Geologic and structural studies around two geophysical anomalies in Troms, Northern Norway

by

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Abstract.

The geology and structures of two windows (the Mauken and the Divielva windows, see Fig. 1) are outlined. For the Precambrian supracrustal rocks of the Mauken window, two formation names and one group name are suggested. Hyolithus zone sediments in autochthonous position along the southern margin of the Mauken window show that the Caledonian thrusting exceeded 70 km. In both window structures "Reliefüberschiebung" took place. A magnetic anomaly in the Mauken window is explained by local concentrations of normally accessoric magnetite in an antiformal hinge zone in sericite-chlorite schists. The relations between an E-W directed magnetic anomaly and the structures of the Divielva window are discussed.

Sammenfatning.

De geologiske og strukturelle forhold omkring to vinduer (Mauken og Divielva vinduerne, se Fig. 1) opridses. To formationsnavne og et gruppe-navn bringes i forslag for de prækambriske suprakrustaler i Mauken-vinduet. Fund af Hyolithus zone sedimenter langs sydranden af Mauken-vinduet viser, at den kaledonske overskydning beløb sig til over 70 km. I begge vindue-strukturer fandt reliefoverskydning sted. En magnetisk anomali i Mauken-området for-klares ved koncentration af ellers accessorisk forekommende magnetit i en antiform ombøjningszone i sericit-klorit skifre. Relationen mellem en Ø-V rettet magnetisk anomali og strukturerne i og omkring Divielva-vinduet diskuteres.

List of contents:

Introduction.

Since 1963 SYDVARANGER A/S has conducted systematic prospecting in eastern Troms. This work has embraced geophysical surveying, general prospecting such as "block hunting" and geochemical search for ore in addition to photogeologic and field geologic mapping. The coordination of all these activities and the programming of resulting drilling operations were managed by bergingeniør Andreas Eriksen, Sydvaranger A/S. Mr. Eriksen is cordially thanked for many inspiring discussions.

The writer also wishes to thank Mr. Bruno Rothé, geologist (Syvaranger A/S), fil. lic. Nils Marklund, consulting geologist, and his colleagues and students from Aarhus University, who participated in the work, for their collaboration and permission to draw from their unpublished results. Last, but not least, the writer wants to thank *all* who assisted in and contributed to a successful realisation of the field program.

The first part of this paper deals with the Mauken area and in particular its stratigraphy, structures and their relation to some geophysical anomalies. The Mauken area has also been studied and is still being studied by the director of the Natural Museum of Tromsø, Dr. K. Landmark, who is preparing a comprehensive description including petrographic and chemical data to accompany the geological map of the Målselva area. Our work, however, have been carried out independently and differs in methods and scope.

The writer is indebted to Sydvaranger A/S for the permission to publish this report. He also wishes to express his gratitude to Norges Geologiske Undersøkelse for accepting this paper for publication.

Regional Geology.

In Troms the eastern front of the Scandinavian Caledonides (Strand, 1961, Oftedahl, 1966) crosses the Norwegian territory and the extreme south-eastern part of the district is made up of Precambrian crystalline basement rocks comprising: gabbro, syenite, gneisses and granites. Close to the marginal Caledonian thrust, these basement rocks are nonconformably overlain by a fairly thin cover of fossiliferous Cambrian strata, the so-called Hyolithus zone of the eastern foreland. The overthrust, metamorphic units of the Caledonides rest with a marked tectonic contact on the autochthonous cover; Vogt (1918) and Holtedahl (1953 and 1960).

In Fig. 1 the Precambrian terrain of the eastern foreland is shown together with two tectonic windows inside the Caledonides, where the Precambrian basement rocks (wholly or partly fringed by a thin autochthonous cover of the foreland type) are exposed below the allochthonous units, which owe their
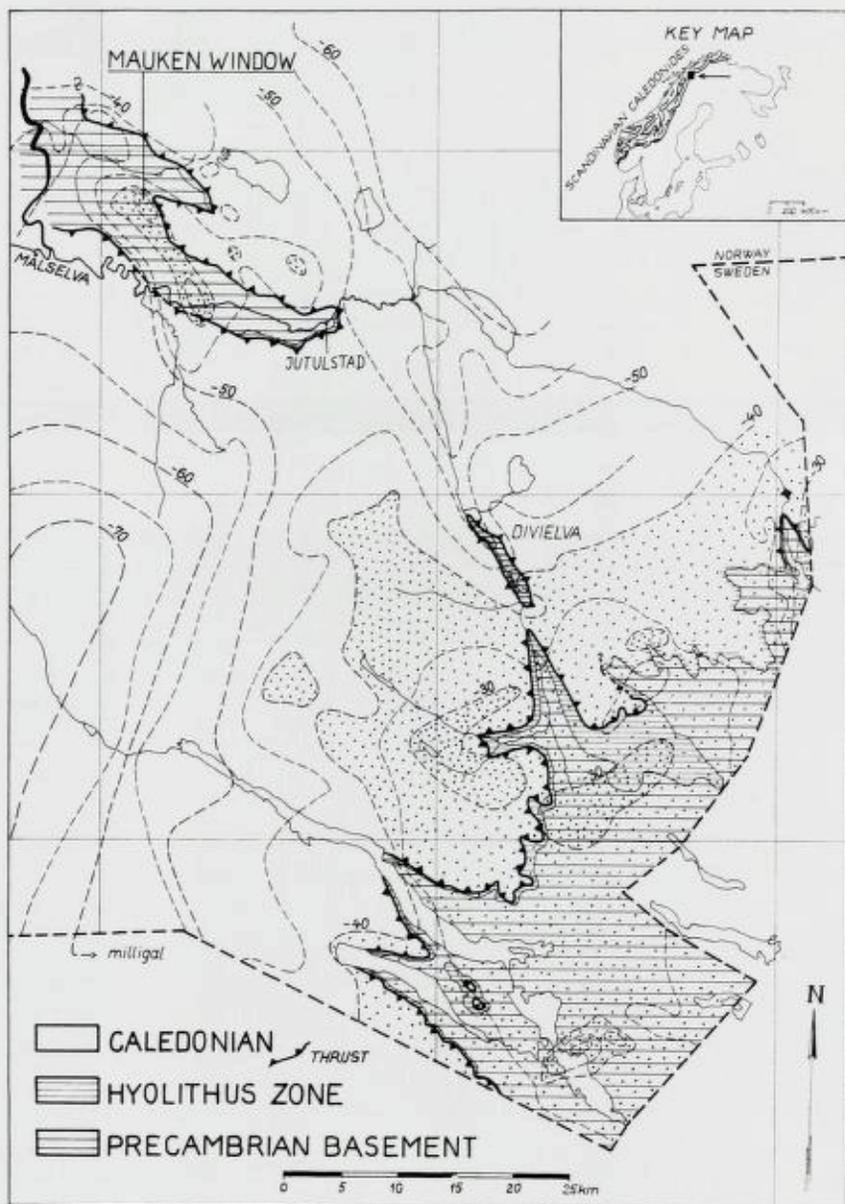
Fig. 1. Sketch map of eastern Troms.

