2. Studies of the morpho-tectonics of the Mälar depression, Sweden.

By

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(With pl. IX—XI).

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Introduction.

The present investigation chiefly deals with mineralized breccias and joints, and their relation to certain post-Archaean rocks — dolerite dikes, the Almunge massive, Mälar sandstone, and more or less horizontal Cambro-Silurian sediments, and to the topography (for orientation cf. pl. IX—X).

The field work has been done chiefly in the summers of 1932—1936 (10 months), during which there have been recorded and studied about nine thousand joints. At shorter excursions near Kristinehamn, at Lake Vänern, in the summers of 1938—1939, and in the years 1936—1942 the studies and records were extended to more than a thousand joints in order to contrive a comparison of the Mälar joints with the joints of the Gotokarelians (its situation, cf. BACKLUND, 1936—1941). An attempt to settle the age of the latter was made during one week of the summer of 1941, when the joints on and near Kinnekulle at Lake Vänern were studied.

The dots of the stereographic projections (pl. XI, except fig. 9 and 11) represent the perpendiculars of joint planes on the upper half of the sphere, as also the zones, within the surface- and angle-true Postel net (WRIGHT 1911, pl. 11). The dots in the projections demonstrating the striae of the striated slickensides, thus, on common joint planes, represent the striae themselves; i. e. dots in the centre of the circle represent vertical striae, that is, their pitch.

A very large amount of joints have been plotted in projections in order to gain a general impression of their dips. However, when they are either pronounced, or occur close to the very fault escarpments nearest to Lake Mälaren, they are omitted. An abundance of vertical and horizontal joints are present in the more or less horizontal Cambro-Silurian sediments. In the pre-Cambrian rocks they are mostly more or less vertical.

Lake Mälaren covers an area of 1,200 km^2 according to STEN DE GEER (1910, p. 25). Thus, the study of the region described for practical reasons may have been limited fairly arbitrarily (compare Fig. 1 with pl. IX—X).

A number of gneisses and leptites, or slightly recrystallized volcanics, generally strike in W—E as indicated by stippled lines inside the compass roses of the gneisses. These strikes largely agree with the faults (pl. IX—X), limiting the lake depression in the south. However, strikes in NW occur inside the areas of the gneisses (cf. points 15 and 16 on pl. IX) thus, along topographically prominent channels, bays and firths of Lake Mälaren.

The surroundings of this lake north of the faults and of the southern Sörmland block show very few lakes as pointed out by GERARD DE GEER (1897). This probably means that the post-Archaean Mälar sandstone and possibly the Cambro-Silurian sediments, too, have until rather recent geologic time covered the Mälar surroundings protecting its gneissose basement against erosion.

1. The age of the dolerite dikes striking W—E.

The dolerite of Granholmen and Vargholmen (pl. IX—X, and Fig. 2—4) crops out together with true Mälar sandstone-fillings in fissures — especially at Vargholmen (Fig. 3—4). Less sure are Mälar sandstone-inclusions (at loc. II, Fig. 2) with evenly distributed microscopical prehnite, possibly formed by contact influence. However, it is very difficult to decide if a sandstone patch on the surface of an outcrop represents a real fissure filling in case of obliterated crossing fissures, or if the observed patch

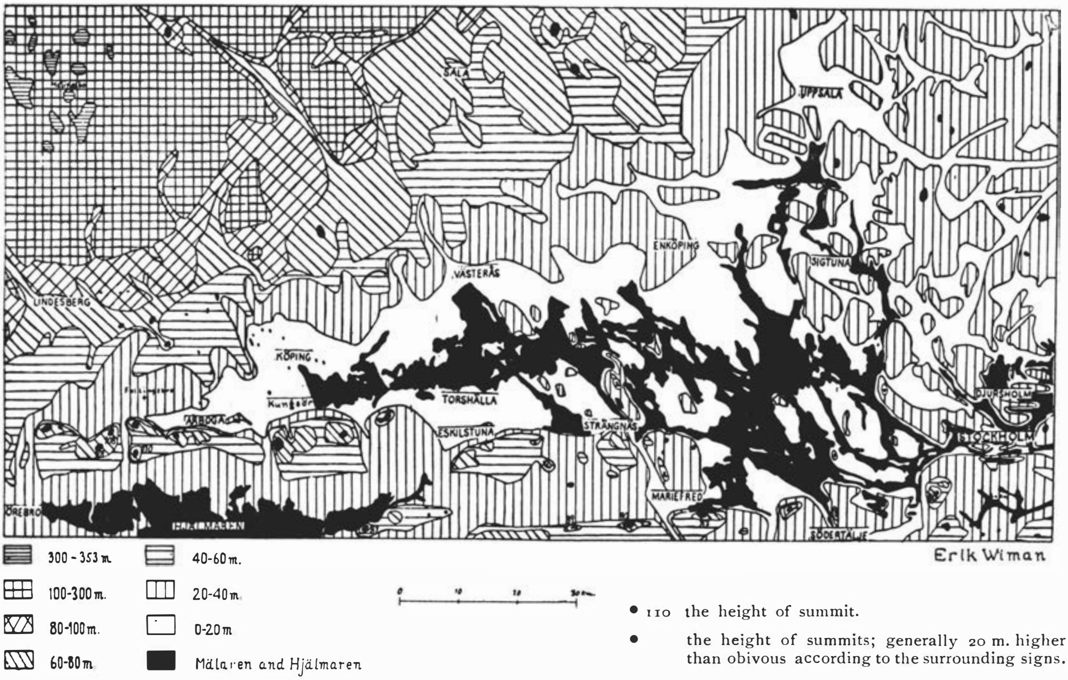

Fig. 1. The Mälar depression. Heigths of summits.

