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Tittel
"Geology in the Høydal district" og
"Volcano-strtatigraphy and Volcanism in the Høydal Area, Central Norway"

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Sammendrag

Ei HORIKOSHI

Hbidal

J.L.

E. Horikoshi:

GEOLOGY IN THE HÖYDAL DISTRICT

The Hoydal area is about 70 km southeast of Trondheim and about 3 km east of the active Lokken mine. The Green Rocks called the Stören formation are eastwesterly distributed in the Hoydal area. The clastic sediments called the Hovin formation, Lower Ordovician age, dips about 70° in the southern outcrops and consists of conglomerate, sandstone and shale from the north to the south, although it shows the facies changes along the strike. The fragments in conglomerate consist exclusively of basalt and red chert, almost of which are certainly derived from the Stören formation. These geological features indicate well the existence of inverted structure. To the north the Stören formation becomes rather weak in dip. Several antiforms and synforms appear eastwesterly in the northern part of this area. Further northward the Stören formation dips southward and becomes vertical in the northernmost part. They form as a whole a large synform structure. The whole rocks were metamorphosed to the chlorite facies as a result of the Caledonian orogeny. The deformation, nevertheless, progresses northward. Hence, in the northernmost part, it is very difficult to distinguish conglomerate from brecciated pillow lava, if the conglomerate does not contain any fragments of red chert. It seems likely, however, that conglomerate in the Hovin formation comes up again in the northernmost part of this area.

The Stören formation has been described as a single rock unit before, except for gabbro distinguished as an intrusive from ordinary basaltic rocks. The field work was intended to classify the Green Rocks into many cooling units, if possible. The Stören formation is intercalated with pyroclastics and thin chemical sediments such as red chert, siderite and pyritiferous stilpnomelane-quartz beds. These were regarded as the efficient key ones to divide the formation into many beds. It was noticed in the early step of the investigation that each single unit of basalt shows vertically a definite succession in its textural change: massive at the bottom and pillowy at the top. Thus, there could be the boundary of two units between massive and

pillowy basalts, even if no chemical sediment occurs. In fact, the chemical sediments appear and thin out along these textural boundaries. By this way the stratigraphic succession of the Stören volcanics in the Hüydal district was elucidated enough to consider the mode of eruptions.

The Stören formation is divided into three members: Lower, Middle, and Upper ones. The Lower member consists of pillow lava, small pillow breccia lava and red chert. Pyritiferous stilpnomelane-quartz bed is scarcely found. Each single bed of volcanics is less than 150 m in thickness except for only one bed, on which the strata-bound type deposit in the Amot mine occurs. This thick bed comes out in the middle part and becomes thicker eastward. Its real thickness is not measurable, because it is distributed along the axial part of the synform. It is presumably more than 1 km. Well-developed pillow texture is characteristic of it.

The Middle member consists exclusively of a thick basalt lava with several overlying basalt beds which is more than 2 km thick. Its thickness increases more westward up to 3 km. in the outside mapped area, while it decreases eastward to 1.5 lm. The pillowy part fringes the upper margin, less than 100 m in thickness, but also appears scarcely inside this unit. Three separate gabbroic facies appear near the lower boundary in this bed, although the map shows only one of them, and never cross the boundary. It grades gradually into the fine grained basalt. The great thickness, the paucity of pillow texture and gabbroic facies are characteristic of this member.

Basalt beds in the Upper member is less than 200 m in thickness. Each bed is very variable in the texture. The mud flow-like sediment is the lowest one. It consists of bleached and hematitized basaltic fragments and red chert ones. The second lowest bed is tuff breccia, which displays well the graded bedding. The rest of beds show a definite tendency in their textural variation from lower beds to upper ones. The lower beds are generally more pillowy, while the upper beds are more massive and coarse grained. The pillowy beds are intercalated with

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The sulfide deposits in the Höydal open pit occur at the top of the Middle member. The underlying pillow lava becomes smaller in its size upward and siliceous. Sulfide facies grade downward into the' siliceous sediments and is overlain by the oxide facies, red chert, covered by mud-flow like sediments, in the Upper Stören formation.

We might be able to learn something about the strata-bound deposits of gabbro affinity through the geology of the Höydal area. Gabbroic facies is not an intrusive origin, but represents the slow cooling part of a gigantic lava flow. There is another evidence to prove the existence of such a gigantic lava flow, more than 3 km thick. The pyroclastics would not give rise at the bottom of the deep sea because of the high hydrostatic pressure. The first generation of pyroclastics in the Höydal area followed the pouring of a possible thick lava flow. It seems likely that the deep sea in the initial stage of the Stören formation was mostly filled up by a huge extrusion of basalt and most probably the thick basaltic pile appeared in part above the sea at the time. Fragments in the Hovin conglomerate might have been derived partly from the terrestrial lava flow, although the fragments of pillow lava are common in conglomerate. There is a big possibility that the mineral deposits in Höydal and even Lökken were formed under the shallow sea environment.

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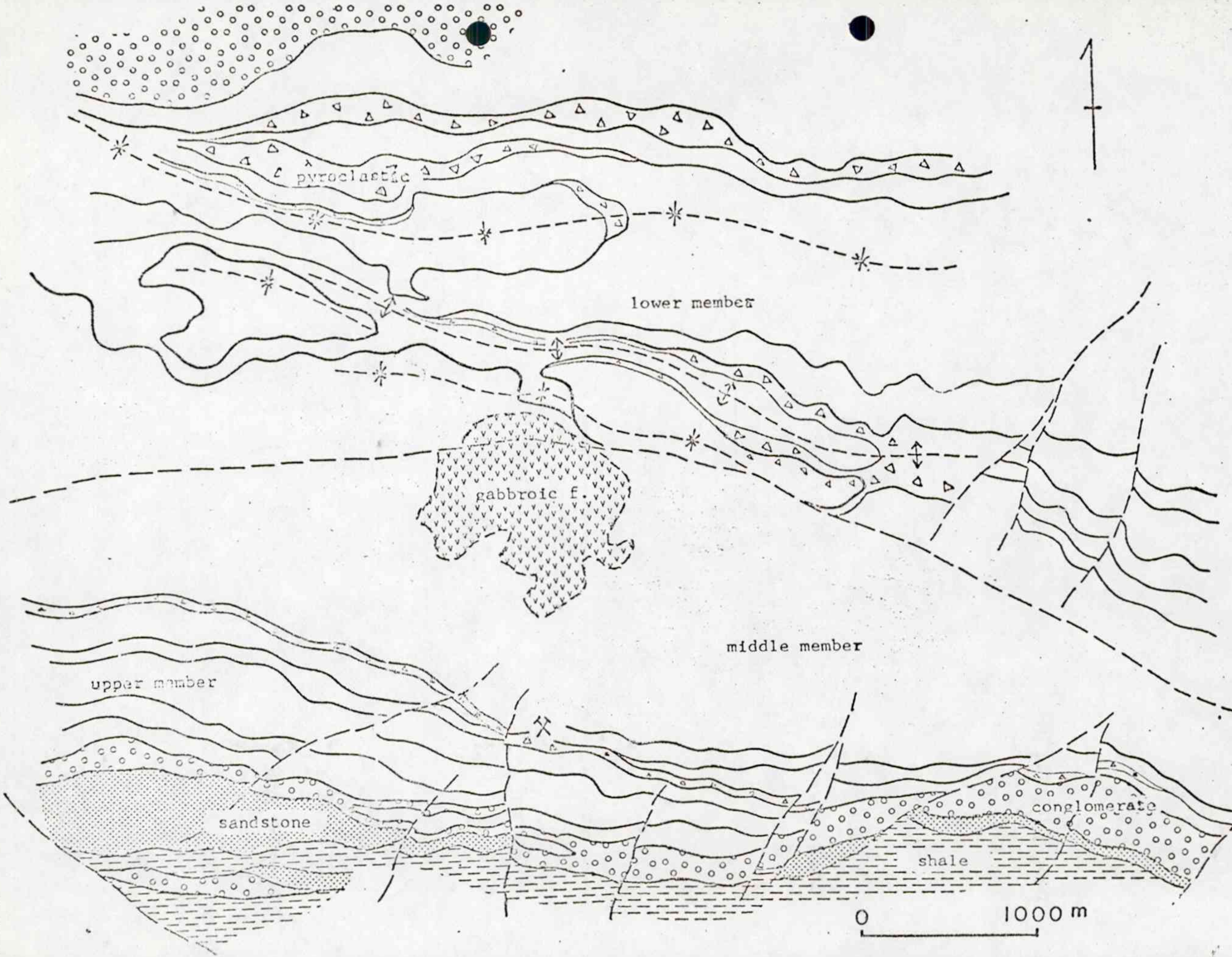
pyroclastic
lower member
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shale
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1000 m

J.W.

Fitton Koski:

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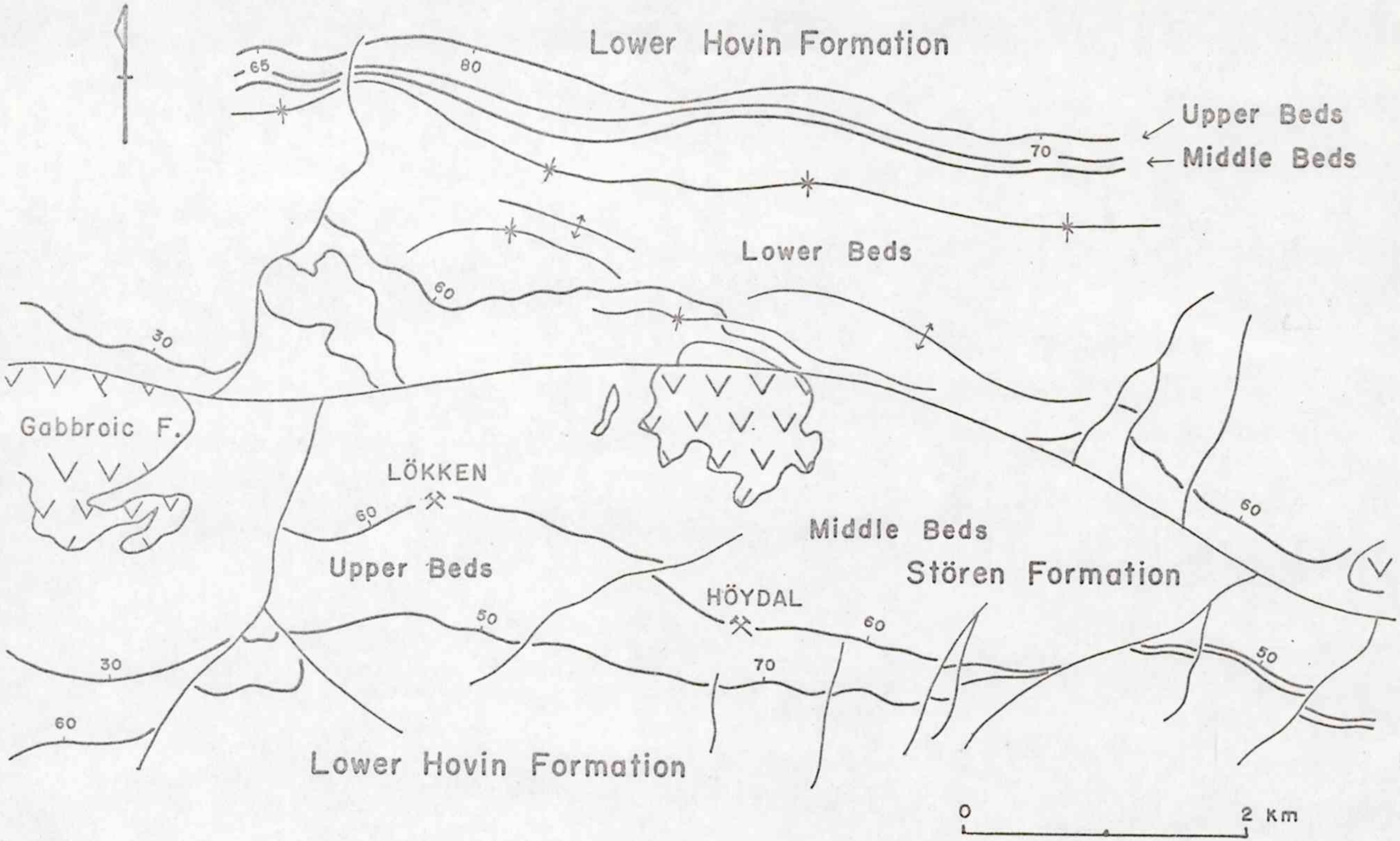
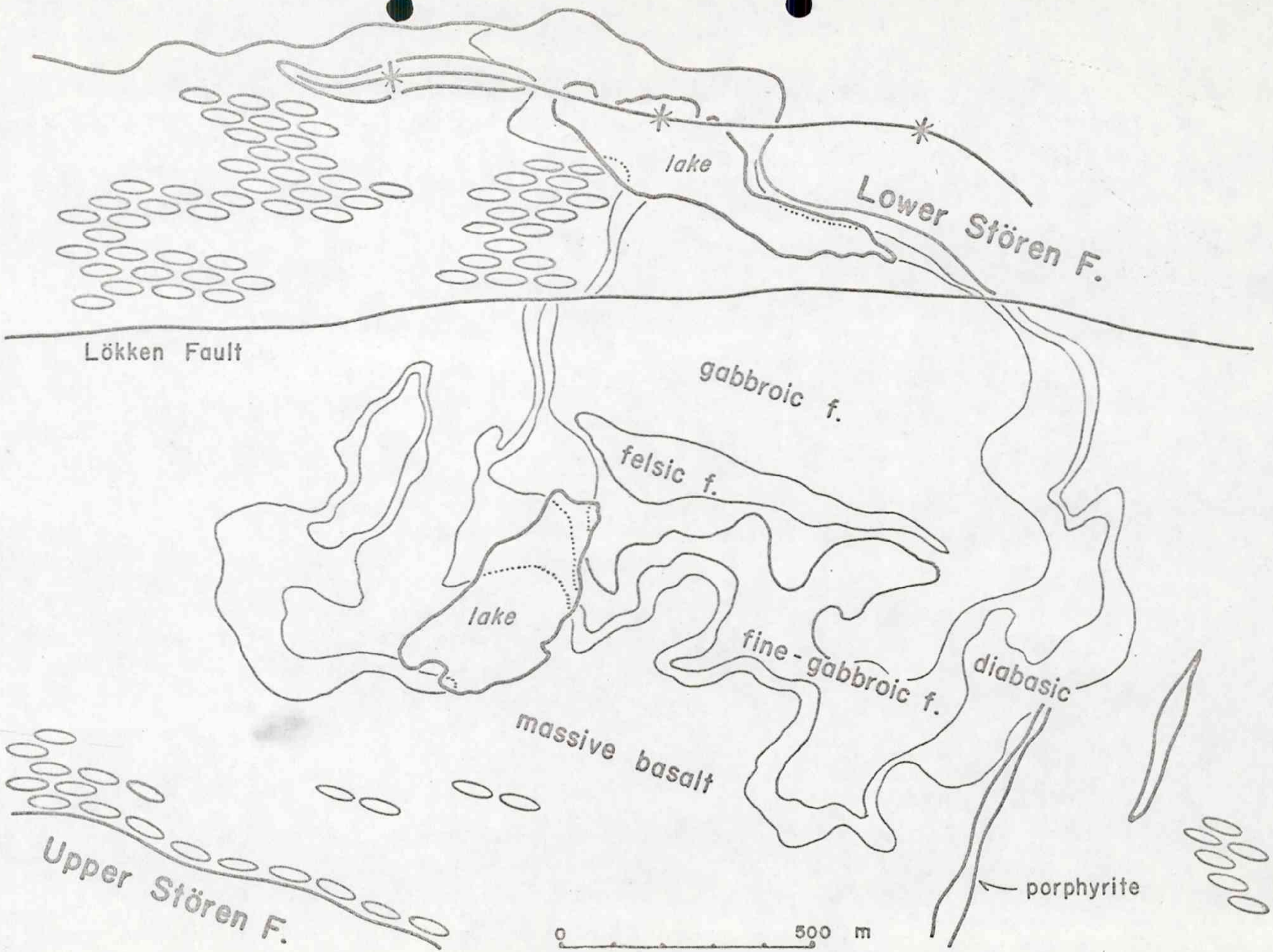


Geologic Map of the Lökken Area


lake
Lower Stören F.
Lökken Fault
gabbroic f.
felsic f.
lake
fine-gabbroic f.
diabasic
massive basalt
porphyrite
Upper Stören F.
0
500 m



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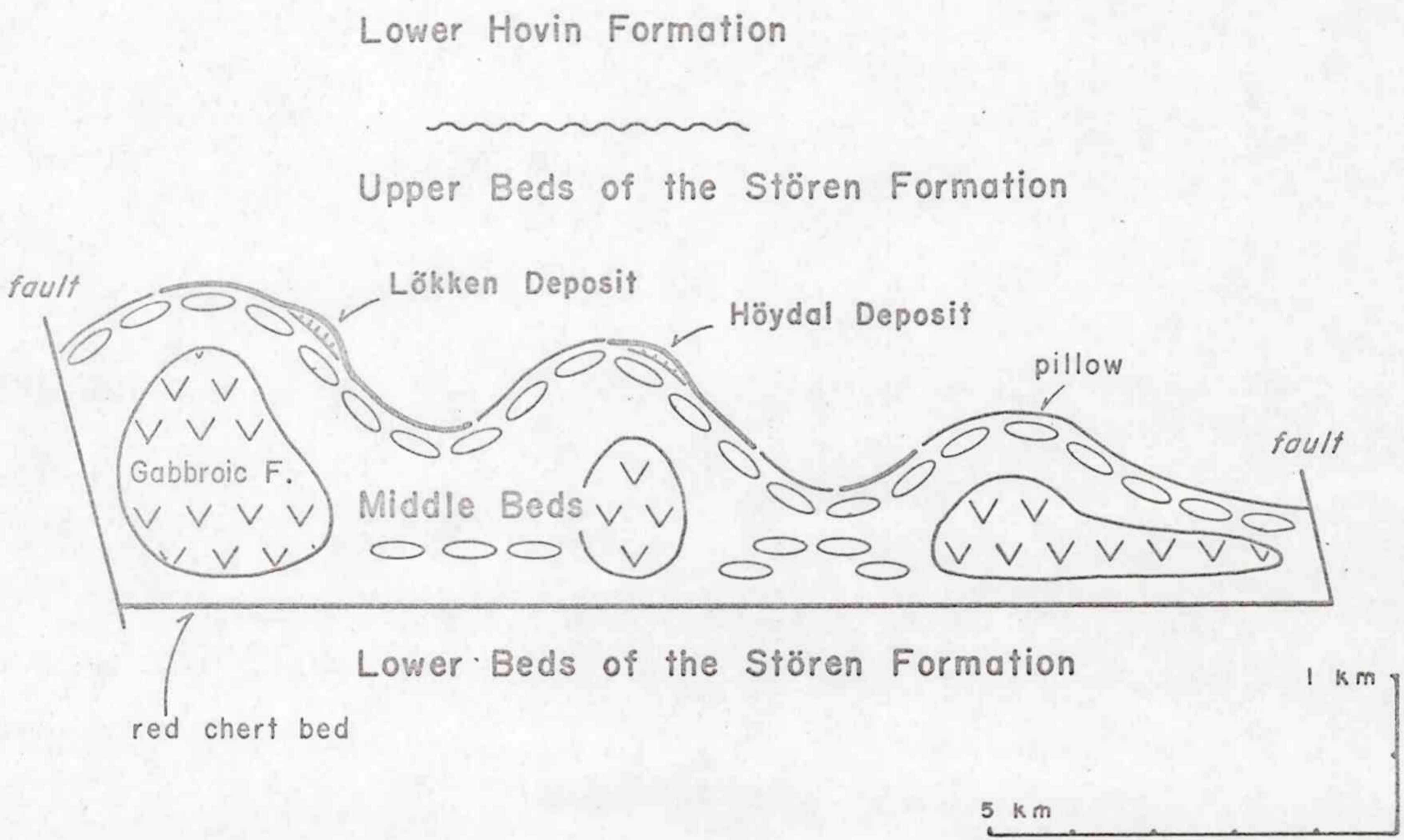
Schematic Rock - Feature of the Middle Beds