"mise en place" to the Caledonian orogeny. Since these units may include rocks of Precambrian age, they are referred to in the following as the *Caledonian overthrust units*.

The main feature of the gravity field are also shown in Fig. 1. The milligal curves were constructed by bergingeniør Andreas Eriksen, Sydvaranger A/S, from the data supplied by Norges Geografiske Oppmåling. Although no corrections were made, the map clearly shows that the regional gravity field depends on the large scale geologic structures. A pronounced minimum in the south-west corresponds to the depression within the Caledonian thrust masses, and a similar minimum is indicated to the north-east. A gravimetric high extends from the Precambrian foreland area (south-east corner of the map) in a north-western direction, and is clearly accentuated in the Mauken window around Målselva and Takelva, and even the elongated window along Divielva (Gustavson, 1963) influences the anomaly trend.

No doubt, the gravity field betrays a major culmination within the Caledonides caused by a NW-SE directed uplift of Precambrian basement rocks.

The Mauken Window.

The area of the Mauken window is, for its greater part, covered by the geological map (1 : 100.000) published by K. Landmark (1959). Obviously, the idea that Precambrian rocks occur in this region were in Landmark's mind when he drew his map, since in the stratigraphic legend he placed the granodioritic rocks as older than the overthrust units of Stormauken. However, in the geological map accompanying Holtedahl (1960), the granodiorites are shown as Caledonian intrusives.

Photogeological studies and reconnaissance work carried out by the author and his collaborators (1964-65) showed that the Precambrian rocks of the Mauken window are completely surrounded by Caledonian overthrust rocks and that Hyolithus zone rocks occur along the southern and southeastern edge of the window below the basal Caledonian thrust. Gustavson (1966, p. 18 and pp. 47-48) discovered these autochthonous rocks in 1963.

On the spur rising from Alappmo towards Alapp Mt. we found the basal ? Cambrian conglomerate overlying both granodiorite and chlorite schists unconformably. The conglomerate is succeded by dense quartzites grading into grey, partly phyllitic, shales which are in thrust contact with hard-schists and quartzites of the lower "quartzite division" of the Caledonian sequence. Lithologically, the Hyolithus zone rocks of the Mauken area show a close resemblance to the autochthonous rocks found within the southern part of the Divielva window (see p. 70).
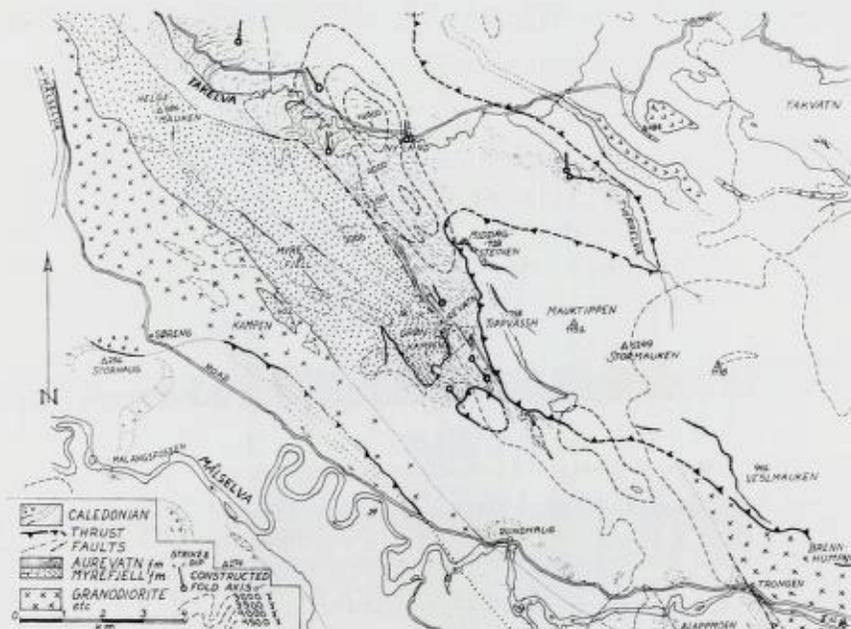
Fig. 2. Geologic sketch map of the Mauken area. Geology from Landmark (1959), Bruno Rothé, J. F. Touborg and the author. Aeromagnetic anomalies from a total intensity survey performed by Compagnie Générale de Géophysique (Paris) on behalf of Sydvaranger A/S. For location of the area see Fig. 1.

East of Jutulstad, the basal Caledonian thrust crosses Målselva and climbs the south-facing slopes of Veslmauken and Stormauken. At Brennhumpan and Veslmauken, the thrust zone, as mapped by Landmark (1959) cuts into Precambrian granodiorite (see also Fig. 2). The two localities offer an illustrative example of a tectonically produced pseudoconformity between basal crystalline and Caledonian overthrust units, the latter including here large masses of reworked Precambrian material.