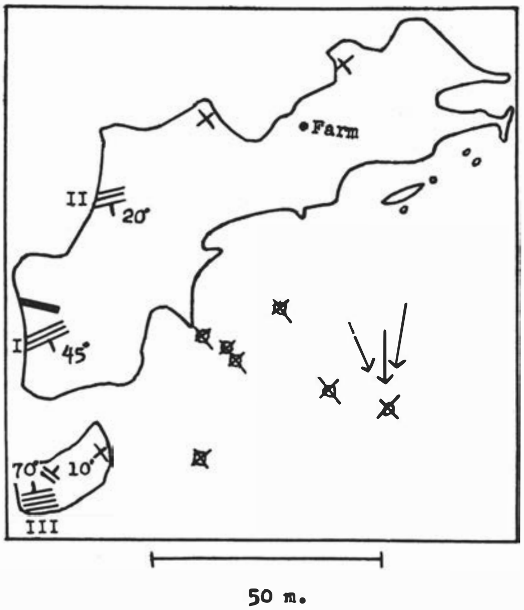

Fig. 2. Sketch-map of outcrops on Granholmen and Vargholmen (dolerite within contours). Outcrops of solid sandstone (parallel lines), sandstone filling fissures in dolerite (crosses) and breccia (broad black line). Arrows = direction of ice movements. Strike and dip of sandstone strata: loc. I, N 55° E, 45° SE, loc. II, N 70° E, 20° SE, loc. III, N 80° E, 70° NW and N 50° W, 10° NE.

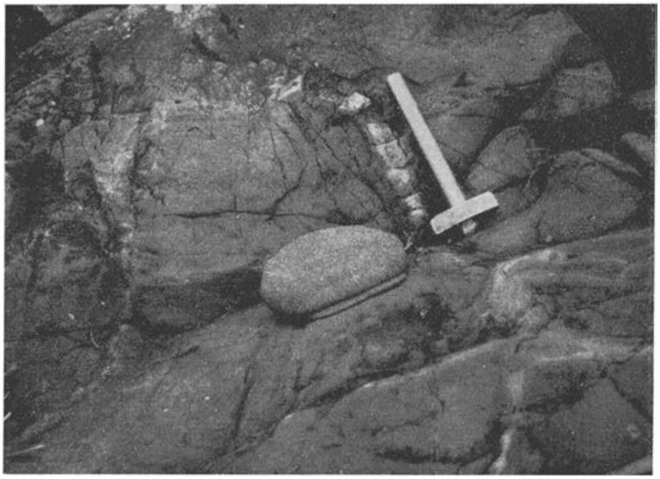

Fig. 3. Lighter sandstone filling fissures in dolerite. Northeastern part of Vargholmen. For orientation cf. Fig. 2.

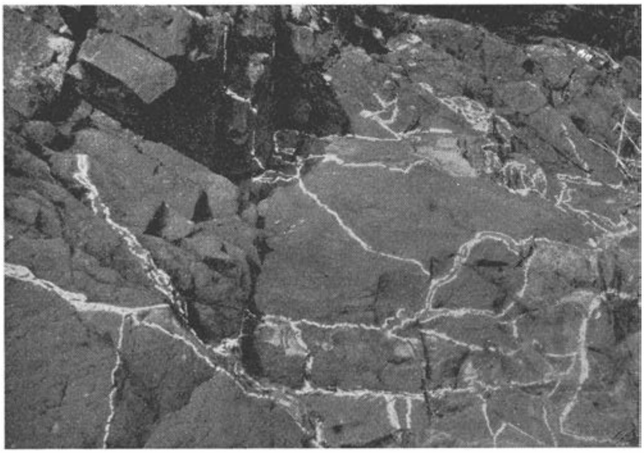

Fig. 4. Sandstone filling fissures in dolerite. The same locality as on Fig. 3. Sandstone marked by chalked lines, thus, very thin sandstone veins fully chalked.

really represents an inclusion. Thus, the dolerite is at least older than the sandstone, but possibly younger too. The sandstone discovered and mapped seems to rest on the dolerite, but it contains no pebbles of dolerite. Thus, the dolerite is probably intruded between the sandstone and rather heavy layers of conglomerate composed by all kinds of gneissose and aplitic pebbles and as represented today by large glacial boulders on the shore immediately S. of Granholmen.

Thus the dolerite is both older and younger than the Mälar sandstone, and probably of the same general age as the sandstone counted by BACK-

LUND (1941) as the molass of the Gotokarelians preserved in the Mälar depression. The Breven and the Hällefors dolerite dikes lately described by T. KROKSTRÖM (1932 and 1936) and marked on pl. IX—X, are probably of the same general molass age as the Granholmen dolerite. The dolerite of Granholmen carries plagioclase (55 weight %), pyroxene (17,13 %), chlorite representing olivine (20,47 %), ore and brown mica.

2. The age of the joints in relation to the dolerites (pl. IX).

When comparing the joint diagram of the Breven dolerite (p. 25) and the one of the Breven granite (p. 26) with the joints of the gneisses close to the dike (p. 11) one is inclined to believe that the joints of the dike represent its private property, and that joints decidedly younger than the dike are chiefly indicated only by the NW-fault discovered by KROKSTRÖM (1932) — and by joints connected with this faulting. The difference between points 12 and 27 representing the gneiss joints close to the Hällefors dolerite, and the dike joints respectively is hardly pronounced enough to allow a conclusion that all the local gneiss joints may be chiefly older than the dike. The joints, which have been open to the dike intrusions, are of course older than the dikes. These two comparisons manifest that at least many of the gneiss joints are older than the dikes.

The very diffuse character of the joint rose of the Granholmen dolerite (p. 28) is probably due to a sheet or sill appearance of the rock.

3. Short data of the general orientation of the joints in relation to massive structures and gneissose strikes.

The joints dealt with generally have a length of 2—25 m and they can very often be observed not only as joints but also as limiting and partly causing *roches moutonnées* as described by SAHLSTRÖM (1914). The less joints are, the larger is each separate *roche moutonnée*.

In post-Archaean umptekite (p. 24 — diagram for practical reasons somewhat enlarged), more or less massive granites (p. 4—8, 23, in the Fellingsbro granite p. 17—20) and Archaean porphyries (p. 2) the joints appear with strikes of NW and NE — not much pronounced. The dips of these joints are rather steep in different directions (pl. XI except fig. 9 and 11). An old pre-Serarchaean (late Archaean) age of at least some of the NW-joints is indicated by NW-strikes of amphibolitic dikes inside the area of the Upsala porphyries (ERIK WIMAN, 1930, pl. IX). The NW-dikes cut the Archaean Vänge granite at Born and Nyby, and the Archaean Upsala granite at Walloxen (cf. pl. X).