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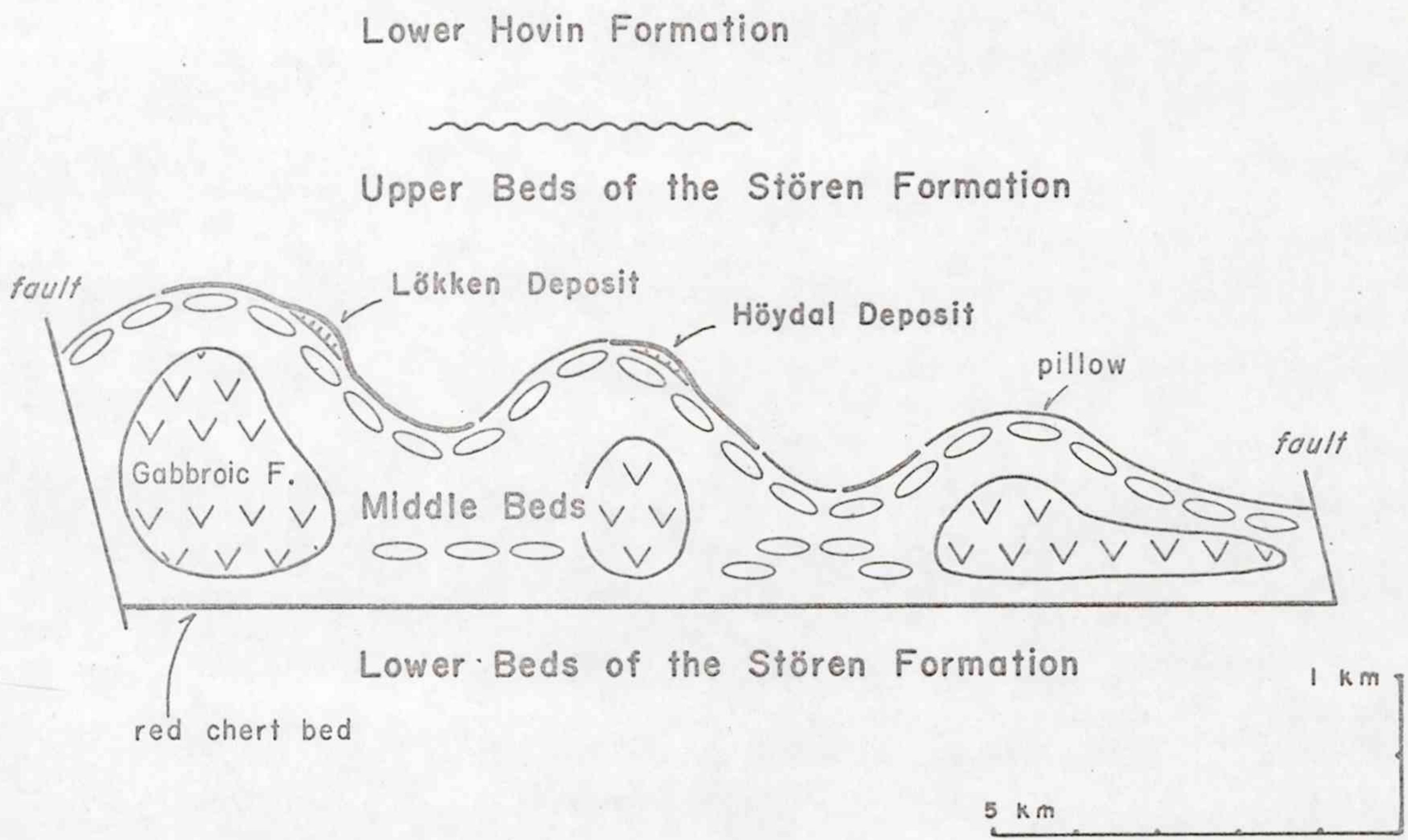
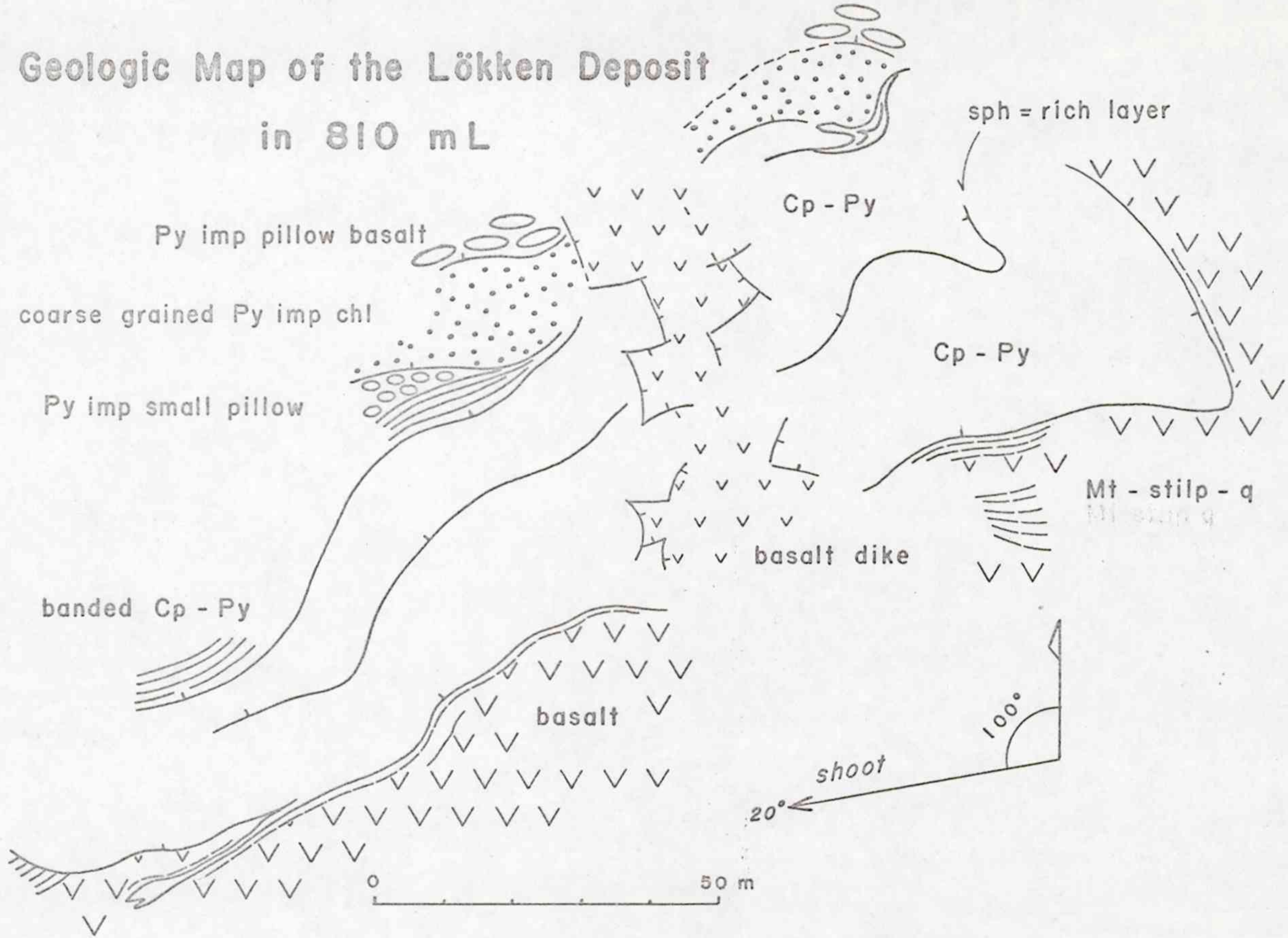


Geologic Map of the Lökken Deposit in 810 mL



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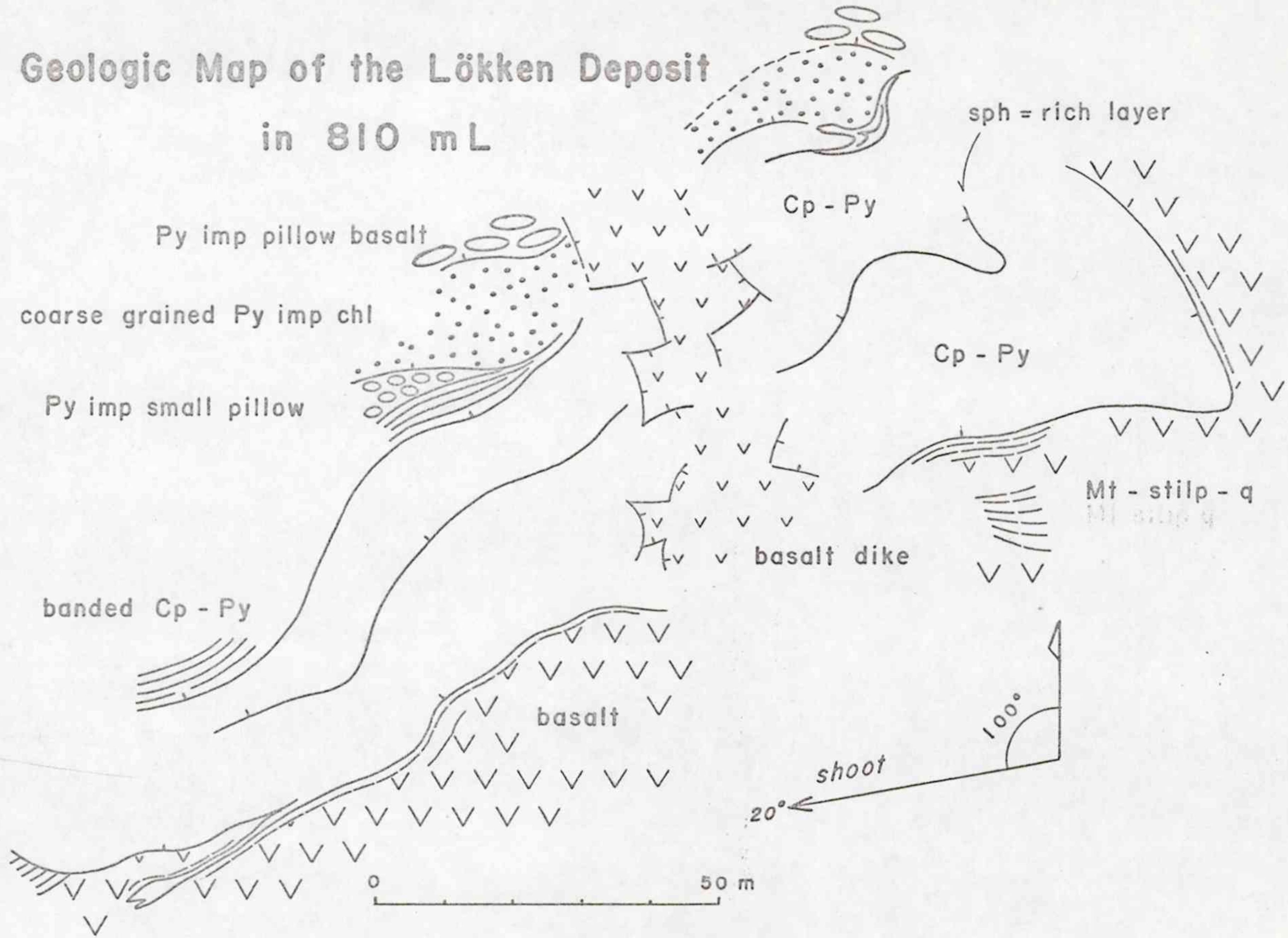
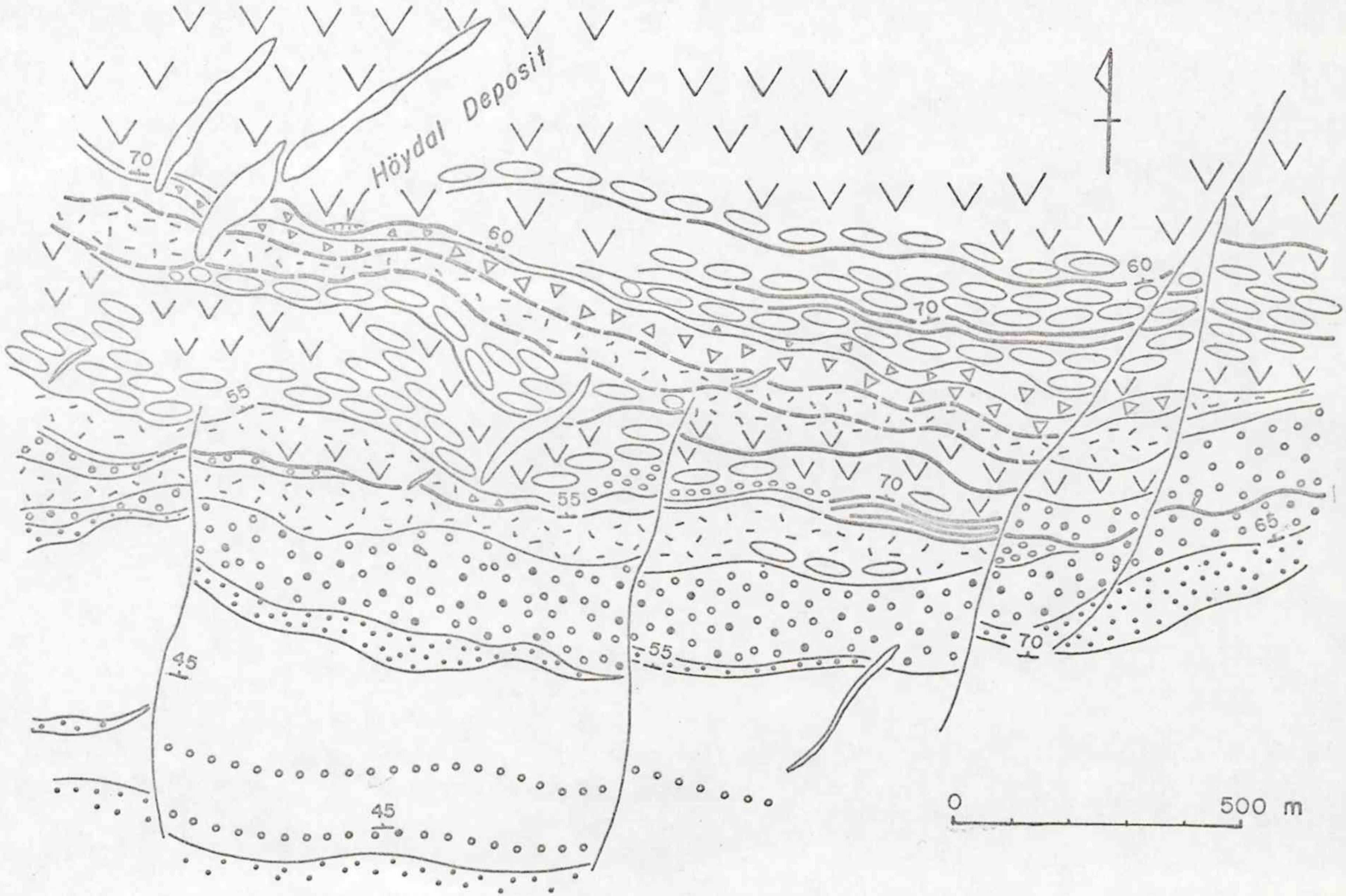


