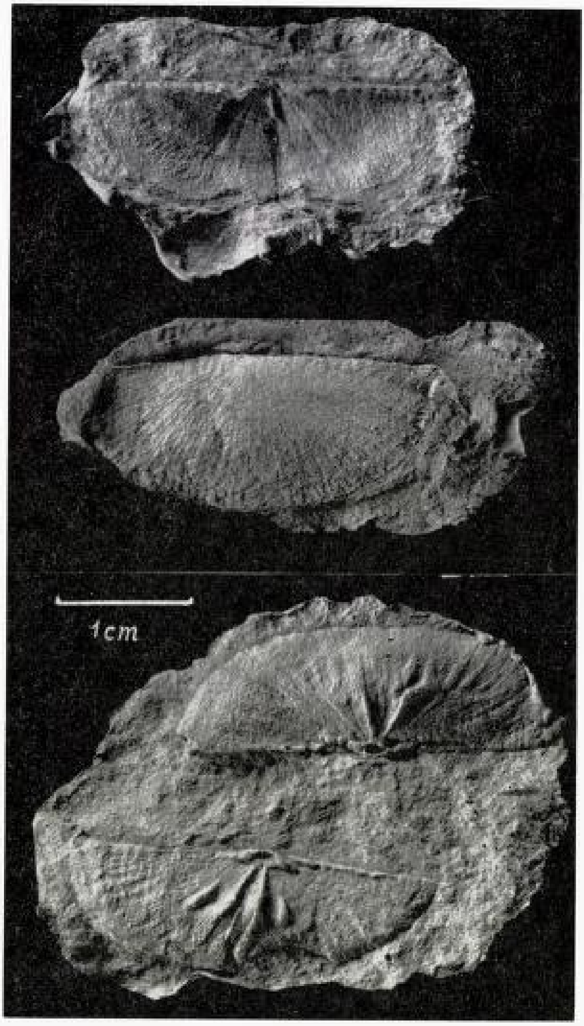

Fig. 13. Latex casts of brachiopods Sowerbyella (Sowerbyella) Jones, 1928, in limestone, Lower Sandå Group. 1,5 km ESE of Lundseter.

are shown on the air-photos deposited in the NGU, Trondheim. The best preserved fossils (brachiopods) were collected from the westernmost locality, ESE of Lundseter (Fig. 13).

According to Dr. V. Havlíček of the Geological Survey, Prague, the brachiopods belong to one species, classed undoubtedly in the Sowerbyellidae family. They can be assigned with a high degree of certainty to the genus and subgenus Sowerbyella (Sowerbyella) Jones, 1928, which is widely distributed throughout the world except for the Mediterranean province where it is lacking altogether. The stratigraphical range of this subgenus is considerable covering the Middle and Upper Ordovician (Llanvirnian to Ashgillian). From the Ordovician (Caradocian) of Norway it has been recorded, for example, by Spjældnes (1957) from the environs of Oslo.

As indicated by the reconnaissance mapping of the geologists of the Orkla Grube-Aktiebolag (the group working at the Løkken mine), the limestones described link up in the west with the Kalstad limestone, the fauna of which is probably of Caradocian up to Ashgillian age (Kjær, 1932). In an analogous stratigraphical position are the limestones from the vicinity of Hølonda which Vogt (1945) correlated with the limestones from Ven-Stenset yielding fossils of Upper Llanvirnian to Llandeilian age (Vogt, 1945, Strand, 1949). The fossiliferous limestones of the Ven-Stenset area, however, seem to be earlier, being the facies equivalent of the dark grey slates in the lower part of the Krokstad Group.

From the palaeontological finds it can be inferred that the entire Lower Sandå Group is most probably of Caradocian age, extending partly into the Ashgillian.

Upper Sandå Group.

The Hovin sandstone, beginning with basal conglomerates, is one of the youngest members of the Early Palaeozoic complex in the mapped area. It is preserved in the cores of the synclinal folds in the south.

Quartzite conglomerate.