The main and secondary partings of the acid Vänge granit W of Upsala follow the direction of faint stripes of quartz and biotite and develop perpendicularly to these stripes. Unexpectedly these partings are not exactly congruent with the nearby joints which strike NW and NE (cf. p. 6 on pl. IX). The 1:st parting runs N 30° W and the 2:nd is perpendicular to the quartz-biotite stripes, i. e. N 60° E in a quarry at Born 11 km WNW of Upsala.

By aid of stone cutters it was possible to fix up the main and secondary partings of the Uppsala granite precisely in the quarries represented by the joint-diagram 4 on pl. IX. The 1st parting strikes N 60° W, dipping 70—80° E conformably to stripes of feldspar, the 2nd N 35° E, 90°, and the 3rd is horizontal. The more or less vertical partings coincide rather exactly with the maxima of joints striking WNW, and NNE, on both p. 4 and 5 of pl. IX, but the joint maxima of ENE and NE do not correspond to any known parting.

The gneissose strike is indicated by stippled lines or stripes on pl. X (p. 1, 3, and 10—16). The gneisses break or burst easily along with or perpendicularly to gneissose strikes. A control with chisel and hammer reveals the presence of its partings.

The Silurian limestone of Närke discloses joint diagrams similar to those of more or less massive rocks, i. e. with maxima striking NW and NE (pl. IX, p. 31—33). In heterogeneous anisotropic Cambrian shales below the Silurian limestone, resting on basal Cambrian sandstone, rather near its gneissose basement, the joints show slack orientation in W—E and N—S (pl. IX, p. 29 and 30) — thus, conformably with joints of the basal gneisses (cf. pl. IX, p. 10—14 and the diagram representing the slightly gneissose andesite W of Upsala at p. 3).

The striated slickensides of the Fellingsbro granite area (pl. X, p. 4), and those of the gneisses close to the fault escarpments (p. 6), the prehnite joints close to the lake (p. 8) and the calcite-laumontite joints (p. 9) close to the faults develop maxima with an orientation more or less perpendicularly to the faults. This seems to be true for joints in general, also north of the lake (pl. X, p. 7). Striae on slickensides are met with both in the dolerites and in the Silurian Orthoceras limestone.

The breccias (pl. X, p. 1, and pl. XI, p. 1) and the joints, along which horizontal dislocations have occurred in the whole region investigated (pl. X, p. 2 and pl. XI, p. 2), develop rather undecided strikes compared for instance with zones of the feather joints (pl. X, fig. 3), which strike chiefly in the NE-quadrant (only »Rechts-Spalten»), exactly as the vertical, mineralized joints near Upsala (ERIK WIMAN, 1930, fig. 33—35) and the prehnite joints (pl. X, p. 10) SW of Ekerön, on the peninsula between the churches of Övre and Yttre Enhörna.

Consequently, the W—E-direction is the dominant in the Mälar region and expressed by the gneissose strikes, the gneiss cleavages, the strike of the dolerite dikes, and the faults; the N—S-direction is common to joints in general and the NE-direction is manifested by partings in the

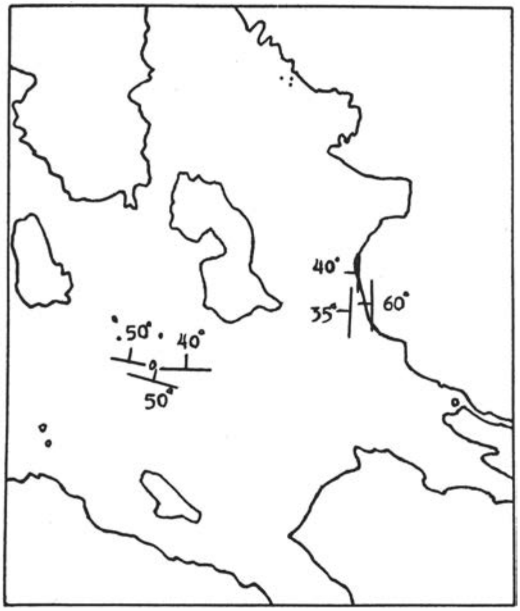

Fig. 5. Strikes and dips of sandstone strata on the isles of Ekerön to the right, and of Midsommar to the left, according to WIMAN. For orientation cf. pl. X. Ekerön: strikes NNE and N., dips 35°, 40° and 60° W. Midsommar: W—E and WNW dips 40°—50° N.

Vänge and Upsala granites, by the strike of the mica schists at Widbo, and its gneissose parting (pl. IX, p. 1), by vertical, mineralized joints at least in the eastern part of the Mälar depression, and by the zones of the feather joints in the whole region. The NW-direction finds its expression by the strike of the gneisses at Strängnäs and Södertälje and by their partings, by those of the Upsala and Vänge granites, by the strike of the amphibolitic dikes and by the firths of Lake Mälaren.

The NW-firths of Lake Mälaren are supposed to be at first of tectonical origin as shown by the dip towards the bottom channel of such a firth of the sandstone on the western shore of the isle of Ekerön, and by the presence of real faults, along which parts of the dolerite dikes have been displaced, but their very late development seems to be due to fluvial, and (later) glacial erosional work.

4. Breccias and mineralized joints.

Breccias are marked as black dots on pl. IX, and on pl. X they occur as black dots with letters QO, Q, P, L, C, QC, LC, U, S, which mean cementation qualities of quartz with potassium feldspar (on prismatic and pyramidal faces of quartz), of quartz only, of prehnite within micro-breccias one inch across, of laumontite, of calcite, of quartz cut by calcite, of laumontite together with calcite (observed at the Vaksala cutting near Upsala in the summer of 1937); of unmineralized, thus, uncemented breccias (U), and of schistose, shaly or slaty, not cemented breccias (S).

The lack of occurrence of minerals in mean joints depend on absence or presence of fresh cuttings, the age, the depth of the road cuttings, and on the amount of lime, leachable out of the minerals along joints. The joint-filling is seldom thicker than one cm.