Geologic Map of Upper Beds in the Eastern Part of Höydal



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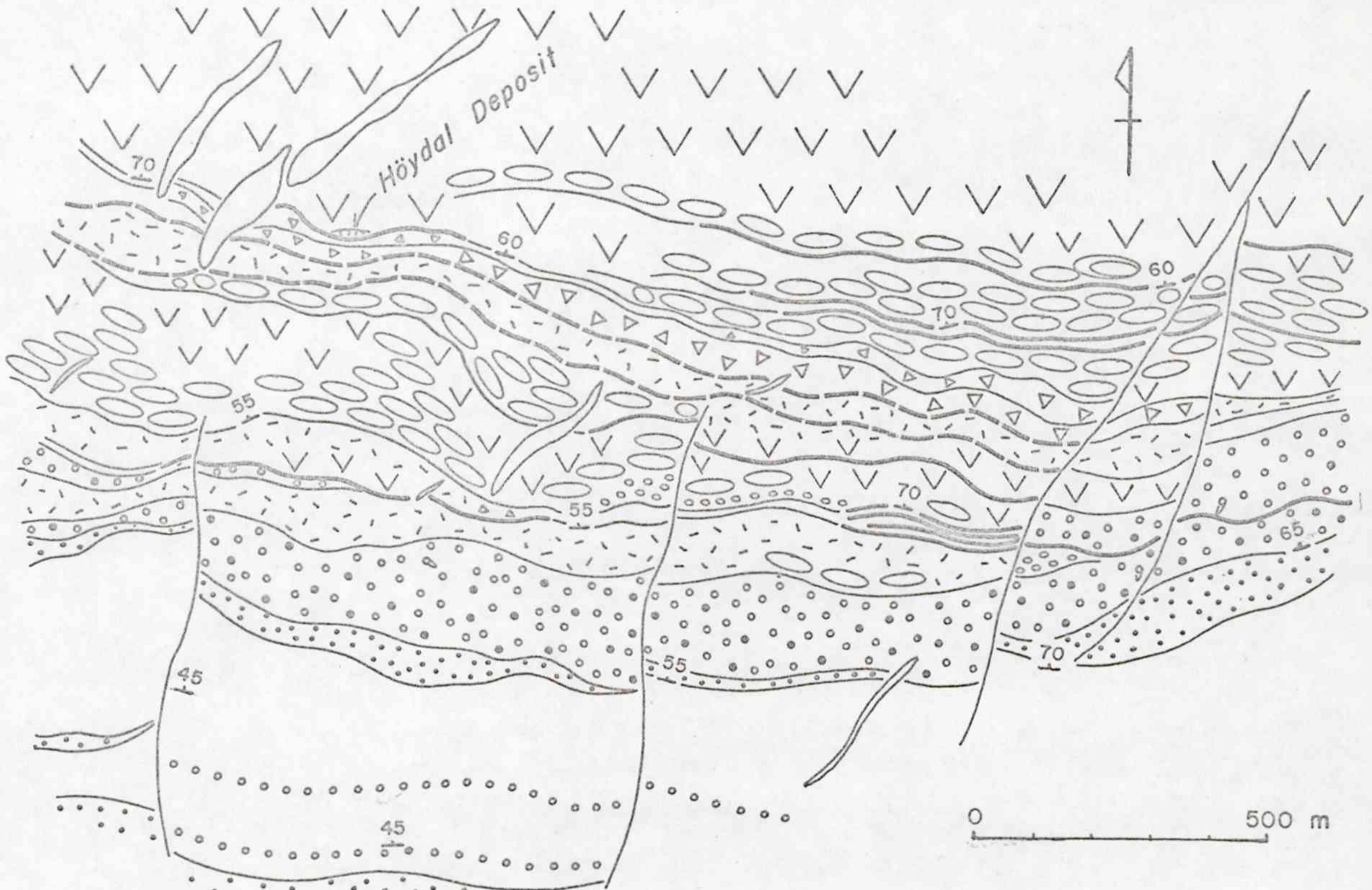
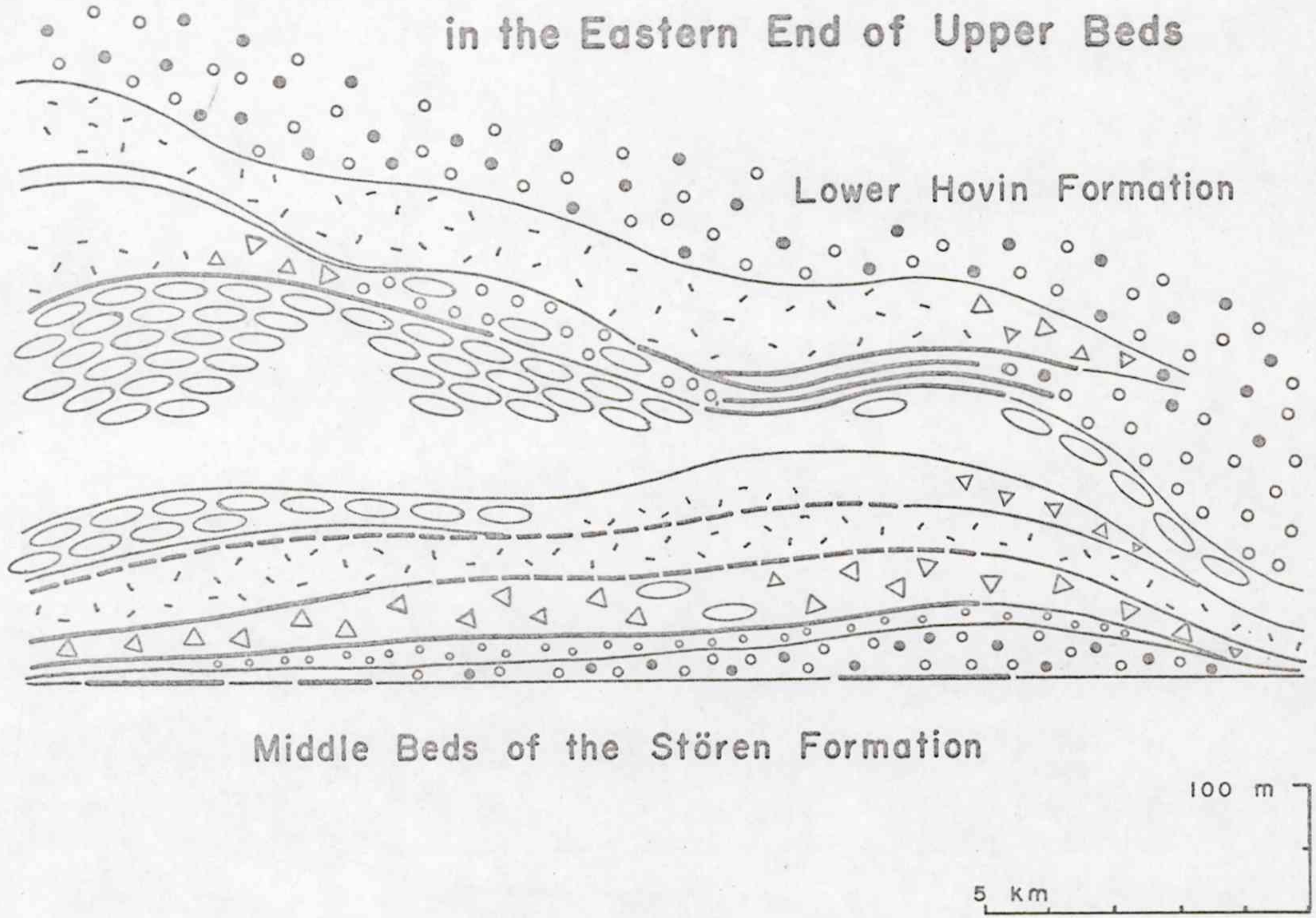


Schematic Rock - Succession in the Eastern End of Upper Beds



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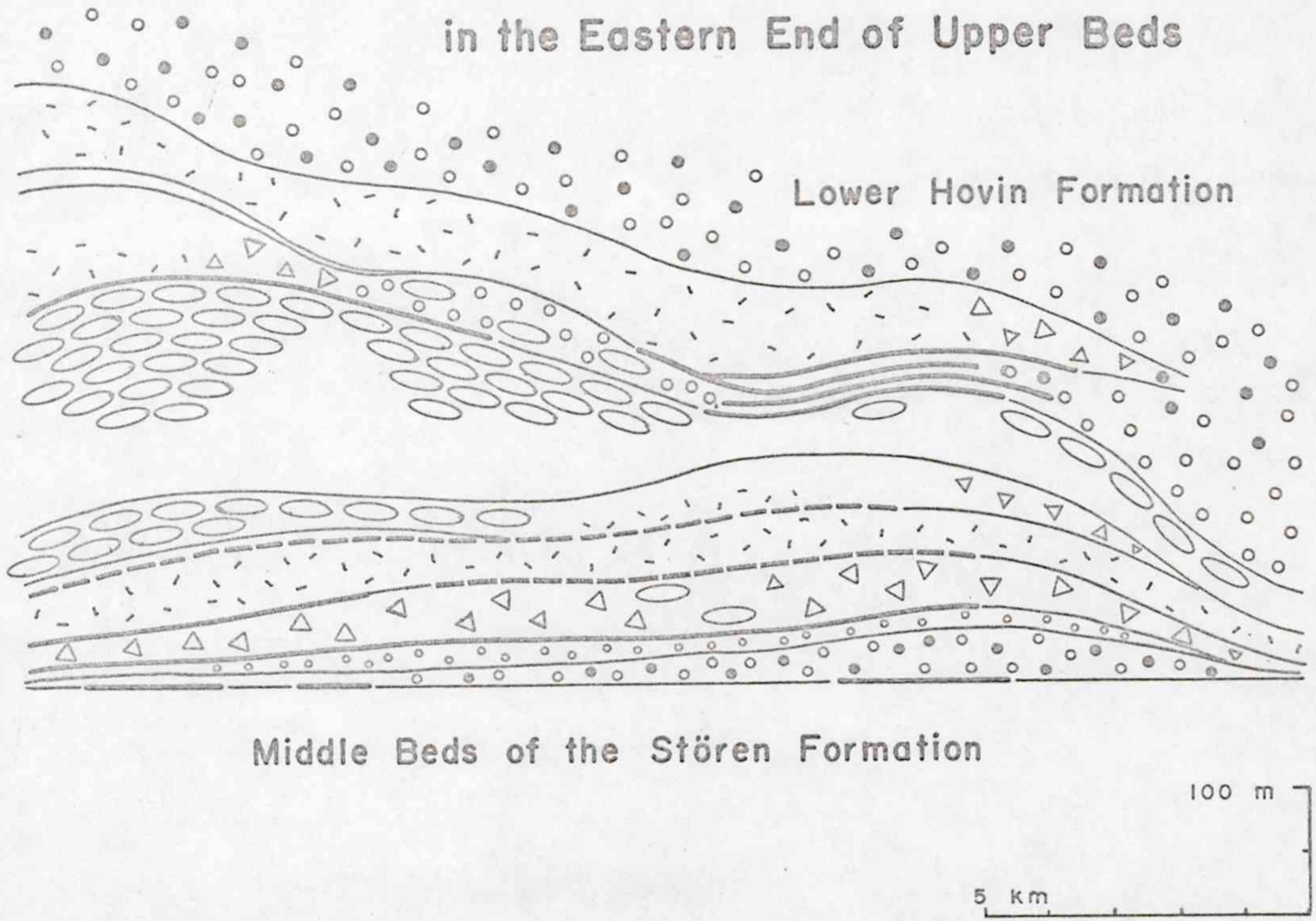
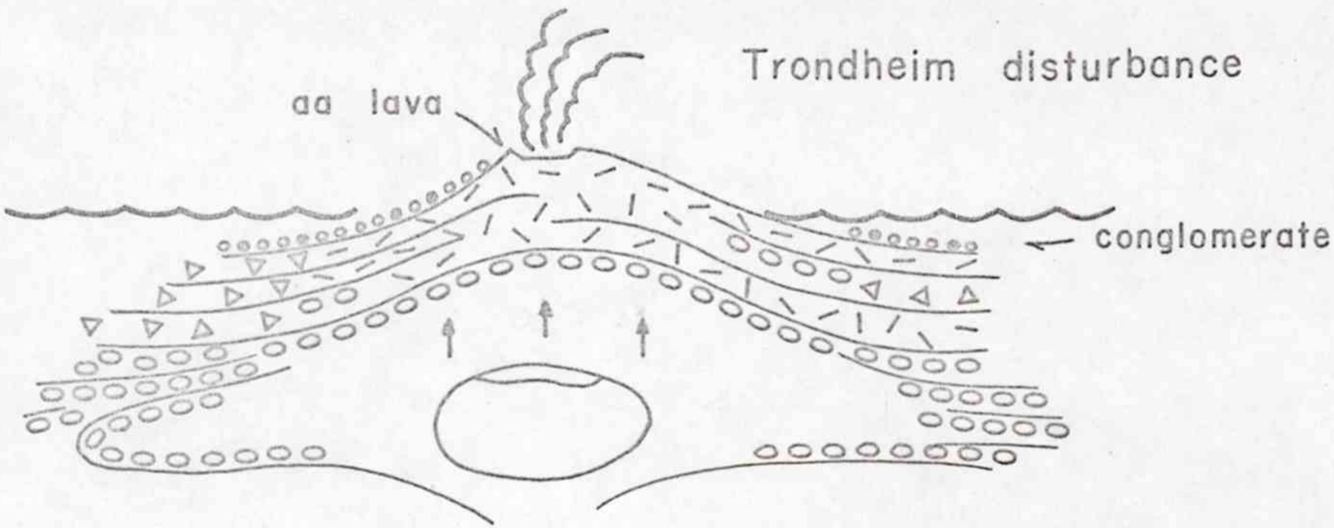
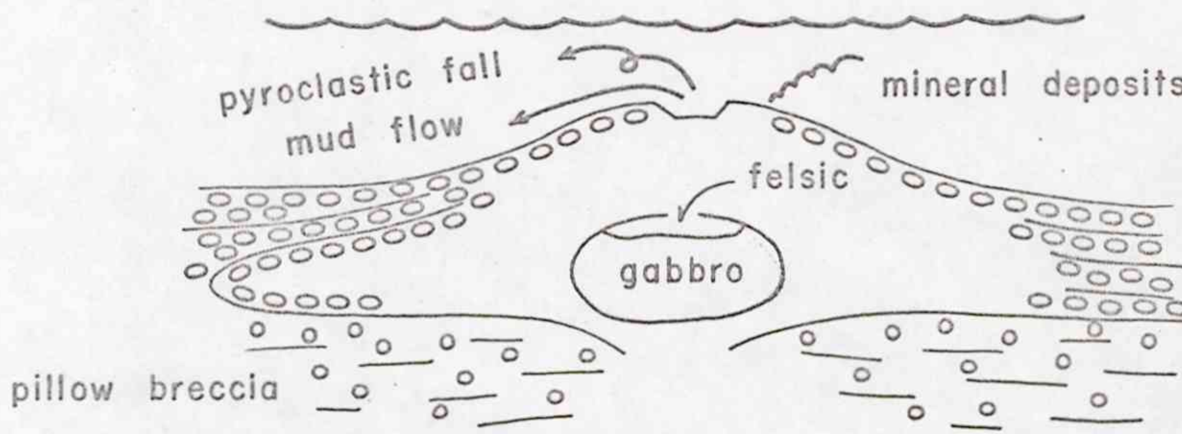




Latest stage

viscosity ~~decrease~~ increase

(T, H_2O)



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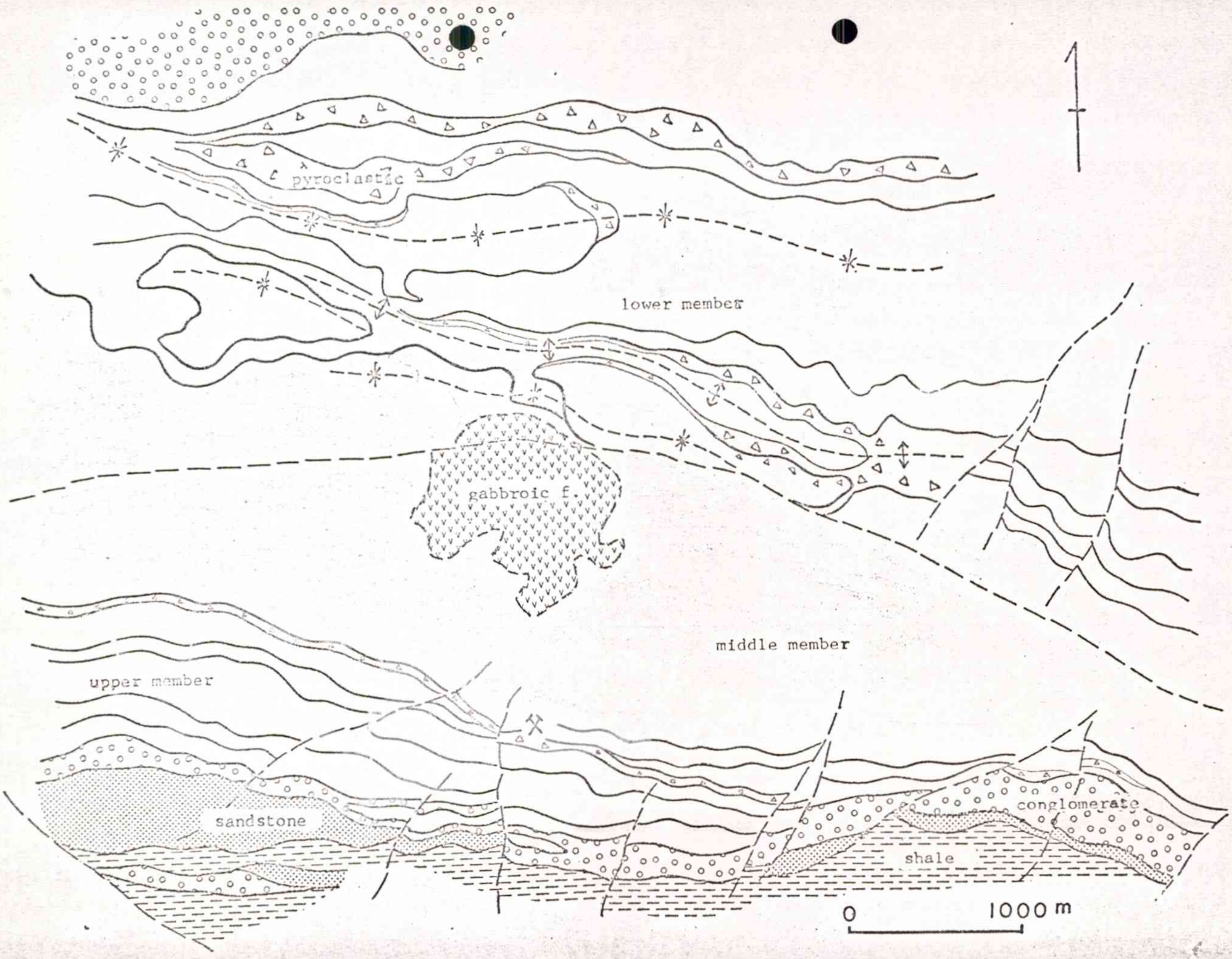
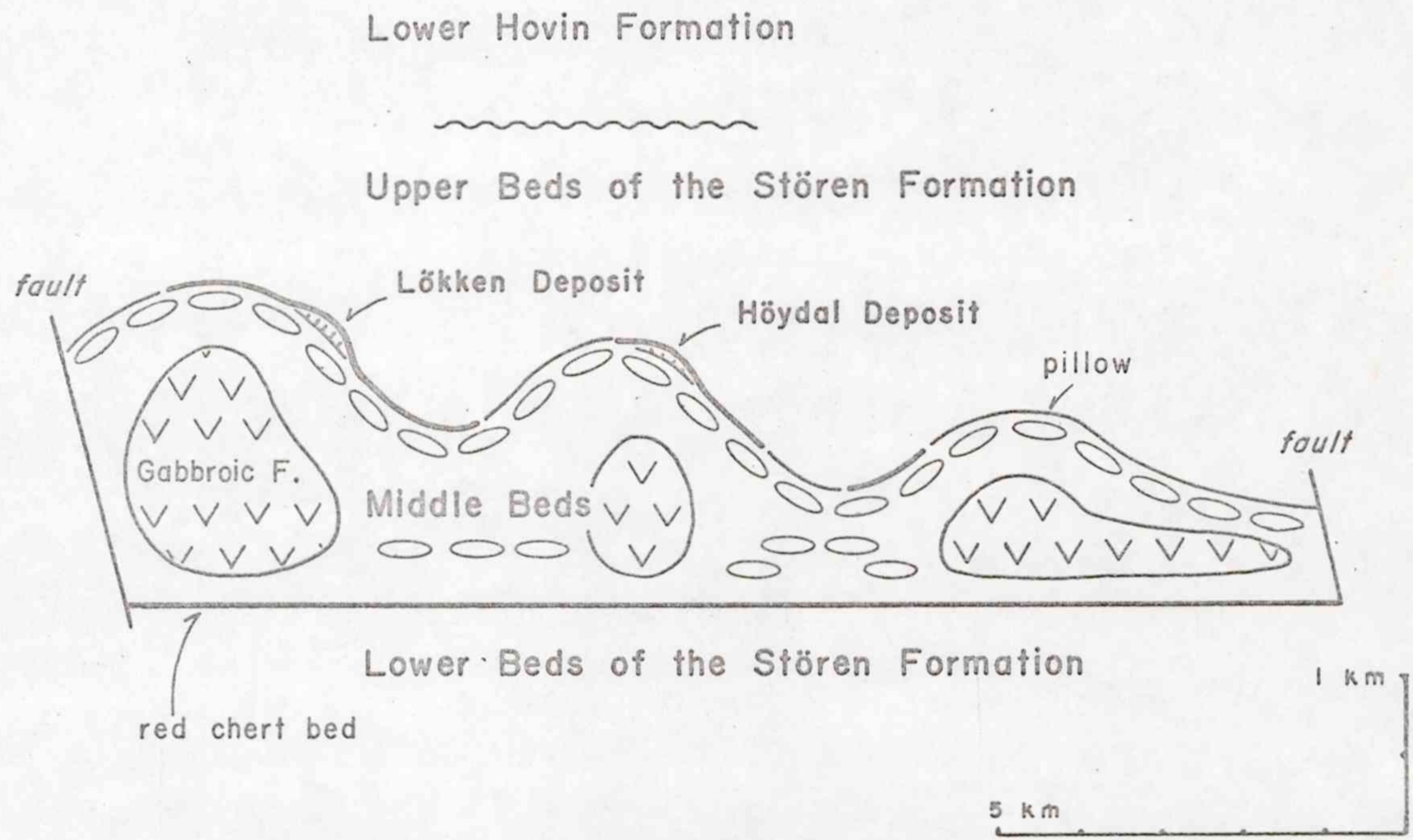