The basal quartzite conglomerate, up to tens of metres in thickness, is a distinctive horizon separating the dark slates of the Lower Sandå Group from the overlying Hovin sandstone. It is composed mainly of well-worn, generally closely packed boulders of light-coloured quartzite, and subordinately of various volcanic and sedimentary rocks. (Fig. 14). The thickness of the conglomerate and its composition, size and proportions are inconstant. In lithology the rock often resembles the generally polymictic conglomerate from the base of the Lower Sandå Group. Where the conglomerates are not intimately associated with the typical Hovin sandstone, their precise stratigraphical position is difficult to

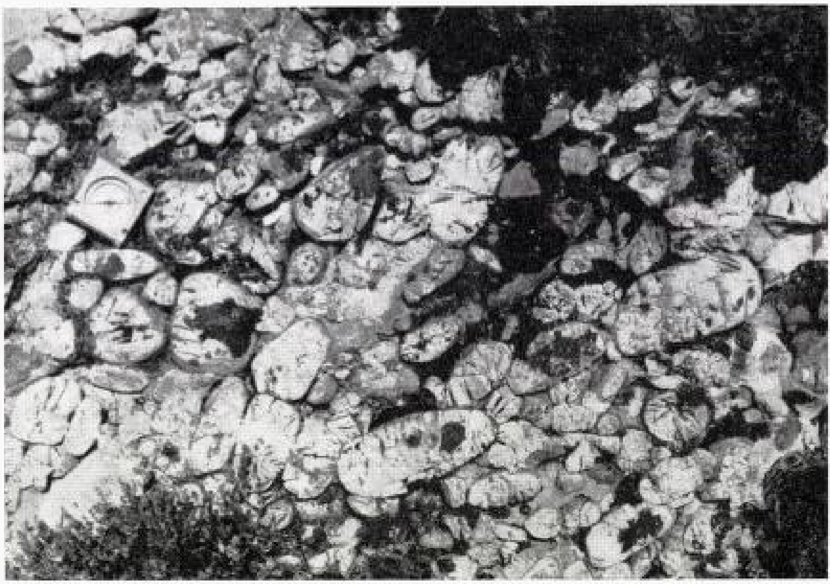

Fig. 14. Quartzite conglomerate, Upper Sandå Group. 2 km W of Kleivlykkja.

establish (e.g. north-west of the Hulsjøen Lake). Reliable criteria for the differentiation of the two conglomerates are obtainable only after a detailed petrographical examination.

Hovin sandstone.

The sandstones overlying the quartzite conglomerate are distinguished by the alternation of sandstone beds, several dm- to m-thick, with thin beds of dark-grey slate. Sandstones are grey and fine- to medium-grained. They contain an increased proportion of calcite and consist mostly of the angular quartz grains, fragments of slate, feldspar and scattered flakes of muscovite and/or decomposed biotite. In appearance the Hovin sandstone looks quite like the grey fine-grained sandstone intercalated in the dark slates of the Lower Sandå Group. The criteria enabling the Hovin sandstone to be distinguished from the older sandstone in the field are, in addition to its close connection with the quartzite conglomerate, its relatively strong weathering, low strength, typical slabby jointing and a fairly large admixture of macroscopic muscovite flakes.

From the Hovin sandstone no determinable fossils have so far been recovered. On the basis of the new stratigraphical table, the Hovin sandstone together with quartzite conglomerate represents the youngest Early Palaeozoic formation in the mapped area. It overlies the Lower Sandå Group of unquestionably Caradocian and possibly up to Ashgillian age, so that the Upper Sandå Group can quite likely be dated as Silurian.

History of the sedimentary complex and its stratigraphical correlation.

The major part of the Early Palaeozoic sedimentary complex overlying the Støren volcanic group is distinguished by a flysch type of sedimentation. As remarked by Chadwick et al. (1963) «evidence such as the great variety of rock types and rapid facial changes along the strike indicate that sediments were probably laid down in an unstable near-shore environment with a certain amount of pene-contemporaneous erosion in some places». Moreover, the products of magmatism — rhyolite and rhyolite tuff, amygdaloidal greenstone and intrusive porphyritic andesite — are not scarce.

The whole Early Palaeozoic complex has been divided into four separate groups differing in lithology and separated by conspicuous layers of syn-orogenic conglomerate (Fig. 15).