The mode of occurrence of minerals along the joints may be schemed as below:

1. Epidote nearest to the wall and welded to it. Prehnite coats the epidote dressing. Thus, prehnite is present in the central part of the vein. When epidote and prehnite occur together, they always occur quite uniformly in the whole area investigated. Prehnite veins sometimes cut other prehnite veins and they are also cut by very single quarts veins.
2. Prehnite coating with fluorite in veins (E of Eskilstuna).
3. Quartz and epidote finely mixed and evenly distributed (E of Eskilstuna in gneiss, in the Breven granite, and in the gneissose pebbles of the Mälar sandstone), or epidote dressing with quartz (late Archaean granite near Kungsör).
4. Quartz and laumontite. The latter mineral really coating the wall (8 km E of Eskilstuna) — probably due to waters ascending between an unfixed quartz dressing and the wall.
5. Calcite and fluorite (6 km E of Eskilstuna in gneiss and near Upsala in Upsala granite).
6. Epidote welded to the wall and laumontite coating the epidote (E of Eskilstuna).
7. Prehnite and laumontite together, und one or the other mineral close to the wall.
8. Laumontite coating the wall and fluorite coating (with three layers) the laumontite dressing (9 km ENE of Eskilstuna).
9. Gypsum in Cambrian shales in Närke. Of recent origin?

The age relationship of the mineral fillings presents itself as below:

1. Epidote, often in mixture with quartz and older than the Mälar sandstone. Oldest veins.

2. Prehnite.
3. Prehnite veins cutting the former.
4. Quartz veins in very few instances cutting prehnite veins.
5. Laumontite and calcite. Prehnite often occurs together, but not mixed with laumontite. The laumontite is generally brick-red, but in the Arnö granite S of Upsala and Knivsta it is white or brick-red.

Very thin (less than 1 mm) coatings of calcite only, in the Gotokarelians and in the Almunge umptekite intrusive, are not considered below. The road cuttings in, or near the Breven and Hällefors dikes are very few and unimportant and consequently the P-C-L-mineralization of prehnite, calcite and laumontite respectively of these dikes has not been studied in detail, but at least prehnite and calcite fill joints in both dikes. As shown below, calcite and laumontite within joints are very common in the Granholmen dolerite. Calcite only locally develops in the Silurian strata as thoroughly discussed below.

5. The morpho-tectonics.

The statement that the joint fillings and the cementation of the breccias are represented by identical minerals, especially prehnite, calcite and laumontite, leads to the conclusion, that they may be of the same general age. The occurrence of cemented breccias rather close to the faults which mark the recent fault topography makes it probable, that this topography, at least initially, has been founded in connection with the general joint mineralization.

The nicely welded quartz breccias certainly may be older than the above mentioned P-C-L-breccias because calcite veins cut through the quartz cementation at Upsala (HÖGBOM, 1916, p. 401) and the quartz breccias NW of Södertälje (pl. IX—X) appear 400 m N of a recent fault escarpment. Joint planes dressed with epidote or quartz or both in a mixture, i. e. »E-Q-joints», are extremely rare compared with the P-C-L-joints. The E-Q-joints ocurring in gneissose pebbles in the Mälar sandstone are older than the sandstone. The C-L-joints are younger than the Mälar sandstone, and cut the sandstone veins in the Granholmen dolerite. The mineralized joints define the shape of the *roches moutonnées* in this place. Its mineralization is uncommonly thick, and is easily observed although quarries are absent on Granholmen. In a breccia immediately north of a vertical dolerite dike cutting the Fellingsbro granite at the railway station of Blixterboda (pl. X) prehnite occurs as cement in the granite-breccia, yet is absent in the dolerite itself. This may indicate that the formation of the prehnite cement is due to a contact influence of the dolerite.

Epidote is of common occurrence in short veins of the southwestern part of the Breven granite in the area of the Breven dolerite towards its contact with the dolerite. The longer joints, which determine the shape of the whale-like *roches moutonnées*, cut off the epidote veins without local topographical importance. Although no cuttings are available epidote has been observed in gneiss joints immediately S of the Breven dolerite (Berget). E-Q-veins are rather common in the area of the Hällefors dike, and some of the E-Q-joints determine the shape of its *roches moutonnées*.

The observations at the Blixterboda dolerite, and of the Breven and Hällefors dikes, suggest a connection between dikes and mineralization. Thus, the age difference between the E-Q-mineralization and the P-C-L-mineralization seems to be of minor importance.

If both the P-C-L- and the E-Q-fillings have been formed only once in the Mälar region, and not at the emplacement of each separate intrusion (compare WIMAN, 1930), they ought to have been formed in more or less close connection with the emplacement of the post-Archaean instrusives. The E-Q-fillings would thus be somewhat older.

The P-C-L-mineralization of the joints and the breccias appear abundantly at a certain distance from: 1. the Almunge intrusion (umptekite and canadite, petrologically described by PERCY QUENSEL, 1914), between Upsala and Almunge, 2. the Mälar porphyries, 3. but in the very Granholmen dolerite (laumontite and calcite), 4. exactly at the dolerite in the Fellingsbro granite, 5. on Singö at the Baltic coast E of Upsala, thus, W of the Åland rapakivi granite and its western dolerite sheet at Halsaren (calcite-prehnite breccia described by a A. G. HÖGBOM, 1916, p. 401), and 6. about 10 km ENE of Eskilstuna (with abundant fluorite). On the latter locality a younger post-Archaean intrusion is not known in the immediate vicinity.

The mineralization both of the joints and the breccias may thus have been caused by younger post-Archaean intrusions at one or several occasions. Its minerals ought to have been leached out along the joint planes by water (prehnite and laumontite), CO_2 (calcite), and HF (fluorite). The two latter minerals may also have been leached out of the evenly distributed fluorite and calcite within, for instance, the Upsala granite.

The Mälar depression may be counted as a western, central part of the Svecofennians (BACKLUND, 1936—1941), and it is obviously rather mineralized along joints. Six years' experiences of part of the Gotokarelians of W. Sweden have only got some calcite in joints at a single locality. Tentativily one is attempted to conclude, that a special fissure mineralization belongs to the Svecofennians, and if present in the Gotokarelians, it ought to occur at a certain distance from and with post-Archaean intrusives.

The calcite of the Gotokarelian joints can hardly have crystallized from descending waters, because, at Kinnekulle near Lake Vänern, calcite fills joints of the Orthoceras limestone quite locally, but the calcite does not appear in the underlying Cambrian shales or sandstone. It does not occur in the joints of the gneissose basement — neither at the very basement of Kinnekulle on the Vänern shore nor between Kristinehamn and Kinnekulle — not even in the hyperite. A. G. HÖGBOM (1924, p. 68), believed that the joints of the gneissose basement are to a large extent older than the Cambro-Silurian sediments, which according to the Writer's observations in 1941, must have been formed as NW—NE-joints due to repeated movements along pre-Cambrian conformable joints in the gneissose basement. In the summer of 1941 with low water level at Lake Vänern the Writer made a number of sketches demonstrating the abundance of joints older than the Cambrian sandstone.