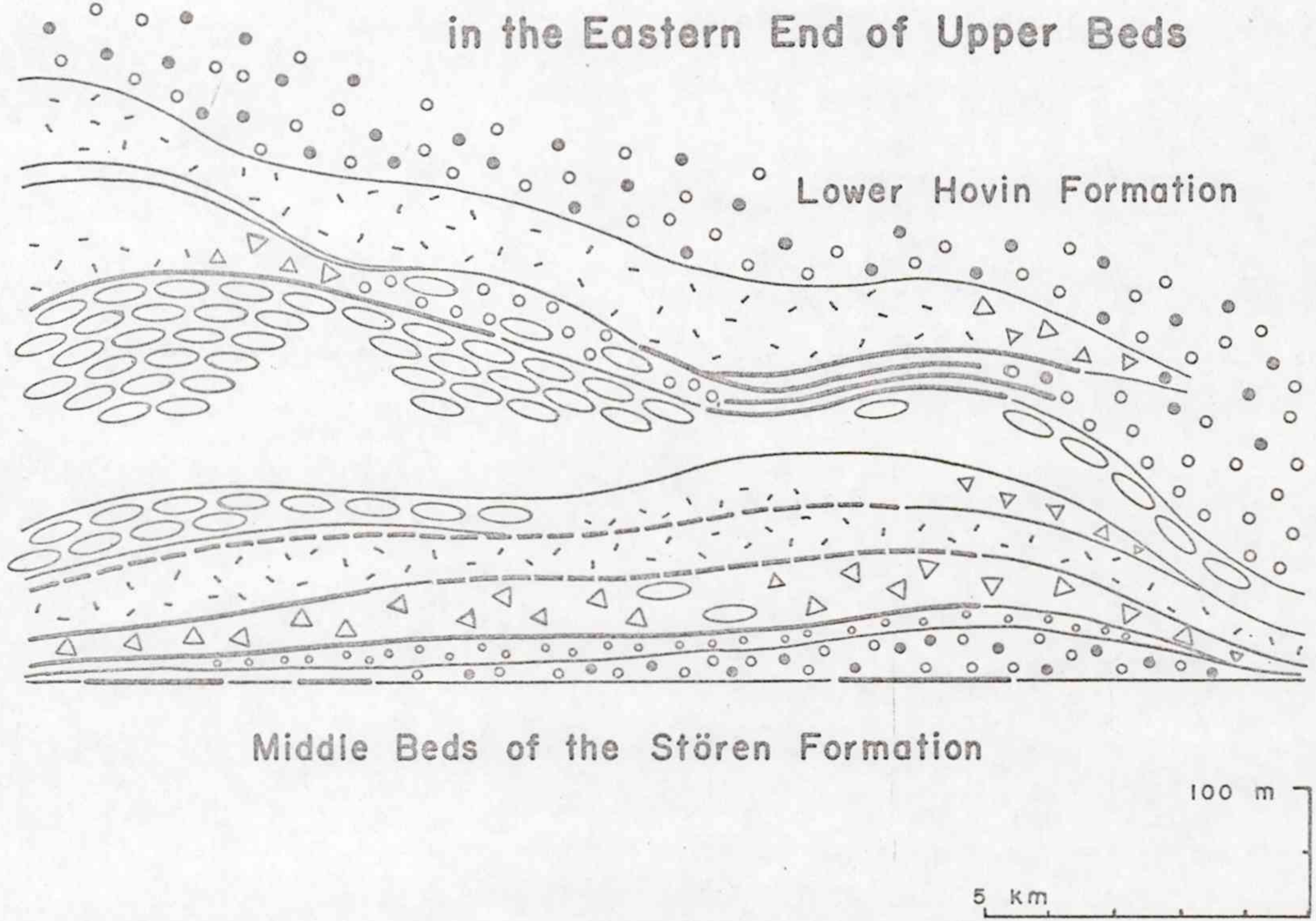
pyroclastic
lower member
gabbroic f.
middle member
upper member
conglomerate
sandstone
shale
0
1000 m

Schematic Rock - Feature of the Middle Beds

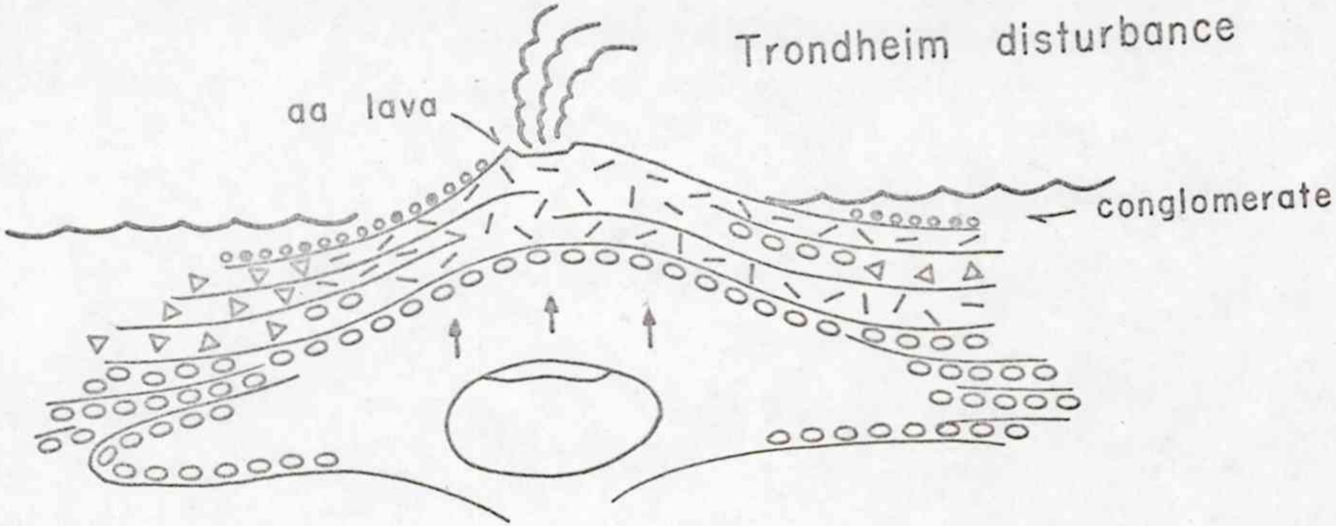


Schematic Rock - Succession

in the Eastern End of Upper Beds



Trondheim disturbance



Latest stage

viscosity ~~decrease~~ increase
(T, H_2O)

Middle stage

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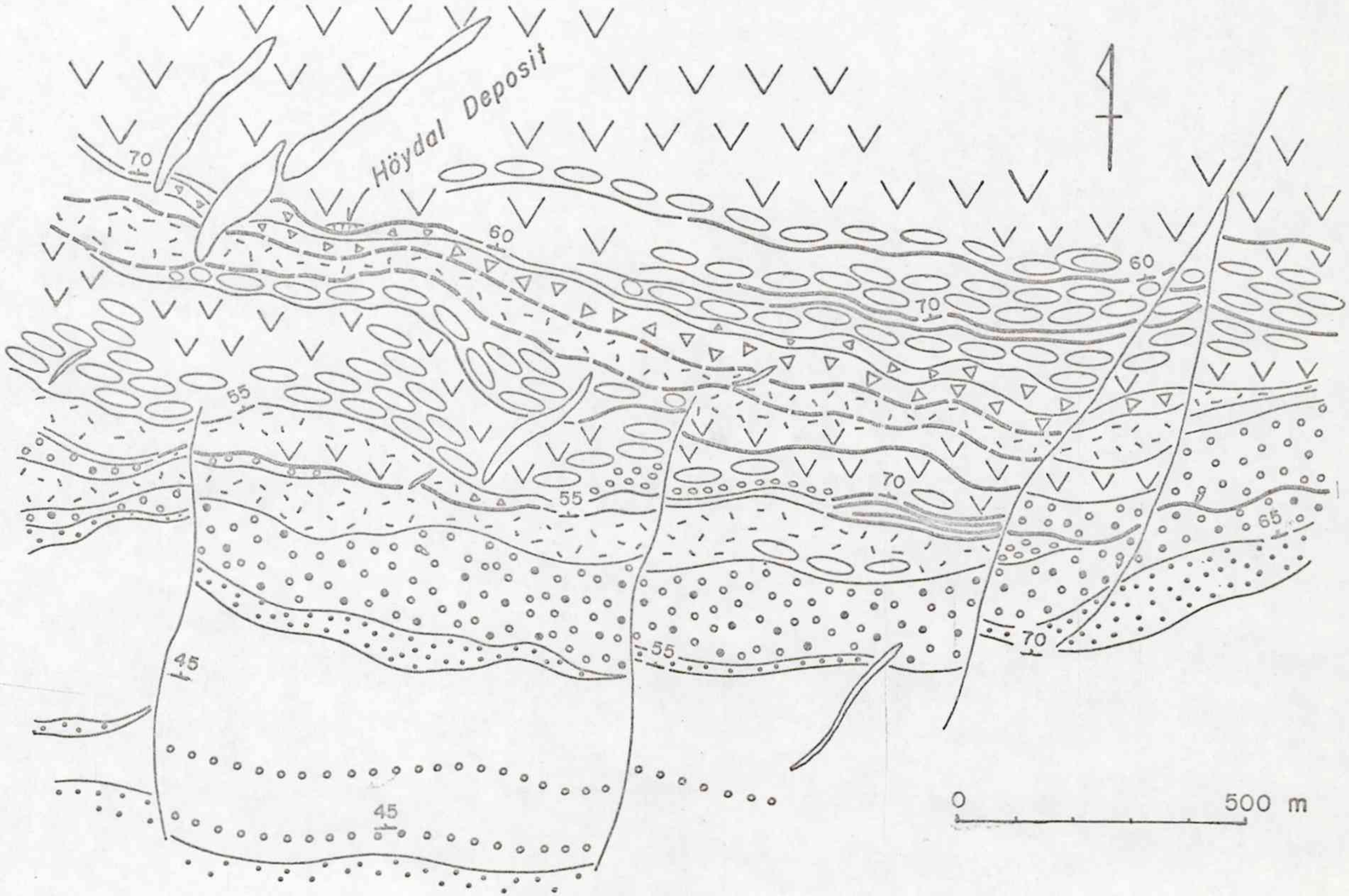

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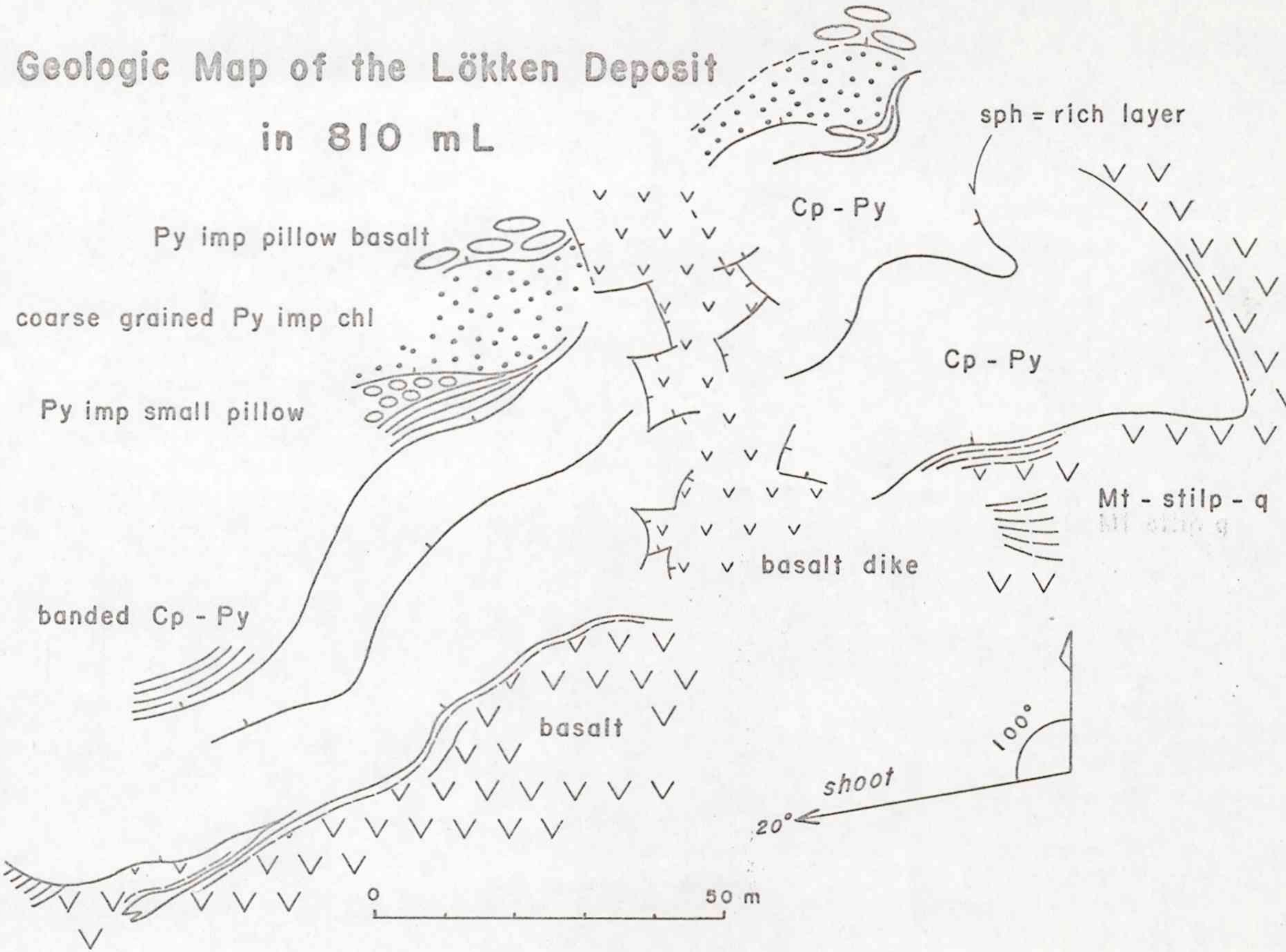