The oldest *Støren Group* (presumably of Tremadocian age) consists almost entirely of basic extrusive rocks and their pyroclasts; acid extrusives are present to a small extent.

The *Krokstad Group* (largely of Arenigian, Llanvirnian and Llandeilian age) is about 400 m thick. It is composed of basal greenstone conglomerate, slates and in the upper part of sandstones with intercalations of grit, conglomerate and breccia. The clastic material was derived mostly from the rocks of the Støren Group. The deposition of this group was terminated by intense volcanic activity (extrusions of rhyolite and rhyolite tuff) and by intrusions of porphyrite.

Fragments of these volcanic rocks appear in the basal polymict conglomerate of the *Lower Sandå Group* and form a substantial admixture in the volcanic sandstone interbedded in the younger dark slates of the same group. The Lower Sandå Group is decidedly of Caradocian and perhaps partly of Ashgillian age.

The youngest *Upper Sandå Group* (presumably of Silurian age) is of restricted distribution. The thick basal conglomerate contains well-sorted material composed dominantly of fragments of Precambrian rocks. The

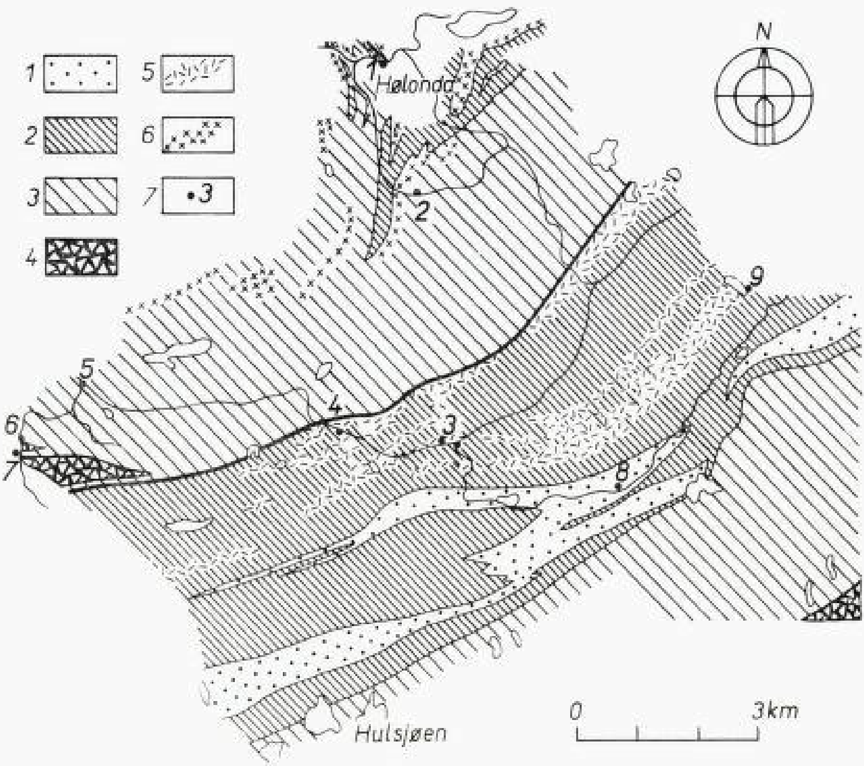

Fig. 15. Distribution of principal stratigraphical units in the Hølonda—Hulsjøen area. 1 – Upper Sandå Group; 2 – Lower Sandå Group, partly folded together with the upper part of the Krokstad Group; 3 – Krokstad Group; 4 – Støren Group; 5 – Rhyolite and rhyolite tuff; 6 – Hølonda porphyrite; 7 – localities on the excursion route.

distinctive nature of this series is made more pronounced by a moderate unconformity between its basal beds and the older formations.

The whole complex displays rapid *facies changes* and locally also striking changes in the thickness of individual beds and even of entire groups. The thickness of the Krokstad Group, for example, decreases markedly in the envelope of the Støren volcanic complex at the western margin of the mapped area. The abrupt change in thickness of the group, however, is not always primary, in some cases being of tectonic origin as evidenced by the dragging out or truncation of beds along thrust planes, increased intensity of folding pattern, or even by differences in the intensity of denudation preceeding the deposition of a new formation.