Neither on Kinnekulle (reposing on the Gotokarelians) nor in the Cambro-Silurian sediments of Närke (laid down on the Svecofennians) I have found any association corresponding to the P-C-L-mineralization or the joint minerals themselves, except the above mentioned calcite, which has also been observed twice in joints of the Silurian of Närke.

Until nothing is published about such a mineralization or something equalling it, and cutting the Cambro-Silurian sediments, I feel inclined to believe that the mineralization of the breccias and the joints of the Mälar depression is chiefly younger than post-Archaean and older than Cambrian rocks. Much of the above conclusions depends on the age of the Almunge intrusion, which seems not to be cut by the mineralized joints.

The recent topography of the Mälar depression towards the south is characterized by the large heaved block of the whole province of Sörmland. It is intruded by dolerite dikes in its central axial part (Breven and Hällefors, pl. IX—X), and, at its N-boundary (Granholmen). The initial uppheavel certainly occurred in connection with the dolerite intrusions along its vertex area and its longitudinal splitting. With all probability the Mälar sandstone was disclocated (Fig. 2 and 5) in connection with the movements and with them the Granholmen dolerite was intruded between the conglomerate and the sandstone during the sedimentation of the sandstone. These movements were accompanied by jointing and faulting of the gneissose basement, followed by a jointing of the dolerites, and by a P-C-L-mineralization of the joints. The upheavel of Sörmland is probably compensated by the downthrow of the deepest depression of the whole Baltic at Landsort E of the Sörmland block.

Thus, the upheavel of the Sörmland block was followed by a dislocation of the Mälar sandstone and the intrusion of the dolerites. Already before the sandstone sedimentation there existed a hilly country. The rather heavy layers of conglomerate with large boulders and pebbles (up to about 1 foot across) at the bottom of the sandstone, occuring both in the western part of the depressions, now as large glacial boulders S of Granholmen, and in its eastern Ekerö, and Pingst part (Fig. 5), testifies of a hilly country at pre-sandstone time in the proximity of the recent Mälar depression. If the hills presented heaved fault blocks or not, can hardly be judged by observations only in the Mälar region.

The Sörmland block appears to have been heaved in the north along several hinge lines-faults expressed statistically by breccias dipping both towards the north and the south (pl. XI, p. 1), and in the south along rather few hinge lines-faults (Kolmården at Bråviken, pl. IX—X), here also developed with dips of joints and pitches of striae (pl. XI, p. 10—11) both towards the north and the south.

The dips of the joints and faults along the northern margin of the heaved block towards the depression, cannot be shown by joint or breccia statistics, but the dip of the Mälar sandstone close to the faults is directed northward.

The unmineralized joints, uncemented breccias, and the striae — the latter generally on the mineral coatings of the joint planes in all the rocks mentioned in the present paper — indicate without doubt movements, which later on have caused the recent fault topography. If these indications only record late tectonical adjustments, the recent fault topography must have been formed in connection with the P-C-L-mineralization, which is hitherto not supposed by me. Unmineralized breccias occur near Kristinehamn at Lake Vänern within the Gotokarelians on the fault escarpments with an orientation more or less perpendicular to the Mälar faults. Although high escarpments are present in that region I have not discovered any mineralized breccias.

The Mälar faults are characterized by rater high escarpments (Fig. 1) and cut off the river channels, which have an NW orientation. Parts of these channels, by the faulting, have been brought into different levels, as described by GUNNAR ANDERSSON (1903). The very dominant and beautiful schistose to slaty breccias formed within amphibolitic dikes at Arboga, and altered into clorite schists, probably represent rather old movements of chlorite genesis. However, these chlorite schists later have been cracked into small pieces with only one inch across; young movements could manifest themselves here, both with regard to its appearance, as to its situation on the recent fault escarpment. However, post-Quaternary movements are not proved here, as the relationships between the different surfaces of the *roches moutonnées* along the Arboga cuttings of the road to Örebro are still visible.

6. **List of joints considered.**

A. Frequency and general appearance of joints.
  1. Joints dying out on the surface of an outcrop.
  2. Single, simple, joints.
  3. Single joints accompanied by small curved cracks — one or a few dm of length.
  4. Sets of several, straight, parallel joints.
  5. Feather joints (en échelon joints = »Fiederspalten», »Rechts- und Linksspalten».
  6. Sets of several parallel short joints resembling feather joints, but striking along with or perpendicular to the zone of the joints.
  7. A horizontal or gently dipping joint bedding.

B. Joints filled with dikes or minerals.
  1. Joints open to mafic dikes.
  2. Joints open to pegmatites and aplites.
  3. Mineralized joints, and joints with a thin coating of rust, calcite, chlorite, or serpentine. Joint minerals filling fissures in pebbles of conglomerates, but not continuing in the surrounding matrix.

C. Joints in relation to dikes.
  1. Joints more or less due to the solidifying of dikes — by heat influence the dike joints sometimes continue into contact rocks.
  2. Joints younger than dikes, but not cutting very resistant types of dikes.
  3. Joints younger than dikes and cutting them.
  4. Joints for certain older than dikes.

D. Movements along joints.
  1. Striated slickensides and striae older or younger than the mineral coating of the walls of the joints.
  2. Dislocations of parts of striated slickensides or joints.
  3. Dislocations of parts of dikes.
  4. Dislocations contemporanous with intrusions of dikes or mineralization of joints.
  5. Dislocations of parts of whole sets of joints.
  6. Dislocations of parts of stripes in gneisses and parts of crystals.
  7. Dislocations of parts of glacial striae.
  8. Movements along joints in connection with folding (Archaean limestone folded and Archaean porphyry jointed and included in the limestone of the same age, near Garphyttan, Närke).
  9. Transversal joints between longitudinal joints.
  10. A fissuring of joint minerals and a regeneration of older joints.
  11. Breccias of several types.

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Bibliography.

Abbreviations.

B. G. I. U. = Bulletin of the Geological Institution of the University of Upsala.
G. F. F.* = Geologiska Föreningens i Stockholm Förhandlingar.