To the NE and SE of Aurevatn it can be demonstrated that the thrust has sheared off the culmination of a Precambrian antiform. Minor slices of Precambrian supracrustals can be seen in the overlying (transported) units which also contain tectonized and double folded gneisses, e.g. north of Tippvassh (see Fig. 2).

The thrust contact delimiting the Mauken window in the south presumably crosses Målselva east of its cofluence with Kirkeselva, since in the mountain slopes between Rundhaug and Søreng SSW-didpping phyllonites, formed at the expense of the granodiorite, overlie undistrubed granodiorite. Further

west, the window border appears on the north side of Storhaugen in a steep, or almost vertical (?faulted), position. The granodiorite reported by Landmark (1959) at Malangsfossen (south of Storhaugen) was not observed by the author. Along the south bank of Målselva, at Malangsfossen, conglomeratic limestones forming part of the Caledonian sequence were seen.

The Hyolithus zone rocks which so far could be traced only along the southern and south-eastern edge of the window, occur, so to say, on the lee side of the window structure, when seen in relation to the Caledonian direction of tectonic transport (NW→SE).

The discovery of the Hyolithus zone rocks in an autochthonous position at the said localities, yields evidence for a Caledonian overthrusting (or underthrusting) totalling more than 70 km (see Fig. 1). The thrusting within this part of the Caledonides can also be described as a kind of "Reliefüberschiebung" since the Precambrian rocks of the window evidently formed a topographic high prior to the thrusting.

Moreover, the Mauken window forms an interesting stepping stone between the Rombak window in the south and the windows of Finmarka in the north.

The Precambrian rocks of the Mauken window.

The Precambrian rocks of the Mauken window form four major units: *The Myrefjell formation* (metavolcanics with intermixed and intercalated metasediments), *the Aurevatn formation* (feldspatic and micaceous quartzites, subordinate calcareous rocks, sericite and chlorite schists), *the Øverbygd crystalline complex* (intrusive granodiorite, gneiss and migmatite, metabasaltic rocks and gabbro), and *the Kampen granodiorite* (massive to foliated granodiorite with a few relics of gneiss).

The supracrustal rocks of the Myrefjell and the Aurevatn formations form a 5-10 km broad SE-NW trending belt flanked on both sides by infracrustal rocks, i.e. the Kampen granodiorite to the south-west and the Øverbygd complex to the east.

Although no direct connection exist between the Kampen granodiorite and the similar rocks of the Øverbygd complex, the assumption can be made that the granodioritic rocks on both sides of the supracrustal belt are of the same age. Landmark (1959) has chosen this point of view. There are, however, some differences between the two regions of infracrustal rocks. While the Kampen granodiorite is mostly made up of fairly homogenous type, the Øverbygd complex, in addition to such types, consists also of grey, banded gneisses and migmatites. The occurrence of amphibolitized and deformed metabasaltic dykes within the gneisses also indicates a more complex history of the Øverbygd

rocks. In the new road cuts north-east of Jutulstad and south of Målselva, the Øverbygd granodiorite is seen to intrude and partly assimilate a minor body of biotite-gabbro. Along the same road, the granodiorites, gneisses and migmatites can also be seen forming a SE-plunging antiform, the nose of which is eroded by the stream joining Målselva at Jutulstad.

K. Landmarks correlation of the granodioritic rocks of the Kampen and Øverbygdas area is supported by the fact that both granodiorites show intrusive relations to the separating belt of supracrustals. The Kampen granodiorite intrudes the Myrefjell formation, e.g. on the 602 m hill north-east of Kampen where a more than one kilometer long enclave of Myrefjell metavolcanics is enclosed by granodiorite. In a low road cut leading to Rundhaug from the west, the original intrusive character of the granodiorite (against amphibolitic greenstone) is also preserved. More often, however, the contact runs parallel to the banding, or foliation, shown by the metavolcanic rocks and has in many places been subjected to postintrusive shearing.

The contact between the Øverbygd complex and the rocks of the central supracrustal belt is well exposed along the roads both north of Målselva (at Trongen) and south of this river (the road turnings east of Alappmoen), where a steeply dipping fault separates the two rock units. This fault can be traced southwards along the spur rising towards Alapp Mt. On the south part of this spur supracrustal rocks (chlorite schists) also appear east of the fault and are here intruded by the Øverbygd granodiorite, which contains schist xenoliths. The basal conglomerate of the Hyolithus zone overlies both schists and granodiorite nonconformably.

The Myrefjell formation.

The name, the Myrefjell formation, is suggested for a sequence of generally steeply dipping, mainly metavolcanic rocks (the Mauken amphibolite of Landmark (1959). The metavolcanics are mixed with sedimentary material which occurs also as separate layers of minor thickness. The predominant rock types are epidote-amphibolites and epidotic greenstones. Relic pillow structures (e.g. due north-west of Myrefjell), graded tuff bedding (north-west of Aurevatn) and flow structures (as in the gorge SW of Grønkampen) all suggest an extrusive, or effusive, origin of the metavolcanics. The intercalated metasediments, which usually dip as steeply as the amphibolites and greenstones, represent originally fairly pure carbonate and arenaceous sediments. At one locality, a quartz-banded iron ore was found in a quartzite bed. In thin section, the tuffogenic metavolcanics are seen to contain notable amounts of terrigenic detritus.

Since repetition on a larger scale may well occur in the Myrefjell rocks, their true thickness is difficult to estimate. With a dip of 70°, or steeper, the formation measures more than 3 km.

The rocks of the Myrefjell fm are generally in faulted contact with the rocks of the Aurevatn formation. Only south and west of Grønkampen normal contacts are found (see p. 66).

The Aurevatn formation.