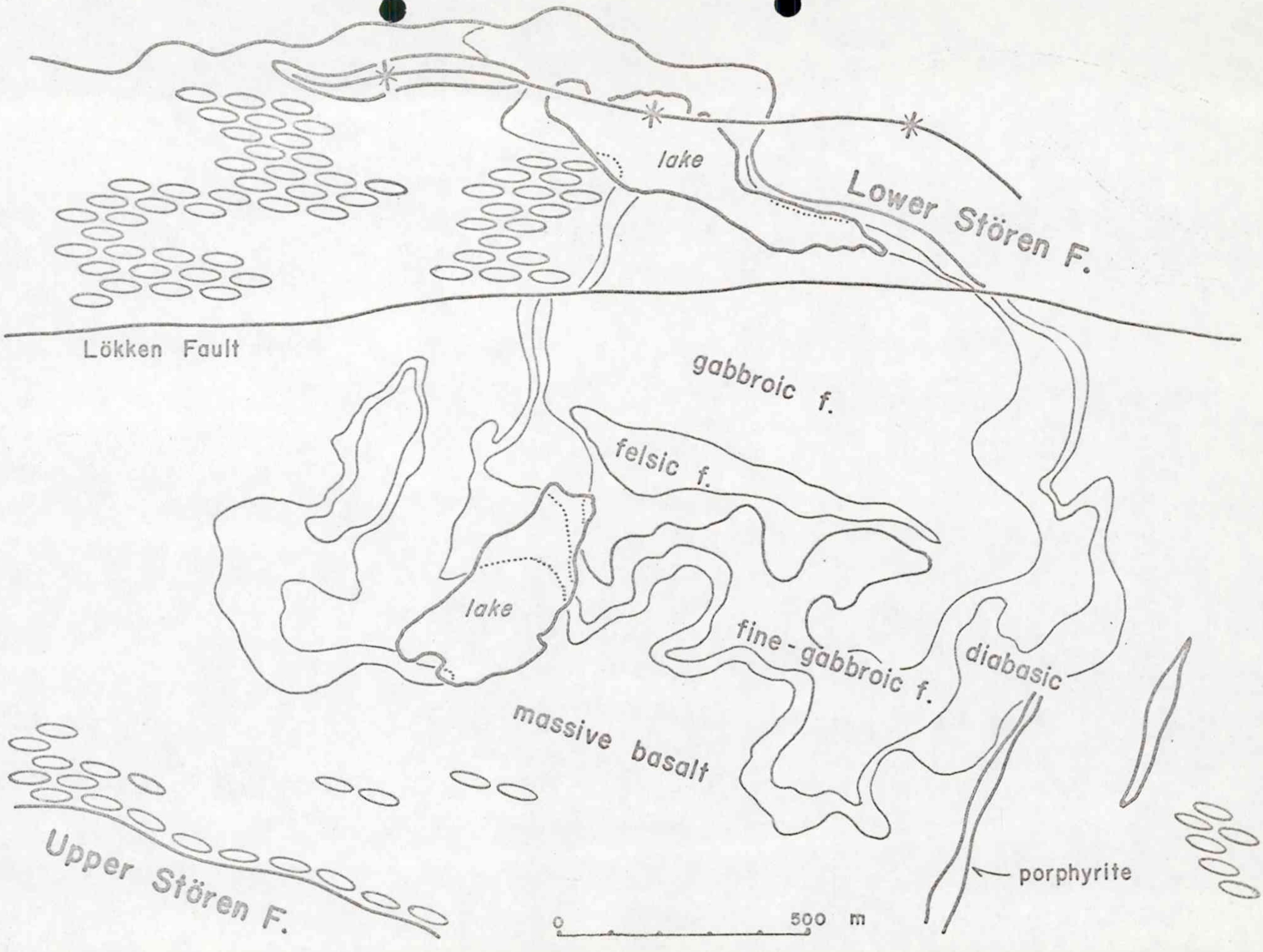

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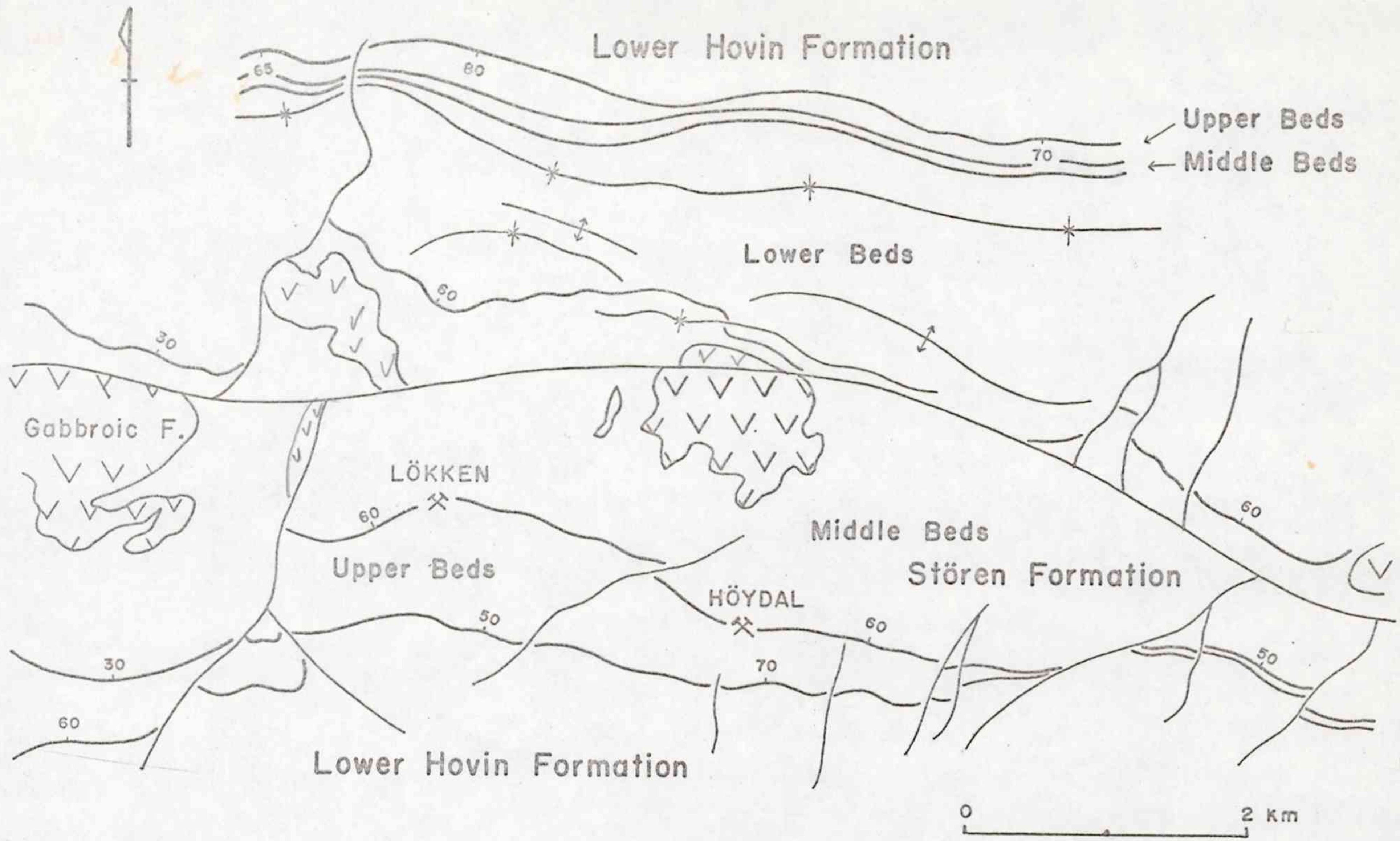

Geologic Map of the Lökken Area

Stratigraphic Succession of the Horg Area.

Devonian	367 m.y.	Trondhjemite	
410 my			
Silurian		Horg Formation	shale, sandstone Lyngestein cong.
440 my		Horg	
	Ashgillian	Upper Hovin F.	sandstone
	Caradocian		Volla conglomerate
		Ekne	
	Llandeilian		shale with tuffite
Ordovician	Llanvirnian	Lower Hovin F.	sandstone, shale Venna conglomerate
	Arenigian	Trondheim	
		Stören F.	basaltic rocks
	Tremadocian		
500 my			
Cambrian		Gula Formation	micas schist black phyllite

Volcano-stratigraphy and Volcanism in the Høydal Area, Central Norway

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Introduction

The Caledonides in Norway was most well studied in the Trondheim region, Central Norway. The Paleozoic strata are distributed in the spindle-shaped area, which is about 300 km in long axis extending to the NNE direction and about 90 km in short axis. The geology of the area was recently compiled by Roberts et al. (1970). According to them the Caledonian strata consist of the Gula, Støren, Lower Hovin, Upper Hovin and Horg formations in the ascending order. They nominated Group for Formation by the transitional Norwegian usage. The author follows, however, the international terminology. The Caledonian terrene has a small branch about 60 km westward. It is already shown in Goldschmidt's well-known metamorphic facies map (1915). The Støren formation consists predominantly of basaltic volcanics. It has been previously thought that the Støren volcanics are continuously aqueezed out from the main Caledonian terrene in the Trondheim region to the branched Høydal-Løkken district. Chadwick et al. (1964) showed, however, that the eastern extension of volcanics in the Høydal district was cut by a fault near the Svorksjøen lake (Fig. 1). Thus, volcanic formation in the Høydal area is isolated from the Norwegian standard of Paleozoic sequence. However, volcanics in the Høydal district are obviously correlated with the Støren formation. Carsten's map (1952) covers widely the Høydal-Løkken district in the scale

1 : 50,000. He made clear the general distribution of constituent rocks in the area mapped by the present author. Chadwick et al.'s map (1964) falls in part on the eastern margin of Fig 2, whereas Rutter et al.'s map (1968) does on the western one. The latter proposed a synform structure in the Støren formation and an antiform in the Lower Hovin one. On the contrary, Chadwick et al. considered that there is an antiform structure in the Lower Hovin formation. Consequently, there should be a synform in the Støren formation, though they did not mention on it in the paper. It conflicts with Rutter et al.'s conclusion on the structure of the Støren formation in the Løkken district.

In all the previous papers the Støren formation was not divided into rock units. The geologic sequence in the Støren formation has not been established so far. The present author's work is devoted to the Caledonian volcanism in the relation with the genesis of stratabound sulfide deposits. Hence, his field work was concentrated in the weakly metamorphosed part of the Støren formation. The mapping was carried out to divide the Støren volcanics into unit beds. The author's unit bed is a little different from a single eruptive unit bed of volcanics proposed first by Nakamura (1960). The weathered surfaces divide the volcanic pile into many single eruptive units. Thus, it can be applied essentially for the terrestrial volcanics. A single eruptive unit bed would result from a product derived from a successive eruption. There is commonly the case, however, that a successive eruption might yield two or more beds of volcanics, for example a lava and a pyroclastic fall deposit. It is significant that volcanic products from a terrestrial volcano are divided into many volcanic unit with the weathered surfaces, because it is usually impossible to divide the the whole volcanic sequence into beds. The situation is rather different in the case of a submarine volcano. In the case of Hødal area the volcanic pile is intercalated with many chemical sediments such as red chert, carbonate, pyrite-quartz and red colored tuffaceous beds. They are followable with difficulty through the area mapped, though they are very thin, and in fact thin out and reappear again. Beds of the chemical sediment are described as follows.

Pyrite-quartz bed is well bedded. Pyrite is often framboidal. Stilpnomelane, magnetite and hematite are always found as the accessory minerals, but also often as the main constituent minerals. Pyrite-quartz bed is well croped out in some places by the blasting, because it was thought that it may be related to the occurrence of ore deposits. It is called Vasskis in the local name. It has been described so far only in Odegaard's geologic map (1959) cited by Vokes (1960) and Rutter et al.'s one. Carbonate bed consists mainly of calcite, but in part siderite. The exposures are not well, since carbonate is easily dissolved out. The author found the carbonate bed in only several places. Carbonate is usually mixed together with reddish colored materials by possible later shearings. In only one outcrop carbonate and red chert beds occur together. The rock sequence there is pillow lava, calcite and red chert beds in the geologically ascending order. In several outcrops the boundary between basalt and red chert falls in. These spaces may have been filled with carbonate before. Reddish colored bed is usually well bedded, whereas red chert bed is poorly bedded. Reddish colored sediment is most commonly associated with red chert. They are interlayered each other or one of them includes the other as nodules. Those chemical sediments mentioned above occur often in the same horizon. One of them thins out and the other appears. Any regularity in the geologic sequence is not found in the field.

Those chemical sediments must be deposited during the quiescent periods of volcanic activity. A unit bed in this paper is defined as volcanics between two chemical sediments. It could be regarded as products from the rather successive eruptions. It seems likely that a unit bed can be devided into two or more beds, though it depends highly on the exposure in the field. As a result of the mapping, however, it became clear that most of unit beds consist exclusively of the product of a successive volcanic eruption in the case of Hødal area.

The dividing of volcanic pile on the basis of occurrence of chemical sediments is not valid through the whole Høydal area. Most of chemical sediments are less than 1 m thick. Consequently it is very difficult to follow such thin beds through the area investigated. Further, chemical sediments disappear really. A unit bed of basalt shows, however, commonly a vertical change of the feature. As a whole, it is massive at the bottom, and pillowy at the top. In many cases a red chert bed or the other key beds thins out between massive and pillowy basalts. The boundary between two unit beds of basalt can be supposed between two unit beds of basalt different in the appearance, even if any chemical sediment does not occur there. The different feature of each basalt unit is also an useful clue to divide volcanics into unit beds. Some of an unit bed are as a whole massive and rather coarse grained, while the other are more pillowy. Especially the upper part of pillowy unit is distinguishable more easily from the middle and lower parts of it. Pillows at the upper part of an unit are small in diameter and mostly well formed. Furthermore, they are often darker or even reddish brown in color.

More than 10 drilling cores around the Høydal open-pit were re-examined. Recently the new drilling project started.

Only five new drilling cores were available, before the author left the Høydal area. The data obtained from them were useful to confirm the volcano-stratigraphy proposed mainly on the basis of the surface observation. The accuracy of mapping around the horizons, in which the mineral deposits occur, is higher than around the other horizons through which no drilling was digged. There is, however, no great inconsistence between a geological map (Fig. 2) on the basis of the surface mapping and a geological section (Fig. 4) on the basis of drilling cores. This is a reason why volcanics around the Høydal open-pit can have been divided not only into unit beds, but also into beds. Thus the Støren volcanics in the Høydal area are divided into more than 20 unit beds.

There are several stratabound sulfide deposits around the Høydal area: Dragset, Løkken, Høydal and Åmot from the west to the east. Among them the Løkken mine is in production. The author will treat with the volcano-stratigraphy around the Høydal deposit. The Løkken and Åmot deposits occur in the just western and eastern outside of area shown in Fig. 2, respectively. The whole area mapped by the author covers three times more of one shown in Fig. 2 following the eastern and western extension of the Støren formation. The underground mapping in the Løkken mine was also done. The further papers are preparing now, especially refering to the genesis of stratabound sulfide deposits of Løkken. This paper will refer in part to data unpublished as yet, for example in some stratigraphical columns in Fig. 3.

Outline of Geology

The geologic map of the Høydal area is shown in Fig. 2. Strata composed predominantly of basaltic volcanics are widely distributed in the area and are correlated to the Støren formation by Carstens (1952), Chadwick et al. (1964) and Rutter et al. (1968). In the area investigated the distribution of Støren volcanics is about 4.5 km in breadth and generally about N 70° W in strike. Those Støren volcanics form a big synform structure, the limbs of which dip about 70° N to the north in the southern area and vertically in the northern area. The synform axis is situated ~~in~~ less than 500 m from the northern limb (Fig. 3). To the south, the volcanics are structually underlain by clastic sediments correlated to the Lower Hovin formation. Conglomerate, sandstone and shale, and again sandstone occur roughly in this order to the south. It is assumed on the basis of graded bedding in sandy parts that the structually upper part of shale is overturned, while the lower one is normal. Chadwick et al. (1964) considered that the Lower Hovin formation displays a synform structure in this area. It is, however, quite unreasonable, because the synform structure of the Støren formation is very clearly confirmed. It should be antiform as considered by Rutter et al. (1968), though there is no positive evidence within clastic sediments. Volcanics occur again in the farther southern part across the clastic sediments. The meaning of "upper" and "lower" is a little complicated because of the prevalent occurrence of inverted strata. The author will use these words only in the real geologic sequence.

The deformation of rocks highly increases to the north from the ~~syn~~ anti form axis, though the whole rocks in the area belong to the green schist facies. In the highly deformed area including probable boundary between volcanics and clastic sediments it is slightly difficult to distinguish conglomerate, tuff breccia, pillow breccia or even pillow lava from each other. It seems that Støren volcanics are bordered by a conglomerate bed intercalated with sandstone in the northern synform limb. These clastic sediments are correlated to the Lower Hovin formation (Rutter et al., 1968). Judging from the graded bedding there is an another antiform structure within the Lower Hovin formation in this part. The geological relation of Lower Hovin formation to Støren one may be slightly unconformable, though an eroded surface of Støren volcanics has not found in the field so far. The thickness of the Støren formation is extremely thin in the northern synform limb compared with about 2,500 m in the southern one.

Consequently, the volcano-stratigrapgy in the Støren formation was established in the southern limb. The Støren volcanics are divided into about 25 unit beds intercalated with chemical sediments of about the same numbers. A little more unit beds are distinguished in the route map in the scale 1 : 5,000 and through drilling cores. However, most of them can not be followed to the next outcrop. They might thin out for a short distance. Some of them are shown, however, in more detailed map of Fig. 5. Four columnar sections in the southern synform limb are shown in Fig. 4. Each section is N 20° E in direction and 1.7 km far from the nearby section. Those columnar sections, designated columnar section A. B. C. and D. from the west to the east, show respectively the volcano-stratigraphy roughly along the national road No. 700, from the center of gabbroic facies to 700 m west of the Høydal open-pit, along the Betva valley to the village Høydal, and along the eastern margin of the lake Urvatnet. The Støren

formation could be divided into three members on the basis of the occurrence of a very thick unit in the midst. They are called the Lower, Middle and Upper Støren members in the geologically ascending order.

A well-continued fault runs as a whole in the lower part of the Middle Støren member from the east to the west. It may vanish further westward. The fault plane dips perhaps steeply, because it runs straight making high cliffs in some places. The horizontal movement along the fault may not be so large, because gabbroic facies occurring in both sides of the fault fit moderately well each other. It is not obvious on the vertical movement, though it is presumably also not so large. In any way the northern block must have fallen down, because the Lower member occurs at the just northern side of the fault, but not the southern side (Fig. 2). Consequently the displacement along the fault acts possitively on the thickness of the Middle Støren member. It implies that the Middle Støren member may be a little more thicker than shown in Fig. 4.

Lower Støren Member

The lowest part of Lower Støren member is not exposed in the Høydal area, since the whole Støren formation is turned over and eroded out probably a little. The lowest unit bed nominated L_1 occurs along the main synform axis which runs from the east to the west in the northern part of the Høydal area. To the south there are an antiform and a small synform. Both folding structures vanish to the west. Consequently the Lower Støren member is distributed rather monoclinally to the west. The Lower Støren member exposed in the area is less than 1 km in thickness. It is intruded by the gabbroic facies of the Middle member. It is characterized by the moderate occurrence of pillow breccia at the lower horizon.

The unit bed L_1 is a little more than 100 m in thickness and consists of the alteration of pillow lava, pillow breccia and tuff breccia. Amygdaroidal texture in pillow lavas is most well developed in this unit bed among the pillow lavas of the Lower member, but not so predominant. Pillow breccia consists of small pillows spreaded widely in the tuffaceous matrix. Small pillows are quite similar to pillows in the ordinary pillow lava. They lack, however, usually the amygdaloidal texture. Small pillows are very irregular in the form and commonly torn. The matrix is stratified more or less. It does not retain, however, the original texture and minerals. It is about 2 to 5 m in thickness. It is as a whole thinner than pillow ~~breccia.~~ lava. Tuff breccia consists of volcanic fragments in the layered matrix. Volcanic fragments consists of angular to subangular basalt. The chilled margin is rarely observed. The quantity of fragments is very variable from a bed to the other one. However, it is usually less than 30 %. The flattened feature is more

conspicuous as the ratio of matrix to the fragments increases. In some cases the margin of fragments is obscure. Genrally speaking it is very difficult to distinguish tuff breccia from conglomerate in the northern area, because the conglomerate does not contain the fragments of red chert. A single bed less than 1 m in thickness is not uncommon. The uppermost part of unit bed L_1 is observed at only one locality. Pillow breccia is overlain by a red chert bed there. Pillow lava stained very faintly by reddish brown color occurs commonly near the probable uppermost horizon in the other localities. The geologic sequence within the unit bed L_1 is uncertain. The flat-lying structure, the paucity of exposures and the alternation of many thin beds, they all together obstruct to establish the geologic sequence. It seems, however, that pillow lava increases to the east and tuff breccia predominates in the upper horizon. There occurs no clastic sediment in the unit bed L_1. Thus, it is a successive deposit for a short geologic time, despite it consists of products of many eruptions.

The distribution of the unit bed L_2 is a little complicate. It is divided into the northern and southern sides by a minor fault and further into the both limbs by antiform and synform. The unit bed L_2 is about 100 m thick and consists mainly of pillow lava. The main pillowy part is probably interlayered with a small pillow lava to the west. The pillow structure develops more well upward and westward. The common occurrence of epidote is characteristic of the unit bed L_2. It occurs along the just inside of chilled rind of the pillow and even in the massive part. It seems that massive basalt grades upward into well-developed pillow lava in the eastern area. On the contrary, the same kind of vertical change is obscure to the west because of a interlayered small pillow basalt. The uppermost part of pillow lava is strongly stained by reddish brown color to the western margin, but also moderately in the eastern area. The pillowy main body is overlain by thin layered beds to the west. They consist of about 5 m thick massive coarse grained basalt, about 5 m thick reddish brown colored small pillow lava, about 1 m thick red chert and about 2 m thick conglomerate in the ascending order. Conglomerate is about 1 to 2 m thick. It consists mainly of greenish colored basaltic fragments, angular to subangular with a little quantity of fragments of reddish brown colored basalt and red chert. They are probably derived from the underlying part of the unit bed L_2. The conglomerate should be regarded as the basal bed of the overlying unit be L_3, because it overlies red chert bed, that is to say chemical sediment. In the southern limb of the antiform those thin layered beds consist of coarse grained basalt, reddish brown colored small pillow lava, tuff breccia and the other tuff breccia in the ascending order. The lower tuff breccia is rich in the fine grained matrix, while the upper one contains a lot of small fragments. Those thin layered beds vanish to the east. In the eastern margin the pillowy basalt is directly overlain by red chert bed. Pyrite-quartz bed occurs at the top of reddish brown colored pillow lava across the subordinate synform structure along a fault in the most southern area of the distribution.