ANDERSSON, GUNNAR, 1903: Om Mälartrakternas geografi. Ymer. Stockholm.

ANDERSSON, J. G., 1900—1901: Lecture on Granholmen, meeting Sept. 25th, p. 146. B.G.I.U. Vol. 5.

ASKLUND, B., 1923: Bruchspaltenbildungen in südöstlichen Östergötland nebst einer Übersicht der geologischen Stellung der Bruchspalten Südostschwedens. G.F.F. Vol. 45, p. 249.

—— 1924: Mälarporfyrernas läge och sandstensområdet på Ekerö. G.F.F. Vol. 46, p. 301.

BACKLUND, H., 1936: Der »Magmaaufstieg» in Faltengebirgen. Bull. Comm. Géol. Finl. 115. Helsinki.

—— 1937: Die Umgrenzung der Svecofenniden. B.G.I.U. Vol. 27, p. 219.

—— 1938: The problems of the rapakivi granites. Journal of Geol., Vol. XLVI, No. 3, April—May.

BACKLUND, HELGE G., 1941: Gesteinsentwicklungen in Fennoskandia. Zeitschrift für Geschiebeforschung und Flachlandsgeologie. Band 17. Heft 3.

DE GEER, GERHARD, 1897: Stockholmstraktens geologi. Aftryck ur det på J. Beckmans förlag utgifna arbetet: »Stockholm, Sveriges Hufvudstad», skildrad med anledning af Allm. Konst- och Industriutställningen.

DE GEER, STEN, 1910: Explanation of land-formes in the surroundings of the great Swedish lakes. S.G.U. Ser. Ba. N:o 7. Geological Survey of Sweden.

GEIJER, PER, 1922: Problems suggested by the Igneous Rocks of Jotnian and sub-Jotnian age. G.F.F. Vol. 44, p. 411., Stockholm.

HOLM, G., 1901: Kinnekulle. S.G.U. Ser. C. N:o 172.

——, Albert Blomberg och G. Holm, 1902: Geologisk beskrifning öfver Nerike och Karlskoga Bergslag samt Fellingsbro Härad. Ser. Ca. N:o 2.

HOLMQUIST, P. J., 1906: Studien über die Granite von Schweden. On the Fellingsbro granite p. 130. B.G.I.U. Vol 7.

—— 1932: Über sog. Fiederspalten. G.F.F. Vol. 54, pp. 99—118.

HÖGBOM, A. G., 1916: Zur Mechanik der Spaltenverwerfungen. Eine Studie über mittelschwedische Verwerfungsbreccien. B.G.I.U. Vol. 13.

HÖGBOM, A. G., and AHLSTRÖM, N. G., 1924: Über die subkambrische Landfläche am Fusse vom Kinnekulle. B.G.I.U. Vol. 19.

KROKSTRÖM, TORSTEN, 1932: The Breven dolerite dike. B. G. I. U. Vol. 23.
—— 1936: The Hällefors dolerite dike and some problem of basaltic rocks. B. G. I. U. Vol. 24.
QUENSEL, PERCY, 1914: The alkaline rocks of Almunge. B. G. I. U. Vol. 12.
SAHLSTRÖM, K. E., 1914: Glacial skulptur i Stockholms yttre skärgård. S. G. U. Ser. C. N:o 258. Årsbok 7. (1913), N:o 5.
TAMM, O., 1915: Några iakttagelser angående Mälarsandstenen. G. F. F. Vol. 37
TÖRNEBOHM, A. E., 1878—79: Om Granholmen i Mälaren. G. F. F. Vol. 4. N:o 6. pp. 187—190.
WIMAN, CARL, 1918: Kambrisk sandsten anstående i trakten av Upsala. G. F. F. Vol. 50, p. 726.
WIMAN, ERIK, 1927: Über den Gebirgsgrund der Umgebung von Upsala und über den rudimentären Kugelgranit bei Kåbo gärde. Vorläufige Mitteilung. B. G. I. U. Vol. 22.
—— 1930: Studies of some Archaean rocks in the neighbourhood of Upsala, Sweden, and of their geological position. B. G. I. U. Vol. 23.
—— 1932: Some faults and fault depressions in relation to striated slickensides. B. G. I. U. Vol. 24.
—— 1934: Preliminärt meddelande om Granholmen och Mälarbäckenet. G. F. F. Vol. 56, p. 498.
—— 1941: Bidrag till kännedomen om Mälardepressionens sprickbildning och morfologi. G. F. F. Vol. 63, p. 84.
—— 1941: Kristinehamnstraktens geologi. Newspaper. Nya Kristinehamnsposten 12 febr. 1941. Kristinehamn.
—— 1942: Kinnekulle. Newspaper. Nya Kristinehamnsposten 13 and 15 april 1942. Kristinehamn.
WRIGHT, FRED. EUGENE, 1911: The methods of petrographic-microscopic research. Pl. 11 = the Postel or Angle Meridian projection. Carnegie Inst. of Washington. Washington.

Expl. to pl. IX—XI.

Pl. IX.

In order to be able to distribute the joint roses on pl. IX—X at the localities, to which they really belong, and to make them plain and visible, without hiding other features, they have been both diminished and enlarged, but the real number of observations have been recorded in the explanations to pl. IX—X.

Black joint roses: joints in massive rocks and in Silurian limestone. White joint roses: joints in gneissose rocks and Cambrian shales. Black dots: breccias.

1. 100 observ. Mica schists of Widbo, SE of Upsala. Oldest Archaean.
2. 150 observ. Red quartz-porphyry of Upsala. Oldest Archaean.
3. 150 observ. Grey quartz-andesite of Upsala. Oldest Archaean.
4. 200 observ. Upsala granite. Sommarro—Kåbo gärde. Archaean.
5. 500 observ. Upsala granite. Upsala—Almunge. Archaean.
6. 207 observ. Vänge granite. W of Upsala. Archaean.
7. 100 observ. Granite ENE of Eskilstuna. Archaean.
8. 119 observ. Granite immediately ESE of Arboga. Archaean.
9. 200 observ. Arnö granite S of Upsala, Knivsta and E of Sigtuna. Archaean.
10. 313 observ. Gneiss. Hallsberg. Archaean.
11. 416 observ. Gneisses surrounding the Breven dike. Archaean.