The term the Aurevatn formation is suggested as a collective name for the metasedimentary and, probably, mixed metasedimentary and metavolcanic rocks that make up an overturned (to recumbent) antiform, which culminates just south of Aurevatn and plunges northerly under Takelva. The lowermost and ?oldest) rocks exposed around and just south of Aurevatn are mainly compact feldspatic and schistose micaceous quartzites. Then follows a sequence of sericite-chlorite schists, which in the overturned (western) flank of the antiform are sheared and reduced in thickness, but which form a thicker succession of mainly lens-structured chlorite schists in the upper flank of the structure. On both flanks it often contains considerable amounts (5-10 %) of disseminated magnetite which may be concentrated in cm thick bands in hinges of local folds. NE of Aurevatn a thin layer of dark, rusty graphite schists is found in the chlorite schists.

A little further north-east of Aurevatn these rocks are directly overridden by the Caledonian thrust masses, and due east of Aurevatn, the basal thrust cuts into the quartzites occupying the core of the antiform.

North of Aurevatn, the sheared, magnetite-bearing chlorite schists in the western flank of the antiform are underlain by a thin limestone bed and sericite schists, which downwards (? stratigraphically upwards) become calcareous.

South of Aurevatn calcareous schists overlie the Myrefjell metavolcanics in the east flank of the hill 675 m south-east of Grønkampen. These calcareaus schists may be correlated with the calcareous sericite schists found north of Aurevatn.

The described succession from the lower flank of the antiform is also developed around its closure and in its upper flank in Takelva valley, where the different members attain considerably greater thicknesses. The limestones mapped by Landmark (1959) at Soleng (lower Takelva valley, just outside the area of Fig. 2) thus represent an antiformal hinge zone concentration of the mentioned topmost calcareous strata of the structure.

The chlorite schist and other mafic rocks of the Aurevatn fm are wholly

or partly of volcanic origin. In fact, it is often difficult to distinguish hand specimens of the highly sheared Myrefjell metavolcanics from those of the chlorite schists of the Aurevatn fm, just as it is difficult to distinguish between the Aurevatn feldspatic schists and quartzites on one side and the mylonitic rocks of the overthrust unit on the other side. As for both problems, structural mapping affords the only solution (see Fig. 2).

Concerning the age relations between the Myrefjell formation and the Aurevatn formation, the evidence is conflicting. The faulted contact between the two formations (from Aurevatn to lower Takelva) might create the impression that the Aurevatn rocks, due to their lesser dips, originally rested unconformably on top of the Myrefjell rocks. This situation is actually seen south of Grønkampen, where the quartzites of the Aurevatn fm lie with low dips (about 10° to ESE) on top of greenstones belonging to the Myrefjell fm, which dip vertically and strike at almost right angle to the quartzite. Sills of greenstone have, however, been encountered within the Aurevatn quartzites and in these sills traverse cleavage and foliation may be seen. Along the upper course of a stream west of Grønkampen graphitic dark slates and calcareous phyllite apparently underlie the Myrefjell metavolcanics and show very low dips in contrast to the steep structures of the overlying metavolcanics. Poor exposures and insufficient field work render it difficult to interpret the stratigraphic relations here. The steep fold axes found in the Myrefjell rocks could be explained as having been formed along with flexuring which accompanied later faulting, and, therefore, these axes can not be used as safe evidence that that the Myrefjell rocks were deformed before the deposition of the Aurevatn formation.

Because of a lack of evidence to the contrary, and due to the occurrence of metabasic rocks within both formations, it might be advisable to group the Myrefjell fm and the Aurevatn fm together and consider them belonging to one larger unit, for which we suggest the term the *Målselva group*. Thus, the Målselva group includes all the Precambrian supracrustal rocks, forming a belt in a SE-NW direction and extending throughout the Mauken window from Alappmo in SE to the lower Takelva valley in NW.

The supracrustal rocks occurring around Alappmoen could also conveniently be ascribed to the Målselva group, since their correlation with either the Myrefjell or the Aurevatn fms remains somewhat uncertain. They comprise epidotic greenstone, lens- structured chlorite schists and subordinate calcareous layers. At Målselva layers of magnetite ore also occur locally. They are exposed on a small peninsula on the south bank of the river, due NW of Alappmoen.

These occurrences are of no economic value. At Alappmoen and also north of Målselva saussurite-gabbro has been met with. It is not known whether this rock type is of Caledonian or Precambrian age.

Structural control of the Nyland anomaly.

The reason that geological reconnaissance and structural mapping was started within the area of the Mauken window was the discovery of a distinct aeromagnetic anomaly during the systematic geophysical prospecting conducted in the summer of 1963. Comparisons between the NNW-SSE trend of this anomaly and the general NW-SE strike of the formations mapped by Landmark (1959) indicated a "hidden cause" for the anomaly and focussed interest on it, even if its magnitude is not exceptional. Photogeologic studies were made made before the field season of 1964, and soon after the start of the field work it became obvious that the main anomaly (around Nyland, see Fig. 2) could be related directly to a structural element, i.e. the axis of an overturned to recumbent antiform, made up of the rocks now grouped as the Aurevatn fm. The existence of this structure was first proved when its hinge zone around Takelva west of Nyland was mapped. Since the axial plunge was greater than the slopes of the mountains south of Takelva, it could be predicted that the subsurface rocks of the main anomaly region at Nyland would appear on the mountain plateau around Aurevatn. The main emphasis, therefore, was placed on the study of this plateau. The discovery of magnetite-bearing sericite and chlorite schists (which, when crushed, reacted strongly to a hand magnet) both within the lower and upper flank of the antiform left little doubt that the Nyland anomaly should be explained by a slightly higher magnetite content in the schists of the plunging nose of the antiform. Thus, neither the rock association nor the size of the anomaly left much hope for finding ore deposits of economic interest, and, consequently, prospecting was abandoned.