The unit bed L_3 occur only in the western part of the area. It might be intruded by the Middle Støren member. The eastern extension is cut by a fault and fallen ~~down~~ down below the present surface in the northern side of the fault. The unit bed L_3 consists probably of a single pillowy lava flow bed. It is typically massive and coarse grained at the bottom and pillowy at the top. The chilled cracks in pillows develop well in the upper pillowy part. They develop commonly in radial form. The uppermost pillows are commonly surrounded by reddish brown material,

but red chert does not occur as far as investigated. The occurrence of unit bed L_4 is roughly the same with the unit bed L_3. It is slightly altered. It is more pale greenish in color. The pillow structure develops well through the unit bed and the chilled cracks occur also in the pillows except in the uppermost part. Pillows in the uppermost part are smaller in diameter than them in the main part and surrounded by reddish brown material. Further, epidote occur commonly along the inside of chilled margin of pillows. The unit bed L_5 is about 100 m thick. It consists of epidote rich pillow lava. It overlain by red chert and pyrite-quartz beds in the ascending order at one exposure. Small pillows stained by reddish brown color occur at the top of the unit bed to the east. The unit bed L_6 is about 500 m in thickness. The pillow structure occurs more commonly at the top of the bed, while massive and coarse grained facies occur rather to the bottom. It is not intercalated with any pyroclastic or chemical sediments. It is overlain by a red chert bed in the western outside of geologic map.

Generally speaking each unit bed in the Lower Støren member displays the common feature through the vertical section. It is usually massive at the lower part and commonly associated with coarse grained facies, that is to say diabase facies. The chilled cracks develops well at the middle part. Epidote occur commonly along the just inside of chlorite-rich chilled rind of pillows in the upper part. Further the reddish brown colored material fills moderately interstices of the pillows at the uppermost part.

Volcanism in the Lower Støren Age

There occur many beds in the unit bed L_1 of the Lower Støren member. The common occurrence of tuff breccia and probably even pillow breccia indicates that the rather explosive eruption took place repeatedly in the beginning of the Lower Støren age. Small pillows themselves which are bended and torn indicate the stirred submarine environment before solidification of magma. Further, pillow lavas in the unit bed L_1 are more vesiculated compared with ones in the other unit beds. It is said that the amygdaloidal texture may well develop in a rather shallow depth. In Kilauea a vesicle is not formed conspicuously in the depth of more than 2 km. The maximum depth in which the vesicle occur may be variable depending on many factor viscosity, temperature and voratile contents in magma. The feature of volcanics in the unit bed L_1 seems to indicate strongly, nevertheless, that the sea at that time is shallow. Such an environment could be responsible for the repeated explosive eruptions. There are the other field evidences which also indicate the shallow sea prevailing at the beginning of the Lower Støren age. A conglomerate bed overlies the unit bed L_2. The probable source of fragments may be the western part of unit bed L_2, because basalt oxidized so strongly are not found in the other part of underlying rock units. Any unconformable relation has not been observed in the field. However, the unit bed L_2 might have once emerged on the sea-surface. The unit bed L_2 displays as a whole the lateral facies change which could be an indicative of flow direction of a lava. If so, the lava L_2 flowed down from the east to the west in the projection to the present eroded surface. It is possible to infer that the small pillows and conglomerate deposited at the marginal part of the lava flow. Thus, it seems likely that the oxidation

of pillow lava could take place more easily at the front and the upper part of a lava. The same conclusion will be obtained on some pillowy lava unit beds in the Upper Støren member. The sedimentation of conglomerate began after the precipitation of red chert. It implies that a tectonic movement took place during the quiescent period of volcanic activity indicated by the occurrence of red chert bed.

After the rather explosive stage the calm outpouring of pillowy lava was intermittently repeated. The unit bed L_3 to L_6 are products in the calm eruptions. All those unit beds display more or less the vertical facies change in their feature: massive at the bottom and pillowy at the top. The upper pillowy facies represent a part quenched more strongly against the water. The quenching is always accompanied with the element migration as shown by the common occurrence of the monomineralic layers, either chlorite or epidote. The lower massive facies may be less quenched. It is not so simple, because the quenching of magma do not always form pillow lava. Nevertheless, the occurrence of coarse grained facies in the lower massive part is favorable for slow-cooling. It is also possible that the water, either from magma or sea-water, played an important role. It seems, as mentioned later, that pillow lava is more easily formed from magma high in temperature and rich in volatile. Consequently, the upward migration of volatile within a lava may make the formation of pillows easy at the upper part. Thus, the vertical facies change within a lava flow is depicted as follows.

Magma outpoured on the sea-floor forms the pillowy rind as a result of quenching. Molten magma pushed by the ascending magma protrudes from the pillowy rind to flow down ahead on the sea-floor. It would carry more or less pillows, but also form successively new pillows at the front and the upper part of lava protruded newly. At the final stage, when lava stops to flow down, a hot lava covered by a lot of pillow is left on the sea-floor. The hot lava is cooled more slowly to form massive facies underlying the pillowy upper facies. Some papers reported the pillowy basal facies as well as the pillowy upper ones. Such a feature was not observed in the Høydal area. The horizontal extension of unit bed L_4 to L_6 is rather limited because of the occurrence of a fault. It is about 1 km. The unit bed L_3 is distributed through the area, but poorly exposed to the east. Thus, the horizontal facies change which could indicate the flow direction of each lava is obscure as a whole.

Middle Støren Member

The Middle Støren Member consists substantially of only a single unit bed M_1, though it is associated with several subordinate unit beds. The unit bed M_1 is characterized by the extreme thickness and particularly the occurrence of gabbroic facies, which intrude slightly into the underlying Lower Støren member. It dips 70° N at the upper surface and 30° N at the lower one. There is, therefore, a difficulty for measuring its true thickness. The unit bed M_1 attains about 1,000 m in the thickest part, if Busk's method is accepted for drawing the extension of the unit bed. Pillow structure is commonly observed over only 100 m at the top. Otherwise, the typical pillow structure is distributed only sporadically within this unit bed. A variety of pillow structure occurs commonly beneath the pillowy upper crust of the unit bed M_1. It is about 100 m thick. The structure is called a hyaloclastic pillow structure in this paper. It is in part interlayered with the ordinary pillows. The hyaloclastic pillow structure in boring cores is moderately well correlated with ~~them~~ it in the adjacent cores. It implies at least that it occurs predominantely in a limited horizontal layer. A lense is surrounded by the chilled basaltic margin formed by many small convex surfaces compared with them of the ordinary pillow structure. The interstices are filled with hyaloclastic materials and small basaltic fragments. Hyaloclastic materials are often irregularly formed. They are round, angular and also platy. The torn feature is commonly observed. They are mostly about 1 cm or less in short axis. Basaltic fragments are 1 to several centimeters in diameter. There is no hyaloclastic pillow in the middle and lower parts of unit bed M_1 as far as observed in the field. There is no chemical sediment in the unit bed as far as investigated.

Bedded structure is rarely found within it.

Gabbroic facies occur in the lower part of unit bed M_1. It is classified megascopically into three facies in the field: gabbro, fine gabbro and diabase from the most coarse grained facies to finer one. Minerals in gabbro are more than 5 mm in the average grain size, while they are just distinguishable each other in diabase and coarser in grain size than in the ordinary basalt. Fine gabbro is an intermediate facies between gabbro and diabase. The change of grain size from gabbro to basalt is more gradual to the upper and lateral sides, but rather abrupt to the lower one. Gabbro and fine gabbro facies retain fairly well pyroxene and even calcic plagioclase. The possible primary hornblende occurs preferentially at the lowest part. Acidic facies with graphic intergrowth of quartz and alkali feldspar occurs just inside the upper margin of gabbro. It is quartz diorite. The distribution of three kinds of gabbroic facies and acidic ones is shown in Fig. 5. It is remarkably irregular in form. The important thing is that gabbro grades gradually into the ordinary basalt. There is no definite boundary between basalt and gabbroic facies. The structure of the boundary between the Lower and Middle Støren members is not completely obvious. The boundary is exposed in the western outside of area mapped. It is quite conformable. A red chert bed on the unit bed L_6 is overlain by the M_1. The feature is not obvious in the western margin of area mapped. There may be a fault between two members. The boundary runs along the foot of a cliff. To the east the gabbroic facies intrudes into the Lower Støren member. The unit bed L_4, L_5 and L_6 are invaded by the gabbroic facies. The boundary is, however, not obvious as a whole. Further eastward a fault extending from the west restricts the northern boundary of the M_1 and contacts with the uppermost horizon of L_2 unit bed. Thus the reddish brown colored

rocks expose along the fault. A couple of the northern anticline and southern syncline in the Lower Støren member may be resulted from the fault movement.

Three subordinate unit beds of the Middle Støren member occur to the east. They consist of pillow lavas overlain by red chert bed, respectively. They all including the main unit bed M_1 become upward more reddish brown in color. They are followed to the west through the boring cores. They all wedge out, however, around the Høydal deposit as shown in Fig. 6. There are two mineral deposits which were mined before in the open-pits. The main deposit is found in the Høydal open-pit and the other in an another small open-pit, called the Eastern one in this paper, 600 m east of the Høydal open-pit. The unit bed M_3 and M_4 thin out around the Eastern open-pit. Both unit beds are found in the boring core No. 27, but not in No. 31 (Fig. 6), which was digged more deeply. The boring No. 28 digged in the south of the No. 27 attained the mineral deposit through two red chert beds from the lower horizon, though No. 27 did not detect any sulfide layer. It seems that the Eastern deposit occurs on the subordinate unit bed M_4. The upper half of M_2 in the boring No. 31 is heavily pyritized and altered, while the M_2 in No. 27 and 28 digged more close to the Eastern open-pit does not indicate any mineralization. Thus, the mineralization which altered the unit bed M_2 in the boring No. 31 could not result in the Eastern deposit, but in the main Høydal deposit or some others buried deeply. The unit bed M_1 extends probably to the footwall of the main Høydal deposit, if the upper surface comes straight up from the boring No. 30 through No. 31. The thickness of the underlying unit bed M_2 decreases, however, to the Høydal open-pit, about 150 m in No. 30 and about 110 m in No. 31. The unit bed M_2 may occur still below the

Høydal deposit, if the M_2 becomes thin to the Høydal deposit in the above ratio. There is an another evidence to support the latter possibility. The unit bed M_2 and M_4 display well the typical vertical change of feature: massive at the bottom and pillowy at the top. Whereas the unit bed M_1 exhibits poorly the pillow structure, but does well the hyaloclastic pillow structure. The basalt underlying the Høydal deposit is remarkably pillowy in the open-pit. It seems likely, therefore, that the Høydal deposit occurs on the unit bed M_2 of the Middle member, but the Eastern deposit does on the unit bed M_4. It implies that two mineral deposits around the Høydal open-pit occur in the different horizons, respectively.

The Høydal deposit together with the Eastern one is of strataboud pyrite-chalcopyrite deposits of basaltic affinity. They belong to the Besshi-type in Japan (Kanehira and Tatsumi, 1970). The occurrence of country rocks is fairly shown in the ruin of Høydal open-pit. The underlying pillow lava, probably the unit bed M_2, is highly altered by hydrothermal solution. Sericite and quartz as secondary minerals occur commonly and also pyrite dissemination prevails much through the underlying rock. The highly altered zone is over 50 m in maximum thickness. Pillows become upward small in diameter. Siliceous sediment interlayered with sericite-rich one rides on the small pillow facies. It is heavily disseminated by pyrite. The siliceous sediment grades upward into the sulfide deposits. They consist of pyrite and chalcopyrite with a bit of sphalerite. A red chert bed occurs on the sulfide layer in lenticular form. It is the uppermost constituent bed of Middle Støren member (Fig. 7). The pyritization in pillowy part decreases westward. Pillows interlayered with fine grained volcanic materials occur far from the Høydal deposit. Each layer is less than 1 m thick and reddish brown in color.

Eruptions of Middle Støren Member

The main unit bed of the Middle Støren member displays the ordinary and hyaloclastic pillow structures only in the upper margin. The rest of the M_1 shows hardly any water-chilled structure. The central part is occupied by gabbroic facies, which grades upward and laterally into the water-chilled facies. The change of grain size from gabbro to ordinary basalt and even to pillow basalt is perfectly continuous as a whole, though the lower part of gabbroic facies intrudes into the Lower Støren member. The occurrence of quartz diorite facies indicates that the magma was kept in the molten state for a long time, so that the magma can produce more differentiated facies. The previous papers regarded the gabbro as an intrusive rock. They did not show, however, any evidence for the intrusive origin. Chadwick et al. (1964) say, for example, that the intrusive boundary of gabbro is not clear. The contact margin of gabbroic facies has never been detected by any geologists so far. Gabbroic facies is distributed very irregularly as shown in Fig. 5. Nevertheless, they cut the boundaries of rock units only in the lower part, but never in the upper part. The author's mapping was carried out to the farther east and west from the Høydal area shown in Fig. 2. There occur five gabbroic facies in the adjacent area of Høydal (Carstens, 1952). They occur mainly in the lower part of the extremely thick rock unit correlated with the Middle Støren member. They intrude in part into the Lower Støren member, but never into the Upper Støren one. If gabbro intrudes later than the emplacement of any parts of the Middle or Upper Støren member, it could rarely happen that it does not cut the boundary between rock units in any places. It is also noteworthy that gabbroic facies occur exclusively in the extremely thick rock unit, though there are many thin-bedded rock units around the area. It is impossible that the whole Middle Støren member including the gabbroic facies is regarded as an intrusive sheet, because the water-chilled structure occurs even in part in the member. The occurrence of main unit bed in the Middle Støren member indicates strongly that the gabbroic facies is not an intrusive body, but represents the slowly cooled part of thick lava flow as the product of successive eruptions. It was emplaced in a short period through a rather successive coming-up of magma, so that neither chemical sediment nor clastic one was deposited during the activity. The main unit bed may be more than 30 km^3 in volume, if it continues downward about the same distance with the lateral extension. Characteristics of the Middle Støren member may be acounted for by the following mode of submarine eruptions.

The great activity of Middle Støren member began with the rather explosive eruption to produce the hyaloclastic pillow lava. As the eruption turned into the calm outpouring of magma, the ordinary pillow lava overlay the preceding hyaloclastic one. The Middle Støren member is about 200 m thick in this stage. Magma which was still successively coming up was not outpoured on the sea floor, but intruded under the pillowy lava beds as products of the preceding volcanic eruption. The eruptive center may be situated on a plane through the gabbroic facies. As a result of the successive intrusions below the pillowy crust the hot and still-molten layer increased the thickness and pushed the pillowy crust up. Intermittently, the flank of growing Middle Støren member was broken out to extrude pillow or massive lavas. When the volcanic activity declined, the Middle Støren member was more than 1 km in thickness. More than 500 m thick molten magma reserver was formed mainly in the lower part of Middle Støren member. It could be regarded as

a submarine lava lake covered by the water-chilled blanket of pillowy lava. The crystallization of molten magma could proceed as a whole downward from the upper pillowy chilled crust. Gabbroic facies occur in the lower half of a single unit bed, and further the most coarse grained gabbro is situated in the lower part within the whole coarse grained facies. Quartz diorite occurs at the top of the most coarse grained facies and roughly parallel to the general trend of bedding planes in the area. It implies that the crystallization differentiation took place in the submarine environment. The successive ascending of the voluminous magma would be responsible for the crystallization differentiation within a single pillowy unit bed M_1. After the waning of main stage of the Middle Støren activity red chert was deposited mainly to the east, though it is probable that the molten magma was still preserved within the unit bed M_1.

After the emplacement of Middle Støren member the mode of eruption of the Støren volcanics changed slightly. The occurrence of pyroclastics and massive basalt lava is characteristic of the Upper Støren member as described later. Exactly speaking, both mineral deposits do not occur directly on the main unit bed M_1. They occur on the unit bed M_2 and M_4, respectively. From the volcanological point of view, however, three pillowy subordinate unit beds of Middle Støren member are essentially products of the Middle Støren volcanism. Thus, the formation of mineral deposits could be genetically related to the waning stage of peculiar volcanism of the Middle Støren age. Considering the places, where mineral deposits occur, they are not located just above the volcanic center of unit bed M_1 inferring from the occurrence of gabbroic facies. In the case of Høydal main deposit it is at least about 800 m away from the probable volcanic center. Nevertheless, three subordinate unit beds, M_2 to M_4, first occur around the place of Høydal open-pit. They thicken eastward for 1.5 km and disappear. There is no positive field evidence on the flowing direction of them. Their western margins are quite ordinal. No special feature was detected on them, despite many boring cores are available. On the contrary, their eastern margins are heavily covered by moraine. It is likely that the source vent through which those pillowy lavas were erupted are situated around the Høydal open-pit. It is noteworthy that the unit bed M_2 underlying the Høydal deposit first appears around the Høydal open-pit and continues to the east. In the same manner, the unit bed M_4 underlying the Eastern open-pit extends to the east. Thus the volcanic events after the emplacement of main unit bed M_1 could be infered as follows.

The upper surface of main unit bed might have bulged a little. It is probable that several parasitic craters and fumaroles were formed around the main volcanic edifice above the intrusive magma. There was one of parasitic craters in the place of the present Høydal open-pit. The unit bed M_2 was erupted from the crater and flowed down to the east at the present position. The hydrothermal activity which began at the Høydal crater after the outpouring of lava flow M_2 is responsible for the mineral deposit in the present Høydal open-pit. It could have been a little explosive, because the pillowy upper part of probable unit bed M_2 is partly brecciated and silicified around the Høydal open-pit. Those features indicate also that the main pass through which the hydrothermal solution came up is shown by the silicified part of the underlying volcanics. The sulfide deposit does not occur, as a whole, over the silicified part of underlying volcanics. It seems likely that the Eastern deposit was formed in the same way. The underlying unit

bed M_4 is silicified in the upper pillowy part. The brecciation of unit bed M_4 is not obviously observed.

In the case of central eruption as assumed in the Middle Støren member and Upper Støren one as well the thickness of volcanic pile should decrease laterally, as it goes away from the volcanic center. The stratigraphic columns in Fig. 4 do not indicate such a remarkable tendency. The thickness is rather uniform through the area mapped. The widely areal mapping over the Høydal area could give some suggestions on the situation of the volcanic edifices in the Middle Støren member. There occur five gabbroic facies in the member correlated with the Middle Støren one in the Høydal area. It seems that the great activity of basaltic magma took place simultaneously in many other places around the Høydal area. Thus, it is probable that the flank of each volcanic edifice in the Middle Støren member was intercepted to spread more widely by the adjacent gigantic basaltic masses.

Upper Støren Member

The Upper Støren member is characterized by the eastward thinning unit beds. It is about 700 m thick in the thickest western part and becomes eastward less than 100 m thick. The basal unit bed of Upper Støren member ~~here~~ is designated strata beneath the unit bed U_6, which is the lowest one followed through the area. The overlying unit beds consist predominantly of basalt lavas. The facies change within a single lava is recognized in some unit beds, so that a pillowy lava grades eastward into conglomerate through massive lava. The basal unit bed is characterized by the occurrence of pyroclastic beds. It is about 150 m in the maximum thickness and consists probably of more than ten beds. However, the complete stratigraphic correlation among them is rather difficult. Thus, they all are designated the basal unit bed, though several red chert beds occur in it. Some single beds are distinguished, however, from the others in the area which it is possible.