12. 484 observ. Gneisses surrounding the Hällefors dike. Archaean.
13. 294 observ. Gneisses at Eskilstuna. Archaean.
14. 100 observ. Gneisses S of Eskilstuna. Archaean.
15. 511 observ. Gneisses on Tosterön, N of Strängnäs. Archaean.
16. 325 observ. Gneisses at Södertälje. Archaean.
17—22. 900 observ. Fellingsbro granite. Late Archaean.
23. 100 observ. Granite ESE of Kungsör. Late Archaean.
24. 214 observ. Alkaline rocks of Almunge. Post-Archaean or younger.
25. 470 observ. Dolerite of Breven. Post-Archaean.
26. 153 observ. Granite of Breven. Post-Archaean.
27. 625 observ. Dolerite of Hällefors. Post-Archaean.
28. 300 observ. Dolerite of Granholmen. Post-Archaean.
29. 150 observ. Shales of Yxhult. Cambrian.
30. 70 observ. Shales of Kvistbro, Fjugesta. Cambrian.
31. 350 observ. Limestone of Yxhult. Silurian.
32. 70 observ. Limestone of Lanna. Silurian.
33. 110 observ. Limestone of Kvistbro, Fjugesta. Silurian.

Pl. X.

QO = breccias with quartz cementation and with potassium feldspar on prismathic and pyramidal faces of quartz, Q = quartz breccias, P = prehnite breccias, L = laumontite breccias, C = calcite breccias, U = unmineralized breccias, S = schistose to slaty breccias, QC = quartz-calcite breccias, and LC = laumontite-calcite breccias.

1. 34 observ. Breccias. Strike.
2. 54 observ. Joints along which horizontal dislocations have appeared in the whole region investigated.
3. 43 oberv. Zones of feather joints.
4. 46 observ. Striated slickensides in the Fellingsbro granite.
5. 259 observ. Striated slickensides in Archaean rocks near the fault escarpments and close to Lake Mälaren, where road cuttings are rather abundant.
6. 1079 observ. Joints in all kinds of Archaean rocks along the fault escarpments close to Lake Mälaren.
7. 372 observ. All kinds of joints N of Lake Mälaren — except the region of Upsala, which is demonstrated pl. IX.
8. 611 observ. Joints filled with prehnite close to the fault escarpments near Lake Mälaren.
9. 489 observ. Joints close to Lake Mälaren filled with laumontite and calcite.
10. 71 observ. Prehnite joints between the Ytterenhörna and Överenhörna churches NNW of Södertälje.

Pl. XI.

1. Stereographic net. 34 observ. Breccias along the fault escarpments. Black dots = perpendicules to the surfaces of strike of breccias in the breccia zone in Archaean amphibolite at Arboga. White dots = breccias in Archaean granites and gneisses.
2. Stereographic net. 49 observ. Dots = perpendicules of joint surfaces. Joints along which parts of dikes, veins, and sedimentary strata have been horizontally dislocated N and S of Lake Mälaren, except those close to Upsala already shown (WIMAN, 1930, fig. 42. p. 116).

3. Surface- and angle-true projection of Postel (or angle meridian projection). 900 observ. Joints of the Fellingsbro granite. Dips somewhat more to the west than to the east according to the projection. 4—3—2—(1—0,5) %.
4. Stereographic net. 356 observ. Fault escarpments Strängnäs-Arboga. Black dots = joints in Archaean amphibolitic dikes. White dots = joints in Archaean gneisses. A very pronounced dip is hardly observed, which is important with regard to the heaved blocks of Sörmland.
5. Stereographic net. 403 observ. Joints filled with prehnite along the fault escarpments from Södertälje to Eskilstuna, and from Torshälla to Arboga. Veins of prehnite are especially well developed N of the quartz breccias E of Mariefred NNW of Södertälje, between the two fault lines — pl. X, p. 10. The most general strike = NE, and the most general dip = E.
6. Surface- and angle-true projection of Postel. 126 observ. Joints of the very fault escarpment in the well exposed road cutting at Arboga. Most general strikes and dips: NE, E, NW, E, NNE, and W. Thus the dips of the joints are not especially pronounced in relation to the heaved block of Sörmland (1—0,9)—(0,8—0,6)—(0,4—0,3)—(0,2—0,1) %.
7. Stereographic net. 49 observ. Pegmatite veins in the very Fellingsbro granite. Southeastern part of granite body. Road cuttings between Fellingsbro and Arboga.
8. Stereographic net. 128 observ. Strike and dip of striated slickensides along and near the fault escarpments. S of Lake Mälaren. Northern fault escarpments of the heaved block of Sörmland.
9. Stereographic net. 128 observ. Pitch of striae on striated slickensides (recorded pl. XI, fig. 8).
10. Stereographic net. 53 observ. made 1931, Strikes and dips of striated slickensides at Bråviken, N of the town of Norrköping. Southern fault escarpment of the heaved block of Sörmland.
11. Stereographic net. 53 observ. Pitch of the striae on the striated slickensides recorded on fig. 10, Bråviken.