From Fig. 2, where the principal results of the aeromagnetic survey and the geologic mapping are shown, it is also clear that the values over 3500 gamma were obtained only above supracrustal rocks and especially above rocks of the Aurevatn fm.

The Nyland anomaly may serve as an example of a "discordant" anomaly caused by thickening and concentration of magnetite-bearing rock members along the axis of an overturned to recumbent antiform. As shown in Fig. 2, there exists a close parallelism between the anomaly direction and the axial trend. The fold axes shown in Fig. 2 were constructed from foliation poles.

The Divielva window.

During the regional aeromagnetic survey referred to above, a small, but conspicuous anomaly was also found west of the Precambrian window in Dividal. This so-called Frihetsli anomaly was checked in 1965 by means of a geophysical ground survey and geologic field work. Ultimately, a drilling was performed in order to verify the interpretation thus obtained.

The main purpose of the geologic field work was to assist the geophysicists in chosing the right model for further interpretation and calculation, and to arrive at an estimate of the depth to the Precambrian basement below the planned site of a drill hole.

Since the anomaly maximum lies due west of the exposed Precambrian rocks, its cause could be sought either within the overthrust Caledonian rocks or in the underlying Precambrian rocks. A detailed mapping of the overthrust rocks of the anomaly area and of the Precambrian exposures was undertaken, and the autochthonous rocks of the Hyolithus zone were studied as well. This work was greatly facilitated by the grid established for the geophysical ground survey and by air photographs kindly placed at our disposal by the Forestry Department of Troms.

The Precambrian basement rocks.

As mentioned by Vogt (1918) and more recently by Gustavson (1963), Precambrian crystalline rocks and Cambrian sedimentary rocks of the Hyolithus zone outcrop along Divielva in an elongated window. Gustavson (1963) mentions two windows, but strictly speaking there is only one window with two inliers. Since these earlier works contain conflicting results, a redescription of the Divielva window will be given along with the presentation of the structural data. The southernmost and the largest area of Precambrian rocks here called the Frihetsli inlier, is found on the east side of the Divielva around the lower courses of Kleivbekken and Kvernelva, where good sections in the NW-striking basement rocks are seen. Additional exposures are found along a small stream north of Kleivbekken, along the road to Frihetsli and scattered within the forest, which largely grows on morainic deposits.

The predominant rock type of the Frihetsli inlier is a medium-grained, pink gneiss of almost aplitic composition. In the Kvernelva section, it contains layers and lenticles of fine-grained amphibolite, which, like the gneiss, is transsected by slightly discordant pegmatites (usually a few tens of cm thick). The amphibolites may represent folded and metamorphosed basic intrusives (Pettersen, 1874). In the gneisses along Kvernelva, metre-large enclaves and lenticles of talc-tremolite ultramafics also occur. Neither the amphibolites nor
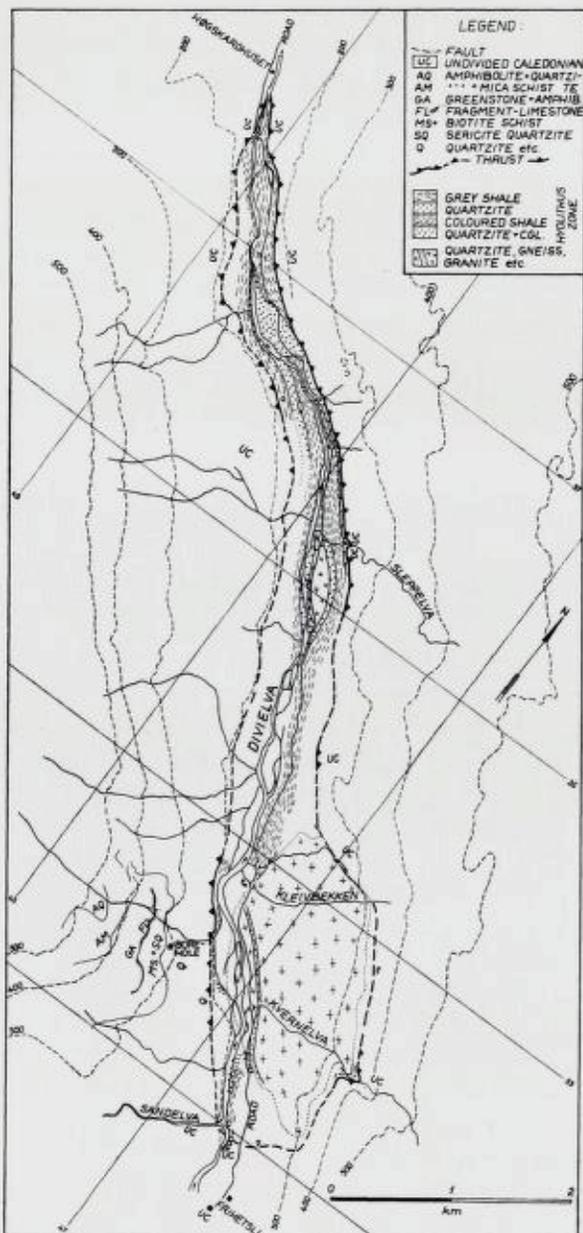
Fig. 3. Geologic sketch map of the Divielva window. Due to scale, the quartzites below and above the coloured shales are not differentiated (cfr. Fig. 4).

the ultramafics contain ferro-magnetic minerals in appreciable amounts and both rock types are quantatively of little importance.

The only mappable member in the basement rocks of the Frihetsli inlier is an, at least 10 metre broad belt of synformally downfolded and lineated, feldspatic quartzites. Thin layers of biotite gneiss also occur in the quartzite belt. The feldspars of the quartzite (up to 10 %) are often whitish weathered, but a similar weathering is also met with in the gneisses and pegmatites in exposures lying close to or representing the sub-Cambrian surface on which the rocks of the Hyolithus zone vere originally laid down. Gustavson (1963) correctly attributed a late Precambrian age to this weathering.