The unconformable nature of individual groups is generally well marked. The apparent unconformity at the contact of, for instance, slate and conglomerate beds, is invariably attributable to disharmonic folding of the more or less competent rocks. The moderate unconformity of regional scale (particularly of the Upper Sandå Group) is only inferable from an examination of the geological map.

The total thickness of the Ordovician-Silurian sequence overlying the Støren volcanic complex is about 800 m. Th. Vogt estimated the thickness of the same complex to be much greater, at about 2000—3000 m. This discrepancy in estimates is due primarily to the different concepts of the structure (see the chapter on structural geology).

As regards the facies development of the rocks, it should be noted that certain rock sequences show changes of lithology in the north-western and south-eastern parts of the area (Fig. 15). The most striking features are the following: characteristic of the central and south-eastern parts of the area is the predominance of acidic rhyolite volcanism in the upper part of the Krokstad Group, the abundance of volcanic sandstone in the Lower Sandå Group (with a considerable admixture of rhyolitic rocks) and also the limited distribution of the youngest Hovin sandstone formation, a possible result of a primary geographical restriction of the sedimentary area. In contrast, the northern part of the area is distinguished by the common occurrence of more basic intrusive porphyrite bodies, widespread carbonate sedimentation, and a lack of conglomerate beds of any great thickness.

Of interest is the *stratigraphical correlation* of beds with those from other parts of the Trondheim region, especially of the Meråker area, east of Trondheim, which has recently been studied by Fr. Chr. Wolff and his team of co-workers (1967). The correlation shows a good agreement in the general succession of strata, although there are some differences in the facies development and thickness of individual formations. Quite remarkable is the analogy in the lithological composition of the upper part of the Krokstad Group, i.e. of greyish-green slates and sandstones with grit, conglomerate and breccia intercalations, and of intrusive porphyrites with similar rocks (including gabbro-diorite sills), all constituting the Kjølhaugene Group. The lower part of the Krokstad Group, from the basal greenstone conglomerate up to and including amygdaloidal greenstone, can then be a stratigraphical equivalent of the Sulåmo Group of the Meråker area. The Caradocian and tentatively Silurian Lower and Upper Sandå Groups can possibly be correlated to a large extent with the youngest Slågån Group, in the dark slates of which Getz (1890) found graptolites of Llandoverian age (near Kjølhaugen). The differing sedimentary environment of the Meråker area is manifested particularly in the lack of prominent conglomerate horizons in the youngest parts of the Ordovic-Silurian sequence, the paucity of acid volcanics and the absence of marked unconformities.

In concluding, the problem of *diastrophism* will be discussed briefly. In Vogt's opinion (1945) the coarse conglomerates represent important erosional breaks. They have been distinguished as the Trondheim disturbance (Late Skiddavian), the Ekne disturbance (broadly between Caradocian and Ashgillian) and the Horg disturbance (Lower Llandoverian). The new stratigraphical positioning of the formations in the area studied necessitates some modifications in the dating of these orogenic disturbances.

The deposition of the coarse greenstone conglomerate above the Støren volcanic complex was undoubtedly a response to an orogenic movement of great intensity. This conglomerate is the first member of the sedimentary cycle of the Krokstad Group, the sediments of which contain abundant material eroded from this volcanic complex. On account of the palaentological finds, Blake (1962) placed this disturbance roughly at the Tremadocian/Arenigian boundary, although Skevington (1963) and Skevington and Sturt (1967) have challenged this and locate the disturbance actually within the Arenig.

The sudden movements of the land mass were also connected with strong magmatic activity, extrusions of rhyolite lava and tuffs, and probably also porphyrite intrusions; the deposition of coarse-grained sediments and polymict conglomerates in the uppermost parts of the Krokstad Group and at the base of the Lower Sandå Group, close to the Llandeillian/Caradocian boundary, can also be due to orogenic unrest.

The third conspicuous disturbance took place either in the latest Ordovician or earliest Silurian time. It may be postulated that a re-delimitation of the Early Palaeozoic sedimentary basin and the partial erosion of beds underlying the basal quartzite conglomerates of the Upper Sandå Group were associated with this disturbance.