The reliable geologic sequence of the basal unit bed was obtained to the east from the Høydal open-pit because of well exposures and many available boring cores. In this area the drilling data is fairly consistent with the surface observation. The U_1 to U_6 are nominated for beds, not for unit beds, in the ascending order. They are not intercalated with any chemical sediment. They all are products from more successive eruptions compared with the others. Thus, their geologic meaning is a little different from the others. On the contrary, the stratigraphy has been established rather poorly to the west. The boring No. 32 shown in Fig. 5 does not save much trouble. It missed to catch any bed in the basal unit bed. It is probable that the boring No. 32 was digged through the

fault plane accompanied by the intrusion of porphyritic andesite dikes. Another possibility is that the basal unit bed characterized by the occurrence of pyroclastic beds is located above the columnar section shown in Fig. 5. The geologic sequence was well established, however, in the central area from the Høydal open-pit to the west until a fault line which runs to the N 60° E direction. It depends on the rather good exposure. The drilling No. 38 was digged in the further eastern part. It showed that there is only one unit bed in the basal part. The western area is from the fault line to the margin of mapped area.

Stratigraphy of the basal unit bed in the eastern area is shown in Fig. 6 on the basis of drilling data. The new bore holes were digged more deeply than the old ones. The persistent differences are recognized between the new and old boring data, and also surface survey. The basal unit bed of Upper Støren member in the eastern area is composed of six beds. The lowest bed U_1 is lapilli tuff to tuff and green to pale green in color. It consists of vesiculated basaltic scoria with a minor quantity of lithic fragments. The scoria are angular, but attenuated usually. They are 5 to 10 mm in diameter. The U_1 is moderately bedded as a whole because of the attenuated scoria and phyllitic on the surface. The distribution is restricted in the quite narrow area around the Høydal open-pit. On the surface it does not occur in the Høydal open-pit. It occurs in the nearby place and is followable about 100 m to the west. It is found, however, in the new boring cores digged below the Høydal open-pit (Fig.6) and also 300 m east. It may be less than 1 m on the average thickness. The fragments of red chert ~~is~~ are characteristic of the second bed U_2. As a whole the bed U_2 displays very dirty appearance.

Matrix is reddish brown or partly green in color. Reddish brown and pale grayish color in basalt perhaps resulted from bleaching. The fragments consist of basalt and red chert. Basaltic fragments are subangular or even round. The fragments of red chert are usually irregular. They show commonly torn-form. No graded texture is observed either in the cores or on the surface. The bed U_2 extends about 1,400 m from the Høydal open-pit to the east, while it is not found to the west. The old borings show well the occurrence of bed U_2, while the new ones digged more deeply does not catch it, except less than 2 m in No. 39. The bed U_3 is found in the old boring cores around the Høydal open-pit, but not on the surface. On the contrary, it occurs on the surface to the east, while not in the new boring cores. The bed U_3 may be 20 to 30 m thick to the most eastern part of distribution. It is brecciated pillow lava. Pillows are very strongly broken to fragments, mostly 10 to 20 cm in diameter, so that the original pillows are found very sporadically in cracked appearance. No grading is observed. The interstices between fragments are commonly filled with siderite. The bed U_3 grades eastward into conglomerate which consists of predominantly of basaltic fragments. They are commonly about 1 cm in diameter. However, the gradual change from brecciated pillow lava to conglomerate is not observed on the surface. Consequently, some doubt is left about it. The bed U_4 is reddish brown colored tuff breccia and shows the graded structure in a cycle. The matrix is stained more strongly. Basaltic fragments are rather round and depressed slightly, especially at the top of the bed. The interstices are usually filled with reddish brown materials. To the east the graded tuff breccia is overlain by the banded sandy layer composed of reddish brown volcanics. It is distributed at least 900 m

to the east from the open-pit, but about 100 m to the west. The bed U_5 is tuff breccia. It is characterized by the graded structure in a cycle and the common occurrence of limestone fragments. Basaltic fragments are abundant to the bottom. They are angular to subangular in form and less than 10 cm in diameter. Calcite occurs commonly as limestone fragments and also in mat rix. Basaltic fragments together with limestone ones display fairly the graded structure in a cycle. The finer attenuated scoria take place also in the graded structure. They increase upward and are always bigger than basaltic fragments at the same place. The bed U_5 is traceable more than 800 m from the Høydal open-pit to the east only through the boring cores (Fig. 6). Several thin basalt lavas overlie the above basal bed, while they underlie the unit bed U_6 followable through the area. Those subordinate basalt lavas are usually thinner than 10 m and intercalated with chemical sediments. The constituent minerals of those chemical sediments are different at the localities. The surface obeservation and the old borings digged into about 100 m depth show the predominance of pyrite-quartz beds, while the new borings digged deeply do the predominance of red chert beds (Fig. 6). There is a basaltic sill just below the boundary between the Middle and Upper Støren member. It intruded along the ore horizon, but in part into silicified small pillow facies. Its rather greenish colored rock is easily distinguishable from the grayish host rock, though the sill itself is slightly sericitized.

The basal unit bed of Upper Støren member in the central area consists of tuff breccia and basalt lava in the ascending order. The tuff breccia displays well a single cyclic grading. Matrix consists of fine basaltic fragments being predominantly angular.

Fragments are composed of basaltic rocks. The fragments more than 10 cm in diameter are found commonly to the bottom. Some of them show bread-crust structure on the crust and are a little vesiculated in the core. Most of them consist, however, of massive and angular basaltic rock. Limestone fragments occur commonly in breccia and in matrix. It is overlain by weakly banded sandy layer. The tuff breccia is probably 5 to 10 m thick. This tuff breccia is directly overlain by a pyrite-quartz bed at the point of 300 m west from the Høydal open-pit. A massive basalt occurs, however, between the tuff breccia and pyrite-quartz bed to the farther west. The similar one occurs also to the west over a fault running the N 60° E direction.

The volcano-stratigraphy of basal part overlain by the unit bed U_6 was hardly established in the western area across a N 60° E fault. The total thickness of the basal part is about 150 m at the western part of the fault. It decreases gradually to the west and becomes about 10 m at the western margin of area mapped. Several red chert beds occur in the basal part. Thus, according to the author's definition, it is composed of several unit beds. It consists, as a whole, of basalt lava interlayered with red chert beds, though two characteristic tuff breccia occur to the bottom. A peculiar tuff breccia occurs first at the bottom of the Upper Støren member in the just western part across a N 60° E fault. It extends to the western margin of area mapped. It consists of dark brownish basaltic fragments in green colored basaltic matrix. Basaltic fragments are about 10 m in the average diameter. They are often spindle-like in form, but very irregular. Amygdaloidal texture is very common in the core of fragments. They are always coated by pale greenish alteration halo ~~is~~ pulled out from the edge of

spindle-like form into the matrix. It is called rimmed tuff breccia in this paper. The tuff breccia which is similar to the bed U_5 in a respect of limestone fragments and graded structure occurs above the rimmed tuff breccia, though the attenuated scoria are more abundant in the U_5. It is probably correlated with the bed U_5. If so, it extends more than 2 km over the Høydal open-pit.

The unit bed U_6 overlies the basal submember to the west, but it extends a little to the east across the N 60° E fault line. It is slightly grayish green compared with the ordinary green colored basalt. It might be altered more or less by hydrothermal solution. It displays poorly the pillow structure. The unit bed U_6 is overlain by pyrite-quartz bed. The subangular to round fragments of red chert are observed in the pyrite-quartz bed at one locality. The overlying unit bed U_7 could be called volcanic breccia. It consists predominantly of basaltic fragments with a little quantity of matrix of the same material. Fragments are angular to subangular. They are very similar to the unit bed U_3, though the fragments coated by chilled margin are rarely found in the U_7. The U_7 does not show the bedded structure, though the slightly depressed fragments display weakly a kind of platy structure. In outcrops the spaces between fragments are not filled usually. The unit bed U_8 is as a whole coarse grained through the area, though the grain size within the unit bed is rather variable. It is less than 100 m in thickness. It becomes a little thicker to the west. The pillowy structure occurs only for 300 m at the western margin of area mapped. The coarse grained facies show diabasic texture. It consists of hornblende-albite, and differs from chlorite-albite with or without relict pyroxene in the prevailing mineral assemblage. Pyrite-quartz bed occurs under the U_8 and also on it. The contact feature between pyrite-quartz beds and the basalt is observed in several localities. It seems to be fairly conformable. It is not impossible, however, to regard the main part as the intrusive sill. If so, the boundary between pillowy and diabasic units must be somewhere on the cliff facing the road No. 700. The pillowy top of U_8 is slightly silicified in the outcrop along the road No. 700. Mineral deposits of the Kattdalsgruva occur on the pillowy part. There are many outcrops of tuff breccia along the northern foot of Høydalsfjellet correlated with the overlying horizon of the unit bed U_8. The feature is not well observed at the above outcrops. It consists probably of basaltic fragments, angular to subangular, and moderate quantity of matrix. It is followed more than 1 km. However, it is not designated especially, because the whole feature is not obviously observed. It may be the brecciated basal part of U_9.

The unit bed U_9 is followable more than 1.6 km to the east from the vicinity of Høydal open-pit. It is as much as 50 m thick. Its western 1 km is moderately pillowy at the top and even at the bottom. Then, it becomes farther eastward massive and even coarse grained especially at the bottom. The transition of both facies happens rather abruptly (Fig. 9 and 10). The eastern end is not observed on the surface. A red chert bed occurs on the eastern massive part. The westward thinning-out of the red chert is well observed on the glacial surface. The unit bed U_{10} is followed through the area mapped. It is about 300 m thick at the western margin in the area. It becomes gradually thinner to the east. The reliable measurement at the most eastern place

indicates about 30 m in thickness. The upper half is pillowy, while the lower one is rather massive as a whole. The pillow structure develops, however, through the bed in the western margin. The pillow structure becomes upward more well formed. The pillows apt to be a little smaller at the uppermost part than them in the main part. The pillows at the eastern part are moderately stained by reddish brown color at about 50 m thick part of the top. The matrix is highly stained. Pillows and their matrix are more strongly stained toward the top. The whole unit bed is overlain by a red chert bed. The vertical change in the feature of basalt is roughly the same with one in the western part. This part of the unit bed U_{10} is overlain by alternation between reddish brown small pillow lava and pillow breccia, and further eastward by alternation between reddish brown colored layered sediments and sandstone which consists of green and reddish brown grains of basalt. The alternated part at the top of the U_{10} becomes more abundant in layered materials to the east. Even conglomerate occurs in the layered part. It is about 1 m thick and consists exclusively of angular fragments of reddish brown basalt. The whole unit bed U_{10} mentioned above is overlain by a red chert and further by two thin basalts, each of which is overlain also by a red chert bed. The reddish brown color in the unit bed U_{10} disappears to the eastern margin. It becomes green colored massive basalt covered by red chert. The brecciated fragments of pillows ~~was~~ were found between massive green basalt and red chert in the most eastern end of the probable U_{10}. 5 cm thick limestone bed is found between the pillowy U_{10} and the overlying red chert in only one outcrop of the central part. The unit bed U_{11} is pillowy to the west and moderately coarse grained to the east. Furthermore, the pillow structure develops at the upper part, whereas the coarse grained facies develops more at the lower one. The transitional zone is occupied by massive facies. The U_{11} grades toward the eastern marginal part into brecciated lava and furthermore conglomerate. In the brecciated facies fragments are usually angular. Limestone fragments are commonly found, but a little in quantity. The unit bed U_{11} is a little more than 100 m in thickness in the western pillowy part. It becomes gragually thinner to the east. It is only several meters in the brecciated part. The unit bed U_{11} is overlain by pale green colored tuffaceous materials to the west, but by reddish brown ones intermingled commonly with limestone to the eastern massive part. The change of appearance within the unit bed U_{11} is rather similar to one within the unit bed U_{10}. The unit bed U_{12} is found only in the western area bordered by a N 60° E fault as shown in Fig. 2. The eastern continuation is not detected on the surface despite of moderately good exposures. The U_{12} is coarse grained unit bed, which does not display the pillowy structure at least within the area mapped. The unit bed U_{13} occurs in conglomerate. It is less than 100 m thick and about 2,4 km in the horizontal continuation. It is coarse grained one as much as the unit bed U_{12} in appearance. The pillow structure occurs only in part. It seems to be lava flow.

Volcanism in the Upper Støren Age

Referring to the surface observations and boring cores, the areal distribution of each basal bed is estimated as shown in Fig. 8. It is projected on a plane parallel to the present bedding planes. The occurrence of basal beds shows obviously that most of them are distributed either to the east or to the west from the Høydal open-pit. For example, the unit bed U_2 to U_4 are found only to the east. Among them the U_2 and U_3 seem to extend rather parallel to the present surface line. They do not occur to the depth. Whereas, the U_5 belongs rather to the bed buried deeply to the east. The U_4 is found on the surface, but also in the boring cores digged deeply. It is roughly four times more in thickness at the place about 400 m deep below the surface. The rimmed tuff breccia is a bed, which is distributed only in the western area as far as mapped. It becomes eastward thick to the N 60° E fault, but it is not detected in the eastern side across the fault. The further eastern continuation could be found in the depth or eroded out already. It is also probable that it did not occur primarily in the eastern side of the fault. The bed U_1 occur only around the Høydal open-pit. It is a minor deposit. The U_5 is probably only a bed, which is widely distributed over the Høydal open-pit. It is noteworthy that the bed U_5 is pyroclastic fall deposit, the distribution of which is not affected so distinctly by topographic high or low. The occurrence of basal unit bed mentioned above suggests strongly that the eruptive center of basal ~~unit~~ beds is situated in the vicinity of the open-pit, in which the Høydal deposit occurs, though they did not derive from a eruptive center. There have been active volcanic centers in the vicinity of fumarole, from which the

the hydrothermal solution came up to form the Høydal deposit, at least, from the Middle Støren age to the early stage of the Upper Støren one.

The Upper Støren age began with the eruption of bed U_1 followed by the emplacement of bed U_2. The U_1 is a minor bed. It is distributed only around two open-pits and very thin in thickness. There does not occur, however, any other well-vesiculated pyroclastic rock as the U_1 in the Høydal area. The U_1 together with the other pyroclastic rocks in the ~~lower part of~~ basal unit bed could result from explosive eruptions. Thus the Upper Støren age is characterized by repeated explosive eruptions in the beginning. The shallowed depth of the sea may be responsible for the change of mode of eruptions. No field evidence is available to estimate the depth of the sea during the volcanic activity of Lower Støren age. In the previous chapter it was suggested that the depth of the sea became deep through the later stage of Lower Støren age. Then, the thick unit bed M_1 outpoured to the sea floor. It is about 1 km thick. It implies that the sea could be filled up with lava, if the sea is about 1 km deep at the beginning of the gigantic and rather continuous extrusion. It seems unlikely that the top of Middle Støren member emerged on the sea surface, because the outer crust of unit bed M_1 is moderately pillowy. Furthermore, the outer four subordinate unit beds are remarkably pillowy. No conglomerate occurs just on the Middle Støren member. Consequently, the Lower Støren member was buried more than 1 km deep from the sea floor at the eruption of U_1. It is not necessary that the sea floor would be more than 1 km deep at the beginning of Middle Støren age, if the transgressive tendensy during the later stage of Lower Støren age lasted to the end of Middle Støren age. The author supposes, in

any way, that the sea was very shallow in depth at the initiation of Upper Støren volcanism. The bubbling of magma would not take place at more than 500 m deep sea because of the heavy hydrostatic pressure. The prevailing occurrence of brecciation, current action, oxidized pillow lava and conglomerate in the Upper Støren member suggests strongly such very shallow environment during the Upper Støren age. The Upper Støren member is, however, about several hundred ~~kilo~~meter in thickness. Thus the transgressive environment must have prevailed also through the Upper Støren age.

The facies of iron sediment may be indicative of the depth of the sea. Generally speaking, pyrite,siderite and hematite sediments indicate shallower sea environment in this succession. The occurrence of iron sediments in the Høydal area seems to be inconsistent with the depth of the sea estimated previously. Hematite beds, that is to say red chert beds, are common through the Lower and Middle Støren members, if the sulfide stratabound deposits are ruled out. Pyrite beds, pyrite-quartz beds in this case, occur moderately in the lower half of the Upper Støren member. Siderite is found only as vein formed mineral in brecciated lavas of the Upper Støren member. The common occurrence of pyrite bed in the Upper Støren member may be related to the formation of stratabound sulfide deposits. The hydrothermal activity might have taken place intermittently after the formation of Høydal deposit and some others. It would be responsible for the reduction environment of the sea favorable for the precipitation of pyrite during the early Støren age.

Under the shallow sea environment formed newly, as discussed above, scoria tuff U_1 was flowed to the sea floor. The feature indicates that it was not suspended in the sea for a long enough to produce a sorted effect in the deposit. The shallow sea environment could prevent to produce a~~n~~ submarine eruption column, in which the sorting mechanism could work efficiently. It seems that it is not the case of U_1. ~~because the U_3 is well-graded.~~ The other model may be probable to accept in the case. The most of scoria floated onto the sea surface. A little quantity of dense scoria settled back to the sea floor. It may be the present bed U_1. The bed U_2 contains a lot of miscellaneous fragments. It seems that they were once altered by the volcanic emanation. The author suggests that the bed U_2 was derived from the crater-filled materials. There would have been a quiescent period of volcanic activity after the Middle Støren volcanism. The previous volcanic crater was gradually filled with volcanic fragments during the period. The hydrothermal activity and the precipitation of red chert took place simultaneously in the crater and also in the surrounding area. The crater-filled materials were altered and oxidized by volcanic emanation to form white to reddish fragments. The Upper Støren activity started with the blowing-up of scoria tuff U_1 probably accompanied by many minor eruptions. Debris in the previous crater were gradually brought up by the ascending magmatic column. They ran over the crater rim and slided down to the sea floor around the crater. The bed U_2 may be formed in such a manner, so that it is regarded as a kind of mud flow deposits. There are many present examples that a new activity of volcanism started with volcanic earthquakes accompanied by many minor eruptions of pyroclastic materials and ascending of the crater bottom. The volcanic activity of Upper Støren age began just like this way. The following eruptions would be regarded as the main stage of the Upper Støren volcanism.

The crater formed newly may be situated a little west from the Høydal open-pit and not far from the previous one. A lava flow U_3 was erupted from there. The cracked pillows occur commonly within the bed U_3. Nevertheless, they are rarely broken down into fragments in the vicinity of open-pit. The fragmentation in the bed U_3 took place very strongly at the marginal part of the lava, so that it can be hardly decided, either pillows once formed were broken down into fragments, or lava was quenched quickly to crack up itself. Those features show that it formed once pillow lava and was broken down later into fragments. The stir by the boiling water or the rolling-down of pillows may be responsible for the fragmentation. Those fragments are mostly depressed slightly. A conglomerate bed occurs laterally in the same horizon with the U_3. Red chert fragments are found a little in it. It should be emphasized that a part of volcanic edifice emerged from the sea to be eroded out in this stage. The bed U_4 is the oxidized one, but overlain directly by pyrite-quartz bed to the east. Rimmed tuff breccia in the western area may occur on or under the horizon of bed U_4. The same kind of pyroclastics was reported by Carlisle (1961). He says that the small pillows were stirred in the hot water and altered rims were pulled out to make a fringe of small pillow. It seems likely that the rimmed tuff breccia was formed by the same way.