The Precambrian rocks of the northerly Sleppelva inlier are made up of homogeneous pink gneisses and granitic rocks.

The rocks of Frihetsli inlier show a general NW strike and moderate SW dips. Small folds, development of lineation and a slight curvature of strike make possible a construction of the fold axis (see diagram I of Fig. 6). The plunge of 25° at 308° is, however, only representative of the norternmost part of the inlier. Towards the south-east the axis assumes a horizontal position, and it shows a weak SE plunge at Kvernelva.

The means that neither the strike nor the axial trend concur with the general EW trend of the neighbouring anomaly. Thus none of the exposed rocks extend — along their strike or down their axis — into the anomaly area. Therefore, a study of the joint directions in the basement rocks was undertaken. Most joints proved to be cross joints (following the ac plane). They showed sporadic coatings of pyrite. Another well developed system strikes NW and dips at moderate to low angles to NE. Coatings with hematite and locally also epidote are found along this system. No joint system, however, parallels the EW trend of the anomaly.

Supposing that the magnetic anomaly is caused by rocks forming part of the buried basement rocks west of the window, it can be deduced that the anomaly-causing body shows discordant relations to its surroundings.

The Hyolithus zone.

The distribution of the various rock members of the Hyolithus zone is shown in Fig. 3 and the stratigraphic relations are illustrated in the diagrammatic profile of Fig. 4.

The Hyolithus zone generally starts with a basal (?Cambrian) conglomerate and quartzites. The basal conglomerate contains rounded pebbles of quartz and, sometimes, also of quartz intergrown with feldspar as in pegmatite. The feldspar grains of these pebbles are whitish weathered. The basal quartzite
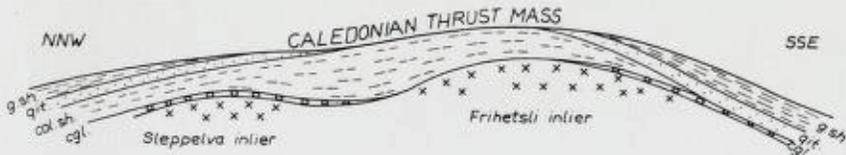
Fig. 4. Diagrammatic profile through the Divielva window.

itself now weathers light brownish but is light greenish to grey when fresh. It is often cut by a system of quartz-filled joints. The basal conglomerate and quartzites are overlain by coloured (red to green) shales except for the southernmost part of the window where the coloured shales are missing. In the bore hole west of the Frihetsli inlier, the coloured shales rest directly on the Precambrian basement. Similar shales are well exposed along the road between Kleivbekken and Sleppelva, showing in places traverse cleavage, which dips steeper to the WSW than the bedding. Folding of the originally vertical joint planes was also noticed in several road cuts.

In the southernmost part of the window (i.e. along the eastern bank of Divielva, north and south of Kvernelva), the basal conglomerate and quartzites are overlain by darkbluish quartzites or sandstones of gritty appearance (due to recent weathering of scattered pyrite grains?). This bluish quartzite is correlated with the more light-coloured and banded quartzites which further north overlie the coloured shales. In the south, the dark bluish quartzite is succeeded by dark shales which upwards become more light-grey. Both the quartzites and the grey shales are folded into a syncline, which is overturned to the SW. Its axis plunges about 10° at 299° (see diagram II of Fig. 6). The grey shales attain a phyllitic appearance and may enclose a few metre large lenticles of chlorite schists in their top parts. The grey shales were not differentiated by Gustavson (1963), according to whom the quartzites (at Sleppelva) are in direct contact with the overthrust Caledonian masses. Gustavson (1963) estimated the thickness of the Hyolithus zone at Sleppelva to 75-80 m. Vogt (1918) mentioned that it varies from a few to hundred metres within the window.

Since in the southern part of the window the present topographic surface lies close to the sub-Cambrian level of erosion, weathering and deposition, it is possible to draw a contour map of this depositional plane. The contours represent the horizon separating the weathered basement and the basal conglomerates. The map (Fig. 5) shows a gentle culmination within a generally WSW dipping surface. In the eastern part of the Frihetsli inlier the basement reaches altitudes of more than 300 metre as mentioned by Vogt (1918), but
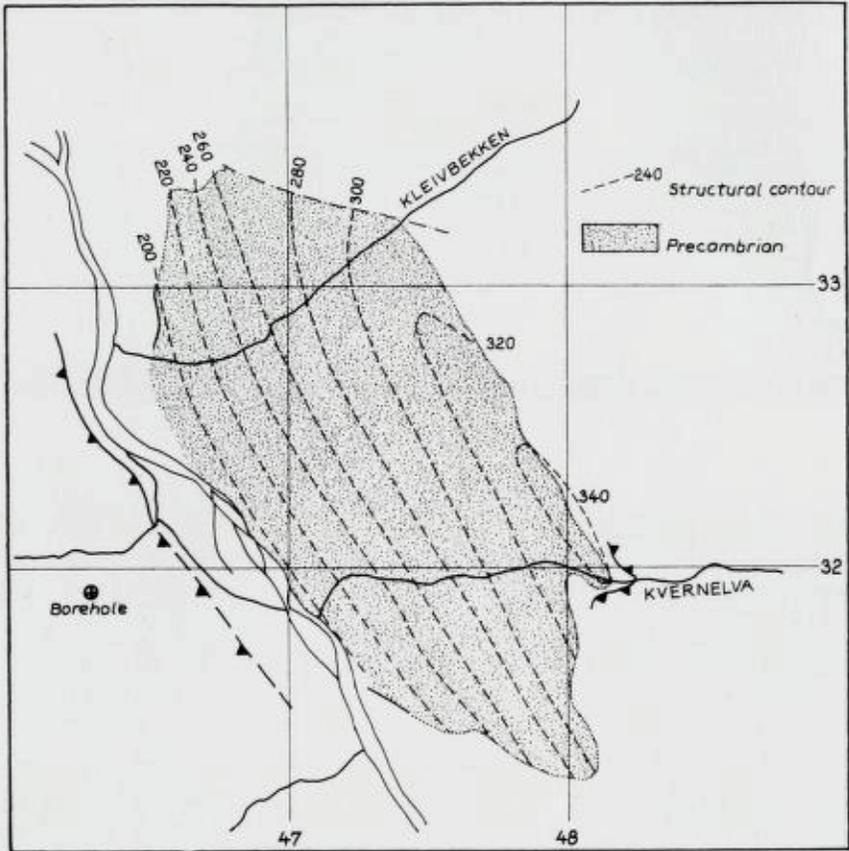
Fig. 5. Contour map of the sub-Cambrian surface (Frihetsli inlier). The borehole is showed by a cross within a circle.