A more precise dating of the extent and effects of the individual orogenic disturbances must await a detailed correlation of the area with other parts of the Norwegian Caledonides.

Remarks on structural geology and metamorphism.

The Early Palaeozoic complex of the present area occurs within the zone of minimum metamorphism in the Trondheim region, the grade of metamorphism not exceeding the lowest chlorite-muscovite subfacies of the greenschist facies. Pelitic sediments with well-developed cleavage surfaces which frequently transect the original bedding, have the character of slates or phyllite slates. Basic volcanics bear the typical mineral assemblages of greenstones. Sedimentary structures, clastic minerals and textures of magmatic rocks are still well preserved.

The various rock types and the slaty cleavage strike predominantly NE—SW to E—W, dipping moderately to steeply to the north-west or south-east. The boundary between the sectors showing opposing dips runs approximately across the middle of the area along the border between the Lower Sandå and the Krokstad Groups, at the northern margin of the northernmost rhyolite belt. This boundary seems to be an important tectonic line, a zone of steep dips, tightly packed folds and numerous thrust faults. It is possible that it may have been one of the paths of ascent for rhyolite extrusions and the site of the striking reduction in the thickness of the Krokstad Group, at least in the west.

The main geological structure of the area, which as yet has not been studied in detail, takes the form of large-scale tight folds overturned either to the SE or to the NW. Individual beds were at first mostly interpreted as separate stratigraphical horizons and the total thickness of the Early Palaeozoic formations above the Støren Group was then estimated at many hundreds of metres (in the area studied by Vogt, about 2000 to 3000 m). Later, on discovering that a number of lithologically identical units join up around tight anticlinal and synclinal closures, it became clear that the geological structure was more complex (Fig. 16). In the author's view the overall structure is interpreted as a series of closely packed tight to isoclinal folds accompanied by shearing and stretching phenomena, which are grouped into extensive anticlinorial and synclinorial belts. This style of folding has much in common with that described by Roberts (1967, 1969) for the north-western part of the Trondheim region. A more detailed analysis of tectonic elements and deformation phases is given in the papers of Carter (1967) and Rutter et al. (1967).

Aerial photographs show that the area is transected by numerous joints and faults, roughly perpendicular to the strike of the beds, but