The bed U_5 is well-graded tuff breccia. It displays apparently two cyclic grading. The lower cycle is formed by the graded basaltic fragments. The attenuated scoria in this part do not show clearly the graded structure. The upper cycle is formed by the graded basaltic scoria. Nevertheless, both basaltic fagments and scoria must have been derived from a single submarine eruption. Because basaltic fragments characteristic of the lower graded part decrease gradually upward, while basaltic scoria increase upward to display the upper graded cycle. There is no stratified material between two graded parts. Furthermore, many scoria are trapped in the interstices of the lower graded part. Consequently, the feature indicates that a single continuous eruption carried up two kinds of material together, fragments and scoria. It seems unlikely that basaltic fragments are the first product at the eruption, because, if so, the fragments would settle back more quickly to the sea floor without the mixing of scoria. Those fragments and scoria were suspended once in the sea water before the deposition. As the eruption declines, the suspended materials fell down to the sea floor. Tuff breccia U_5 would be sorted most effectively, as the materials fall down in the sea water. The dense fragments would reach the sea floor quickly, and the light scoria would follow them slowly. Considering the feature of tuff breccia U_5 it is possible to infer somewhat the depth of the sea at the eruption. The magma is bubbled even in part. It is said that an eruption does not produce the bubbled fragments, either scoria or pumice, at more than 500 m deep sea. Furthermore, the sorting mechanism in the water would not work so clearly in the case that the eruption takes place in very shallow sea, ~~or~~ because most of the eruptive column bursts through the sea surface into the air. Consequently, the sea at the eruption of tuff breccia U_5 was probably about 100 to 400 m at depth. The tuff breccia U_5 is only a pyroclastic bed in the basal unit bed, which is distributed widely over the Høydal open-pit. The formation of eruption column may be responsible for the occurrence. It implies that the bed U_5 may have been erupted from the vicinity of the present Høydal open-pit. However, tuff breccia U_5 was surged even in part, so that it stirred a little the underlying deposit U_4 to take in at the bottom.

After the eruption of tuff breccia U_5 the explosive eruption ended around the Høydal area. However, the outpouring of pillowy lavas still continued in the area. The unit bed U_9 and U_{13} were probably erupted from the same crater which supplied the basal unit bed. On the contrary, the unit bed U_{10}, U_{11} and probably U_{12} flowed into the Høydal area from the western Løkken area. The unit bed U_9, U_{10} and U_{11} display the same kind of lateral facies change. They are more pillowy to the west, and more massive and even coarse grained to the east (Fig. 9). The U_{11} among them grades eastward into conglomerate through the brecciated massive basalt. The brecciated facies is not derived from the brecciation of pillowy lava, because the massive facies occurs between pillowy and brecciated facies. The U_{11} exhibits also the vertical facies change, from the coarse grained bottom to the pillowy top. The vertical facies change indicates that the unit bed U_{11} is not composit lava flow, but a single eruptive unit. It should be noted again that the author's unit bed may be not always correlated with a single eruptive unit. The eastward facies change mentioned above could result from the advancement of a submarine lava. That is to say, referring to the lateral change of rock facies, it may be possible to infer the flow direction of a lava. The unit bed U_{11} flowed obviously to the east on the present surface plane, because it grades eastward into brecciated lava from massive one. The unit bed U_9 and U_{10} flowed probably also to the east, though they lack their brecciated facies. Thus, it seems that the unit bed U_9 was erupted in the vicinity of Høydal open-pit, where the U_9 first occurs to the west, and the other two lavas flowed into the Høydal area from the farther western Løkken area. The feature of unit bed U_{10} is a little different from the others. The eastern pillowy part of the U_{10} is stained, especially at the top, by the reddish brown color and overlain by the reddish brown layers which contains conglomeratic facies. Referring to the flow direction estimated previously, the reddish brown colored facies of a pillow lava could represents the marginal facies of a lava. The similar feature was described in the Olympic peninsula, U.S.A. (Park, Jr., 1946). Most of layered sediments may consist of hyaloclastic material derived from the quenched magma. Such a kind of material could be brought to the marginal apron by the submarine current. The fragments of basalt overlying the U_{10} and U_{11} would be the eroded product of the underlying basalts. The erosion of submarine pillow lava or terrestrial lava has not been observed in the Høydal area.

The cause of facies change within a lava is rather still speculative. Temperature and voratile content of a lava could controll two distinct features of a submarine lava: pillowy and massive. Two kinds of feature in a terrestrial lava are well known: aa and pahoehoe. The high viscosity of magma caused by the high temperature and high water content are favorable for making ~~aa~~ pahoehoe lava. Thus, it happens often that the advanced front of ~~aa~~ pahoehoe lava is fringed by ~~pahoehoe~~ aa lava as a result of cooling and degasing of the flowing lava. The author supposes that the facies change within a submarine lava originates in the same way. When magma comes up on the sea floor, it is still hot and is charged with water enough to form pillows. As the magma flows down, it would cool and loose a lot of water. Thus the massive lava, more or less brecciated, would be formed in advance. In the same line the vertical facies change within a lava is down to attention. The surface of lava is quenched to form pillows in the vicinity of eruptive center, while the underlying part would be kept from the quenching and flow down a head loosing heat and water. As a result the advanced part of a lava would not easily

form the pillowy structure, but the massive structure and in some cases brecciated one. At the final stage when the outpouring of magma ends, the pillowy lava is underlain by still molten magma, which could form later massive rock as a result of slow solidification and upward release of water. Such a mode of emplacement was considered in the case of the voluminous Middle Støren member.

Lower Hovin Formation

The Upper Støren member is mainly overlain by conglomerate, but also grades eastward into conglomerate. consequently, basalts in the Upper Støren member are in part intercalated with conglomerate. Further the unit bed U_{13} occurs in the conglomerate bed. According to the general view ~~the~~ basaltic rocks are correlated with the Støren formation, while the overlying clastic rocks with the Lower Hovin one. In the Høydal area, however, the observed field evidence indicates that the rock-units are irregularly oblique to the time-units. It implies that the boundary between the Støren and Lower Hovin formations is rather transitional. The unconformable relationship between two formations has not been observed in the area mapped.

The basal conglomerate of Lower Hovin formation consists predominantly of basaltic fragments, some of which display the pillowy chilled margin. The complete pillows are also preserved in conglomerate. The fragments of red chert are commonly found, though they are not abundant. In a certain area, however, conglomerate does not contain any fragment of red chert. Two kinds of conglomerate with and without red chert fragments are distinguished each other in Fig. 2. The distribution of fragments of red chert apts to increase eastward as a whole. It seems to correspond to the eastward development of red chert beds in the Upper Støren member. Additionally, the fragments of acid igneous rock scarcely occur. The author observed quartz phenocryst-bearing rock as fragments at only some localities. It is unprobable that it was derived from acid tuff in the Lower Støren member outside the area mapped or the differentiated facies of gabbroic bodies in the Middle Støren member.

Because, it seems that the Støren formation has not been eroded out so deeply in the earliest stage of Lower Hovin age. No fragment of basal Precambrian rocks was observed in any place of Høydal area.

Conglomerate bed grades upward into sandstone and further upward into shale. Sandstone is pale greenish in color. Red chert grain is hardly found even through microscopic observation. Shale is grayish green in color. It is darker than sandstone. It is well bedded compared with conglomerate and sandstone. The bedding plane is easily recognizable. Sandstone and basalt occur again further southward in this succession. The occurrence of shale is about 400 m in width. Sandy facies within shale shows the south up in the north on the basis of graded bedding, whereas it does the north up in the south.

Trondheim Disturbance

Conglomerate in the Lower Hovin formation is composed predominantly of basaltic fragments with a bit of red chert ones. The similar type of conglomerate is commonly known in the Trondheim district. It was described in the locality of Venna by Vogt (1945) in detail. It is called the Venna-type conglomerate. The Venna-type conglomerate has been usually regarded as the basal one of Lower Hovin formation. The prevailing opinion is not simply acceptable in the Høydal area. Some of unit beds grade eastward into conglomerate which is different from the Venna-type one. The unit bed U_{13} streamed down in the midst of sedimentation of the Venna-type conglomerate. However, the conglomerate overlies as a whole the Støren basaltic volcanics in the Høydal area. It is probable that the Støren volcanism has still lasted anywhere after the beginning of sedimentation of the Venna-type conglomerate. It is more probable that the other volcanic edifices in the Caledonian terrene were under the sea, when the top of volcano in the vicinity of Høydal emerged from the sea surface. It could be said at least that the time-units are oblique to the rock-unit boundaries. It has been overlooked that Støren volcanics in the Høydal area are sediments for a short geologic time.

The growth of a submarine volcano would be as follows. In the primary stage, when a volcano submerges deep enough in the sea, a submarine lava is quickly quenched against the water, so that it does not flow down so easily on the sea floor. Thus, a submarine volcano grows usually in the form steeper than a terrestrial volcano. In the second stage, when the

top of the volcano approaches to the sea surface, the physiographical feature would be changed strongly. The decreasing hydrostatic pressure gives rise to more explosive eruptions, so that the volcanic center would be often destroyed and the fragmental debris would be formed more commonly. The fragmental debris formed in this way could run down to form more gentle skirts of the volcano than before. In the third stage, when a crater emerges from the sea, the form of the volcano changes again. The terrestrial lava flow enters for a short distance into the water to form the submarine one. Three distinct slopes would be distinguished in a volcanic edifice at that stage. The emerged top is rather gentle in slope. It is dissected to supply the eroded fragments into the sea floor. The middle flank is steep. It is typical of a submarine volcano and surrounded by very gentle skirt. The Hawaiian example shows well the form mentioned above (Moore and Fiske, 1969). It could occur commonly in the emerged submarine volcano that the submarine lavas are intercalated with conglomeratic sediments. The author considers that the Venna-type conglomerate does not indicate any tectonic movement in some case, but the emergence of volcanic edifice. A submarine volcano could grow up more rapidly than a terrestrial volcano until the top attains the sea surface. After then, however, the volcanic edifice would spread rather laterally. Consequently the time-unit boundaries in a volcanic formation like the Støren one apt to be oblique to the general trend of bedding.

The subsidence of the sea-floor would have progressed as a whole during the Støren age. Total value of the subsidence would be more than 2 km. The present Støren formation represents for a rather short geologic age, as mentioned above. Consequently, the subsidence should happen rather rapidly. Additionally, sedimentary facies in the Lower Hovin formation becomes upward finer in the sequence. It indicates also the transgressive environment in the Lower Hovin age. The thick Støren volcanic pile in the Høydal area is overlain by volcanogenic Venna-type conglomerate. Such a type of conglomerate does not indicate always the emergence of volcanic edifice out of the sea. It is possible to consider that the conglomerate is product from the steam explosions probably near the sea shore. In that case, however, the graded bedding could occur commonly in volcanic fragments. It is not the case in the Høydal area. It is noteworthy that fragments of red chert occur commonly in the Venna-type conglomerate. The conglomerate in the case of Høydal area contains commonly the fragments of pillow lava together with red chert. The Venna-type conglomerate is products from the emerged submarine volcanic edifice, because red chert occurs definitly in the submarine. Those occurrences indicate the regressive environment at that time. Thus the transgressive tendency has prevailed during the Støren and Lower Hovin ages except for the regressive environment in the earliest stage of Lower Hovin age.

The Trondheim Disturbance was proposed in early this century by Holtedahl (1920) on the basis of occurrence of the Venna-type conglomerate. Recent discussions on the reality of the Trondheim disturbance by Roberts (1971) tend not to estimate the significance of it. In any way it is represented by the regressive phase for a geologically short period in the Høydal area. The Lower Hovin formation overlies, however, conformablly the Støren formation as far as investigated in the Høydal area. The author assumes, therefore, that only the highest part of volcano, in which the crater is probably situated, emerged tectonically from

the sea surface to supply the Venna-type conglomerate to the flank of the volcanic edifice. Consequently, the occurrence of Venna-type conglomerate would suggest the location of volcanic center. It seems that volcanic activity declined soon after the emergence of volcanic islands. It is noteworthy, however, that volcano spreads rather laterally after the emergence of the sea surface as mentioned previously. It is possible to infer that the Støren volcanism lasted still anywhere after the sedimentation of Venna-type conglomerate in the Høydal area.

The erosion of volcanic sequence is very little before the deposition of Lower Hovin formation, even if it took place. The probable rock pressure at the basement of volcanic pile is less than 1 kb at the beginning of Lower Hovin age, if the value 3 km is acceptable for the thickness. The metamorphism of Støren formation could hardly begin at that time. Pre-Hovin metamorphism is utenable as suggested by Roberts (1972).

Intrusive Rocks

Two kinds of intrusive dike occur in the Høydal area. A large quantity of the big plagioclase megacryst is characteristic of andesite dike. Andesite intrudes in echelon form and to the N 30° E direction cutting the general strike of volcanics. It consists of plagioclase and pyroxene phenocrysts in fine grained groundmass. Plagioclase is largely altered into albite-sericite-epidote. Pyroxene is also altered into chlorite, but a few relict pyroxene retain in some specimens. Groundmass consists of epidote, albite, chlorite, actinolite and sphene as the alteration products. Those andesitic dikes are classified into two sub-types. One contains a large quantity of the big tabular plagioclase phenocryst. They reach a size up to 5 cm . The other in a minor quantity contains a lot of smaller plagioclase phenocryst. Both sub-types are easily distinguishable each other by naked eyes. However, their mineral assemblages, either primary or altered, are quite similar each other. This type of intrusive rocks may be the same with Th. Vogt's Hølonda porphyrite (1945).

The other type of intrusive dike is mainly distributed in the northern part of Høydal area except for only one dike in the Venna-type conglomerate. It intrudes to the E-W direction roughly parallel to the general strike of strata, and is very thin in thickness, less than 2 m. It is probably dacite in chemical composition. The dacite contains plagioclase and hornblende phenocrysts strongly altered into albite-sericite and epidote-chlorite-carbonate, respectively. Quartz phenocryst occurs rarely. Groundmass consists of quartz, albite, sericite, and small amounts of

sphene and apatite, either primary or secondary, in approximately decreasing order. Dacite may be correlated with an exceptional dike among the minor intrusives described by Chadwick et al. (1964).

Concluding Remarks

Because of the overturned structure the author's knowledge of the lower part of Støren formation is rather limited. It is, however, about 3,000 m thick in the Høydal area. The Støren formation in the type locality where is about 30 km far from the Høydal area is measured about 2,500 m thick. The extremely thick basalt unit bed does not occur in the type locality as far as the author visited shortly. Most of papers do not refer generally to the apparent thickness of Støren volcanics. Because the original thickness is quite uncertain even after the weak metamorphism. Strømer (1967) estimated, however, that the Støren formation in Trondheim is about 2,500 m in thickness. His measurement may have been done in the type locality. Pillows in the Høydal area are not highly flattened out. Thus the apparent thickness may not be extremely different from the original one. It seems likely that the eroded part of Lower Støren member is not so much and most of Støren volcanics are still to be observed in the Høydal area. To say the least, the author investigated more than half of the volcanic pile.

The Støren volcanic sequence in the southern wing of synform in the Høydal area preserves the original feature enough to consider the mode of eruption. It is divided into three members and furthermore into many unit beds, each of which is overlain even in part by chemical sediment. The basal unit bed of Upper member is divided into beds on the basis of boring data and field observations. In the other part, however, a unit bed is not always correlated with a single cooling unit of the terrestrial lava. The feature of unit beds is variable more or less either within a single unit bed

or in the different unit beds. The regularity in the variation of feature within a single unit bed was detected. The pillow structure develops more in the upper half of a unit bed and especially at the top, while the less pillowy or massive part is found usually to the bottom. It was proposed that pillow lava is submarine correlative to the terrestrial pahoehoe lava, while massive lava to the terrestrial aa lava. The gradual change from pillowy lava to massive one is observed. The facies change within a unit bed could be ascribed to the cooling of magma. Magma rich in water and high in temperature apts to form easily pillow lava near the volcanic center. As the magma flows down on the sea floor, it would loose water and heat. As a result, massive lava occurs at the marginal part of an unit bed. The oxidized feature occurs also at the marginal pillowy part. In this way the flow direction of lavas was estimated in the Høydal area. It flowed as a whole from the west to the east.

The occurrence of the extremely thick unit bed M_1 is characteristic of the Støren formation in the Høydal area. It may be a kind of lava flow. The repeated successive intrusions below the pillow crust was infered in the mode of emplacement. In this way the molten magma more than 20 km^3, has been kept just below the sea floor. The cooling of the magma progressed downward gradually to form the gabbroic facies. The occurrence of granodioritic facies indicates that the crystallization differentiation took place. Those coarse grained facies seems to indicate the location of volcanic vent through which magma comes up. There may be many other flow gabbros in the Caledonian terrane, because gabbroic facies have been always regarded as intrusive rock.

The formation of Høydal deposit is a conspicuous event in the latest stage of Middle Støren age. The hydrothermal activity began immediately after the eruption of lava flow with gabbroic facies and in the vicinity of the preceded volcanic center. The preceded ascent of voluminous rock unit may be responsible for the mineralization. There are several Norwegian examples which indicate the similar mode of occurrence of mineral deposits. According to author's investigation, the formation of mineral deposits in the Løkken, Sulitjelma and Vaddas mines followed the extrusion of extremely thick basaltic lava, which displays gabbroic facies at present. Further there is a similar example also in Japan. The Okuki stratabound deposit is genetically related to basaltic volcanism with gabbroic facies. The mode of occurrence is quite similar to the Høydal deposit. Consequently, it could be concluded that the successive activity of basaltic magma either with gabbroic facies or not, is favorably responsible for the formation of stratabound sulfide deposits. It may be noteworthy that the mineralization of the Kuroko-type deposit of dacitic affinity begins mainly after the ascent of a viscous lava dome. The geology of Høydal deposit is typical of the stratabound sulfide deposits of basaltic affinity. It is a general feature of them that siliceous layer overlies directly the pillowy basalt, and sulfide layer occurs on the siliceous layer. The overlying red chert bed is also found commonly. It is not known, however, if the zinferous layer occurs in a definit horizon or not, because of the paucity of data collected.

The sea became shallow during the magmatic activity of Middle Støren age, even if it did not outflow on the sea floor. The occurrence of many pyroclastic beds is characteristic of the basal unit bed of Upper Støren

member. The shallower depth of the sea may be responsible for the explosive activity. Most of them were erupted around the Høydal deposit. The basal pyroclastic unit bed is overlain by several basalt unit beds. It is infered that some of them were erupted in the vicinity of open-pit, while the others flowed into the Høydal area from the western Løkken area. The marginal part of unit beds in the Upper Støren member is commonly fringed and overlain by conglomeratic bed. Furthermore, the volcanic Støren formation is overlain by the Venna-type conglomerate in the Lower Hovin formation. The conglomerate is resulted not only from the growth of volcanic edifice, but also from the tectonic movement. Because submarine rocks such as pillow lava and red chert are contained in it. It implies the prevalence of regressive environment for a short period in the contradiction of the transgressive environment from the Støren to Lower Hovin age. This is the reality of Trondheim disturbance.

Thus, the thick volcanic pile, gabbroic facies, mineral deposits and the Venna-type conglomerate could indicate the locations of volcanic center in the Caledonian terrene, respectively. Some of them occur, however, commonly together in the Trondheim district. The estimated volcanic centers are distributed widely in the Støren formation. It suggests strongly that the Caledonian volcanism in Norway is of the center eruption.

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