doubted by Gustavson (1963). The depth to the Precambrian rocks at the bore hole site west of the Frihetsli inlier was estimated by assuming that the dip of the sub-Cambrian surface remained constant. This estimate proved surprisingly correct.

The general WSW dip of the sub-Cambrian surface around Divielva is a result of a larger basement uplift, which must be limited to the ENE by a fault or a flexure.

Returning to the diagrammatic section of Fig. 4, it may be pointed out that the slight culminations shown by the Sleppelva and Frihetsli inliers do not show any direct relation to the observed wedging out of the coloured shales of the Hyolithus zone. Rather, it seems that increased uplift corresponds to an

originally greater thickness of the autochthonous cover rocks. The way in which the Caledonian thrust cuts off different sedimentary units in various parts of the window, indicates that the uplift took place prior to the thrusting, as advocated by Gustavson (1963) and already mentioned by Vogt (1918). The folding noticed within the rocks of the Hyolithus zone just south of the Frihetsli inlier may have been controled by pre-existing basement structures and may predate the overthrusting because of its opposite directed "Vergenz".

The allochthonous rocks and their structures.

Within the anomaly area, which was mapped in 1 : 10.000, the following rock sequence was found above the basal Caledonian thrust:

Table.

Structurally highest:
(legend in Figs. 3
and 7)

AQ	$>$ 400 metres of massive to schistose amphibolite (of intrusive origin) and white quartzites.
AM	about 150 metres of massive to schistose amphibolite (of intrusive origin) with thin layers of biotite schists and a discontinuous layer of graphite-bearing biotite schists at the base.
GA	about 150 metres of banded greenstones grading upwards into amphibolitic schists (of probable effusive origin).
FL	0.5-3 m of limestone with slump (?) structures.
MS + ...	about 10 metres of coarse-grained biotite schists.
SQ + ...	about 150 metres of the "quartzite division" embracing (from top to bottom): sericite quartzites, dense and
Q	banded quartzites or intensively mylonitized rocks, a discontinuous horizon of calcareous, pyritic dark schists, and at the base, dark quartzites.

— — — — — — — — — basal Caledonian thrust — — — — — — —
Hyolithus zone.

The only unit of this sequence which will be given closer attention is the limestone layer (FL of Fig. 7). This unit, particularly in its lower part, carries fragments of varying size and shape. Some fragments are rounded to ellipsoidal, whereas others are angular. Usually they occur irregularly scattered in the limestone, but in some cases they are concentrated along bedding planes giving rise to gritty laminae. Several rock types may be identified among the fragments: biotite gneiss and granite, tremolite ultramafics, rock quartz, as well as quartzites and rusty, coarse-grained, biotite schists. Except for the quartzites and biotite schists which are very similar to some rocks in the underlying Caledonian units, the rock fragments were obviously derived from a pre-Caledonian basement, i.e. a Precambrian crystalline complex of a composition astonishingly similar to that of the Frihetsli inlier. The limestone layer is generally light to bluish grey and may be somewhat silicified in its top part. It often shows intricate folding highly reminiscent of slump structures. It might, however, be difficult to distinguish such structures from those caused by Caledonian stresses in an incompetent layer. The writer is inclined to interpret the limestone layer as either a conglomeratic deposit or an agglomeratic calcituffite. The occurrence of metavolcanics (of ?effusive origin) on top of the limestone could be taken as a support for the last-mentioned way of origin.

The lowermost portion of the "quartzite division" (i.e. the portion below the sericite quartzites) shows a constant strike (Fig. 7). The higher units take the shape of a west-plunging syncline accompanied by disharmonic folding on a smaller scale. As shown in Figs. 6 and 7 the plunge of the synclinal axis decreases in the higher units. The stereograms V and VI (Fig. 6) compiled from readings taken within the amphibolites of intrusive origin also show a wider scatter of the foliation poles. The seemingly complex pole distribution of stereogram V is due to the interference between the W-plunging synclinal axis and a SW-plunging axis.

Several of the smaller structures in the major syncline have given rise to local and rather insignificant pyrrhotite mineralisations in the anticlinal hinges. These small concentrations explain fully the local anomalies superimposed on the major anomaly pattern.   .