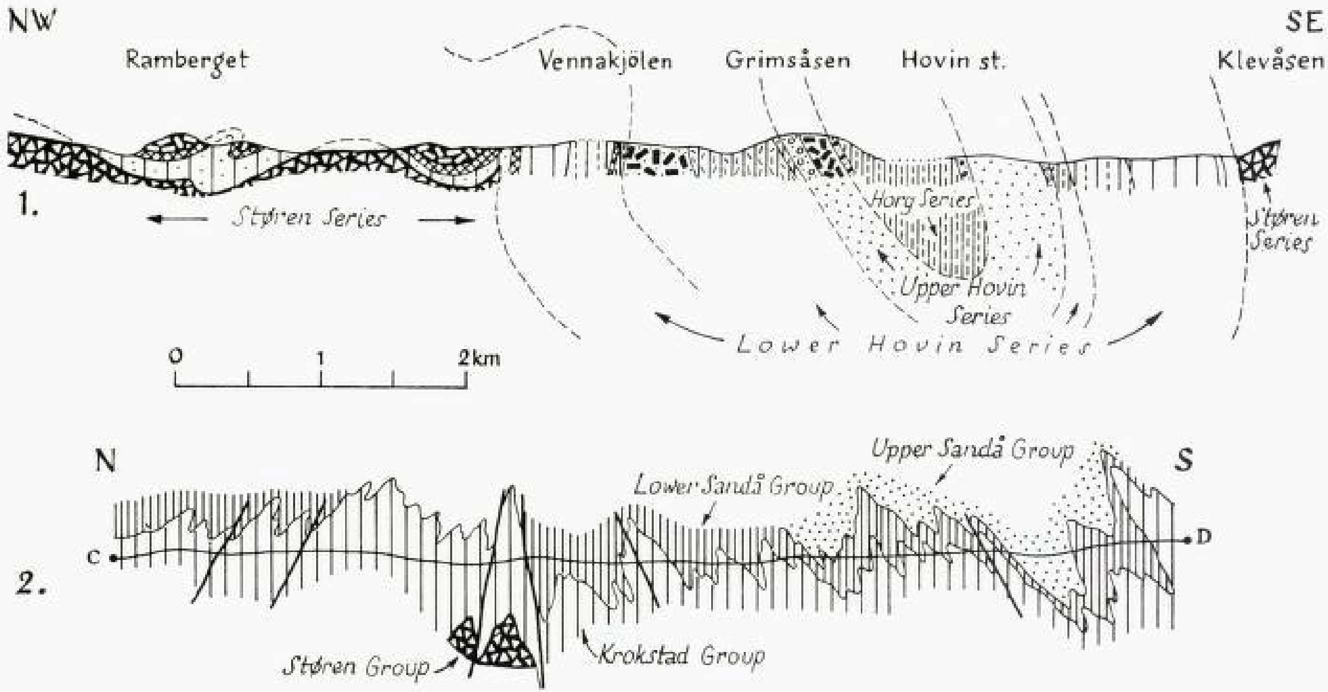

Fig. 16. 1: Geological section through the Hølonda–Horg area constructed from Th. Vogt's (1945) data. For explanation see the geological map. 2: Geological section across the adjacent Hølonda–Hulsjøen area, according to the author. For explanation see fig. 15.

which do not produce any marked lateral offset; these have not therefore been indicated on the map. The only clear-cut fault is located south of Hølonda. The abrupt termination of two strips of the Upper Sandå Group in the heavily drift-covered terrain 3,5 km east of Kleivlykkja can also be interpreted in terms of a fault or a transverse fold structure.

References.

BLAKE, D. H., 1962. A new Lower Ordovician graptolite fauna from the Trondheim region, *Norsk Geol. Tidsskr. 42*, 223—238.

CARSTENS, C. W., 1951. Løkkenfeltets geologi. *Norsk Geol. Tidsskr. 29*, 9—25.

— 1952. Geologisk kart over Løkkenfeltet. Norges Geografiske Oppmåling, 1952.

CARSTENS, H., 1960. Stratigraphy and volcanism of the Trondheimsfjord area, Norway. *Norges Geol. Unders., 212 b.*

CARTER, P., 1967. The geology of an area north of Gåsbakken, Sør-Trøndelag. *Norges Geol. Unders. 247*, 150—161.

GETZ, A., 1890. Graptolitførende skiferzoner i det Trondhjemske. *Nyt Mag. for Nat. Vid.*

CHADWICK, B., BLAKE, D. H., BESWICK, A. E. and ROWLING, J. W., 1963. The geology of the Fjeldheim—Gåsbakken area, Sør-Trøndelag. *Norges Geol. Unders., 223*, 43—60.

CHALOUPSKÝ, J., 1963. Notes on the geology of an area west of Støren (the Trondheim region). *Norges Geol. Unders., 223*, 61—66.

HOLTEDAHL, O., 1960. Geology of Norway. *Norges Geol. Unders., 208.*

JONES, O. T., 1928. Plectambonites and some allied genera. *Mem. Geol. Surv. Gr. Britain, 1, Pt. 5*, 367—527.

KJÆR, J., 1932. The Hovin group in the Trondheim area. With palaeontological contributions by O. A. Høeg, A. Hadding, F. R. C. Reed, A. F. Foerster, T. Strand, L. Størmer and the author. *Norsk Vid. Akad. Skr. No. 4.*

OFTEDAHL, CHR., WOLFF, FR. CHR., and ROBERTS, D., 1969. Excursion guide to the central parts of the Trondheim region. *Norges Geol. Unders.* Unpublished guide. June 1969.

ROBERTS, D., 1967. Structural observations from the Kopperå—Riksgrense area and discussion of the tectonics of Stjørdalen and the N. E. Trondheim region. *Norges Geol. Unders., 245*, 64—122.

— 1968. Tectonic features of an area NE of Hegra, Nord-Trøndelag, and their regional significance. *Norges Geol. Unders., 255*, 10—20.