The general westward plunge of the major synclinal axis seemingly fits well in the E-W trend of the magnetic anomaly (Fig 7). This parallelism, however, is by chance. Apart from the above mentioned local pyrrhotite concentrations in small anticlinal hinges, no traces of mineralisation were found within the overthrust rocks of the anomaly area, and the major syncline itself appears to have exerted a rather negative structural control on possible mineralisation.
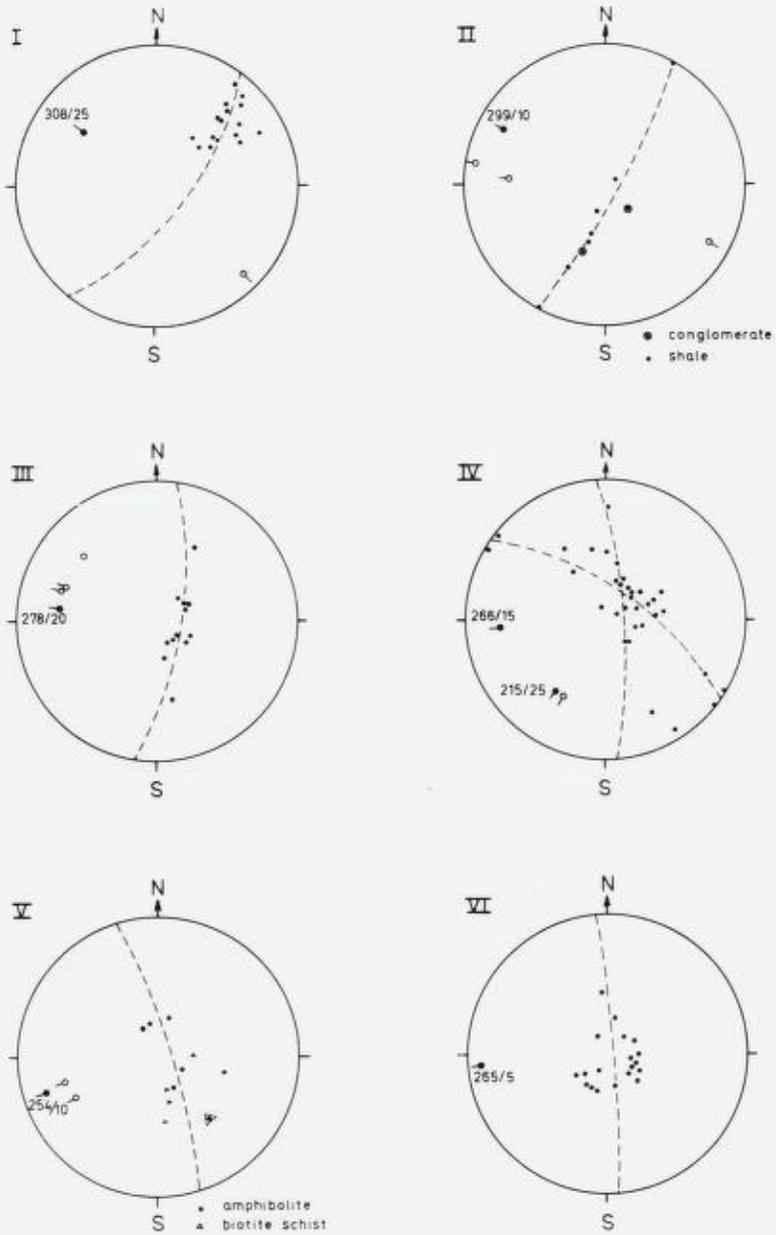
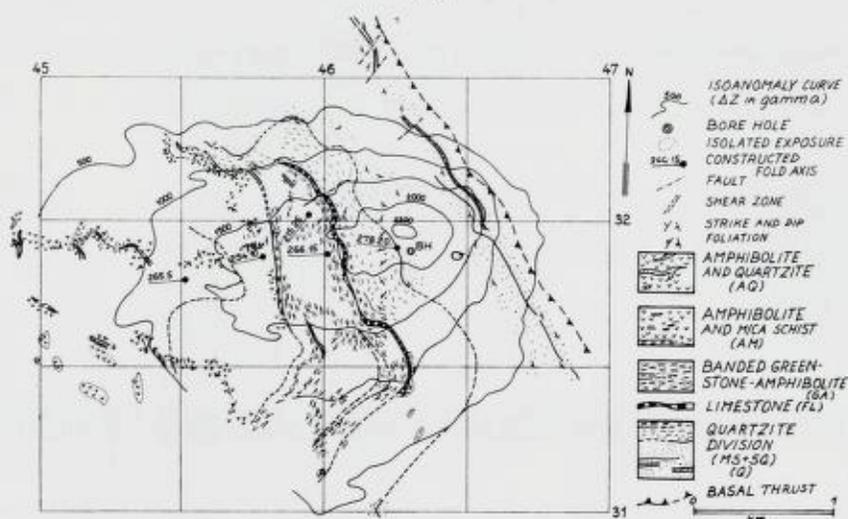Fig. 6. Structures of the rocks of the Frihetsli area.

Fig. 7. The Frihetsli magnetic anomaly. Isoanomaly curves ($\triangle Z$) from a ground survey performed in 1965 by ABEM (Stockholm) on behalf of Sydvaranger A/S. Geology by the author.

Now, after the boring has been drilled, and the cause of the anomaly is known to be a gabbro body forming part of the Precambrian basement, these arguments naturally gain in strength!

The upwards (and westwards) decrease in plunge in the major syncline suggests the presence of an axial flexure. In addition to the attempt to estimate the depth to the basement below the site of the planned bore-hole by means of the known dip of the near-by exposed sub-Cambrian peneplane (see Fig. 5), an attempt was made to use the structures in the overthrust masses. In an E-W profile (including the bore-hole) the basal thrust was thus extrapolated below the mountains west of Divielva, the thrust plane being drawn parallel to the assumed flexured axes in the overthrust masses. The estimate thus made showed to be way too big. The plunge variations, therefore, can now be explained as being due to the formation of imbricate structures within the overthrust masses in response to the obstacle presented by the uplifted basement rocks further to the east.

Concluding remarks.

The two examples described were chosen for publication not only because of their geological interest, but also because they show how geophysical and structural methods can supplement each other. The structural as well as compositional disharmony between 1) the Precambrian basement, 2) its autoch-

thonous cover, and 3) the Caledonian thrust masses resulted in superimposition of internally complex geophysical effects which can only be interpreted satisfactorily once the tectonics of the region are known. In those cases, however, where multiple geophysical methods alone permit a definite conclusion, structural geologists might benefit from the models thus established.

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