RUTTER, E. H., CHAPLOW, R. and MATTHEWS, J. E., 1967. The geology of the Løkken area, Sør-Trøndelag. *Norges Geol. Unders. 255*, 21—36.

SKEVINGTON, D., 1963. A note on the age of the Bogo Shale. *Norsk Geol. Tidsskr. 43*, 257—260.

— and STURT, B. A., 1967. Faunal evidence bearing on the age of the late Cambrian—Early Ordovician metamorphism in Britain and Norway. *Nature, 215*, 608—609.

SPJÆLDNES, N., 1957. The Middle Ordovician of the Oslo Region, Norway. 8. Brachiopods of the Suborder Strophomenide. *Norsk Geol. Tidsskr., 37*, 1—214.

STRAND, T., 1949. New trilobites from the Hølonda limestone (Trondheim region, S. Norway). *Norsk Geol. Tidsskr., 27*, 74—88.

VOGT, TH., 1945. The geology of part of the Hølonda—Horg district, a type area in the Trondheim region. *Norsk Geol. Tidsskr., 25*, 449—527.

WOLFF, FR. CHR., 1967. Geology of the Meråker area as a key to the eastern part of the Trondheim region. *Norges Geol. Unders. 245*, 123—146.

Appendix.

One-day excursion to easily accessible localities in the principal formations of the mapped area.

Excursion route: Trondheim—Hølonda—Lundseter—Hovin—Trondheim.

1. A cutting at the sharp bend of the main road, 1 km WSW of Hølonda church. Partly exposed anticline with Hølonda porphyrite in its core. The envelope of the porphyrites is made up of limestone and younger dark slates of the Lower Sandå Group. Scattered porphyrite fragments are present in the limestones.

2. Road-cutting 2,3 km SSW of Hølonda church, in a slightly elevated terrain. Breccia from the lower part of the greyish-green sandstones (upper part of the Krokstad Group). The breccia, with characteristic fragments of red jasper, contains intercalations of greyish-green slate.

3. Road-cutting, 1,5 km NW of Kleivlykkja. Poorly exposed small outcrop, about 300 m WSW of the confluence of the stream flowing out from the Kleivlykkja Lake, with the Skolda river. Polymict conglomerate from the base of the Lower Sandå Group. About 20 m to the north, in a wood, the underlying rhyolite is exposed in outcrops and is also present as abundant boulders. About 100 m south of the confluence of the streams near a broken bridge, dark grey laminated slates of the Lower Sandå Group are exposed in the stream bank.

4. Road-cutting, 1,5 km north of Skara. In a ca. 100 m profile, strongly folded calcareous slates are exposed; these are interbedded with fossiliferous limestones high above the road.

5. Locality, 1,5 km north-west of Lundseter. In the river bottom close to the bridge, near the road junction, beds of greyish-green sandstone and grit interbedded with greyish-green slates are well exposed (upper part of the Krokstad Group).

6. Locality 1750 m west of Lundseter. In the bed of the stream, about 35 m north of the bridge along a side-road, the contact of the Støren greenstone with the basal beds of the Krokstad Group (greyish-green slates, and grey slates at the northern end of the profile) is exposed. At the contact there are several metres of greenish, locally reddish, chert and greenstone conglomerate.

7. About 300 m to the north of locality 6, the first conspicuous outcrop above the road. Typical basal greenstone conglomerate (breccia) at the contact with the Støren greenstone; abundant fragments of greenstone and red jasper and also some limestone.

8. Roadside exposure approximately 1,7 km east of the Kleivlykkja Lake. The boundary of the quartzite conglomerate with the overlying Hovin sandstone, the latter

containing intercalations of dark slates (Upper Sandå Group). A number of exposures of quartzite conglomerate occur in the neighbourhood.

9. Supplementary locality. South-eastern shore of the Lake on the Grimsåsen ridge, 5 km north-east of Kleivlykkja. Basal polymict conglomerate of the Lower Sandå Group, directly overlying the rhyolites and rhyolite tuffs.

Manuscript received May 1970.

Note added in proof: In the legend the stratigraphical subdivisions have been written as «series». These should be amended to «Group».