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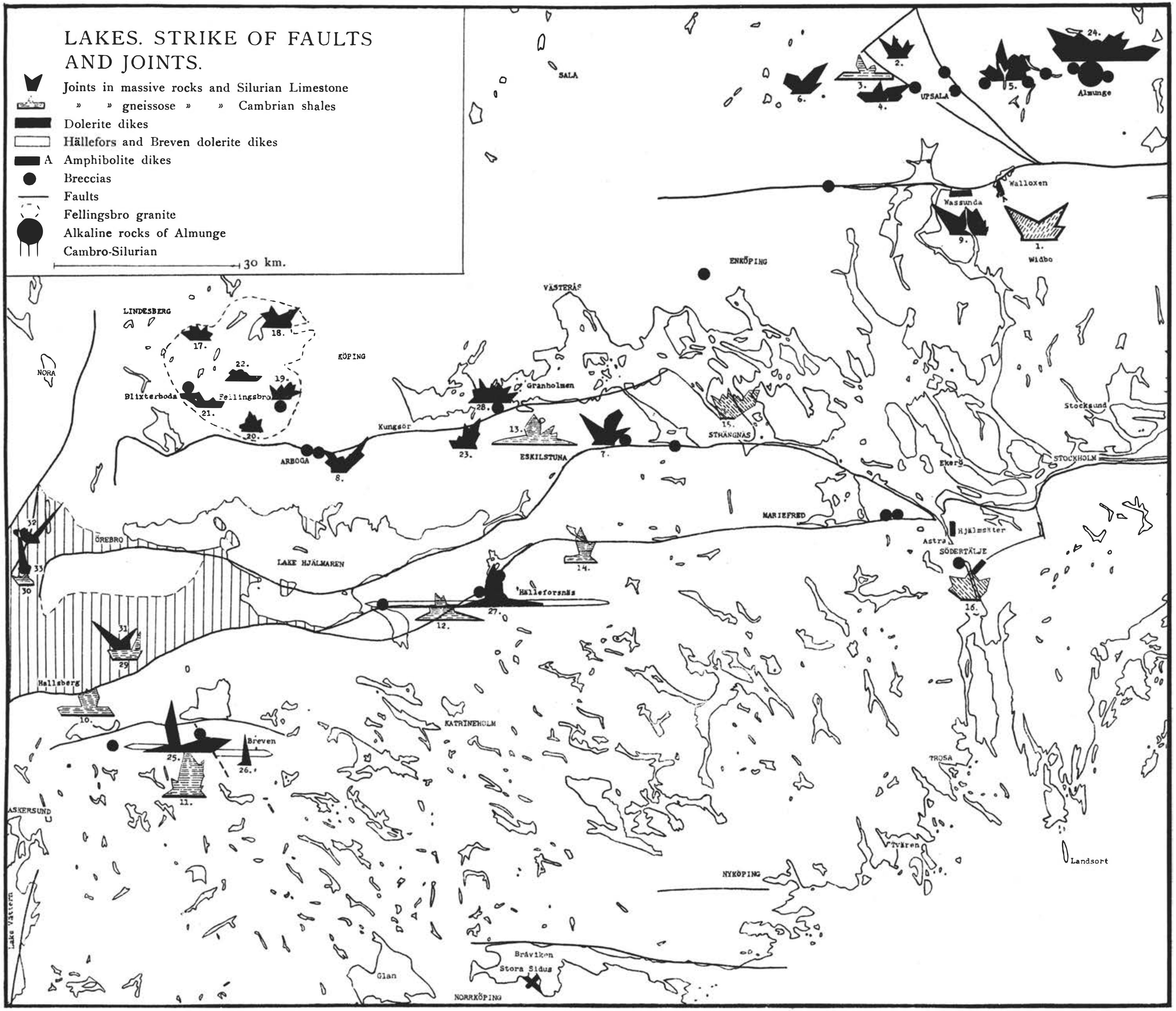
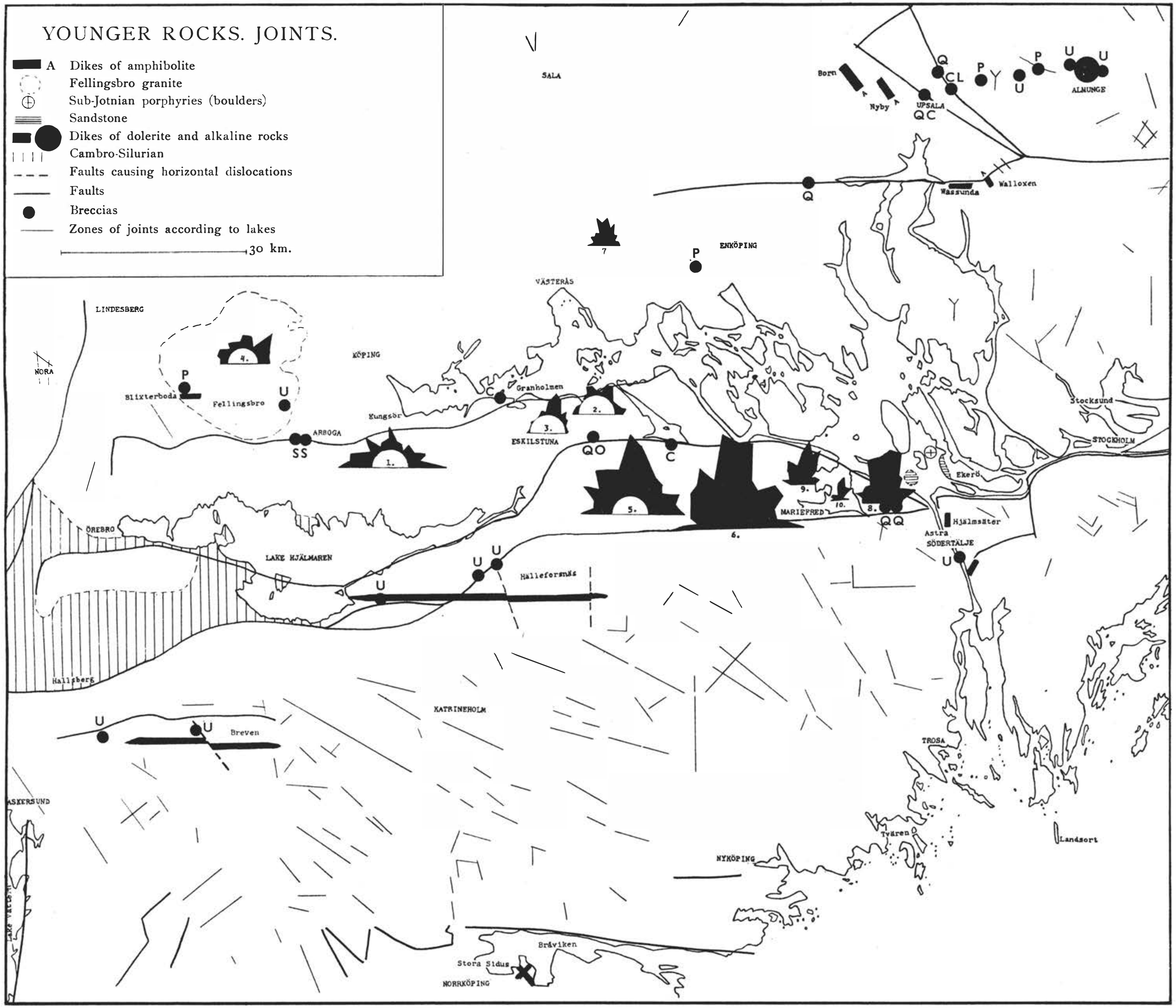
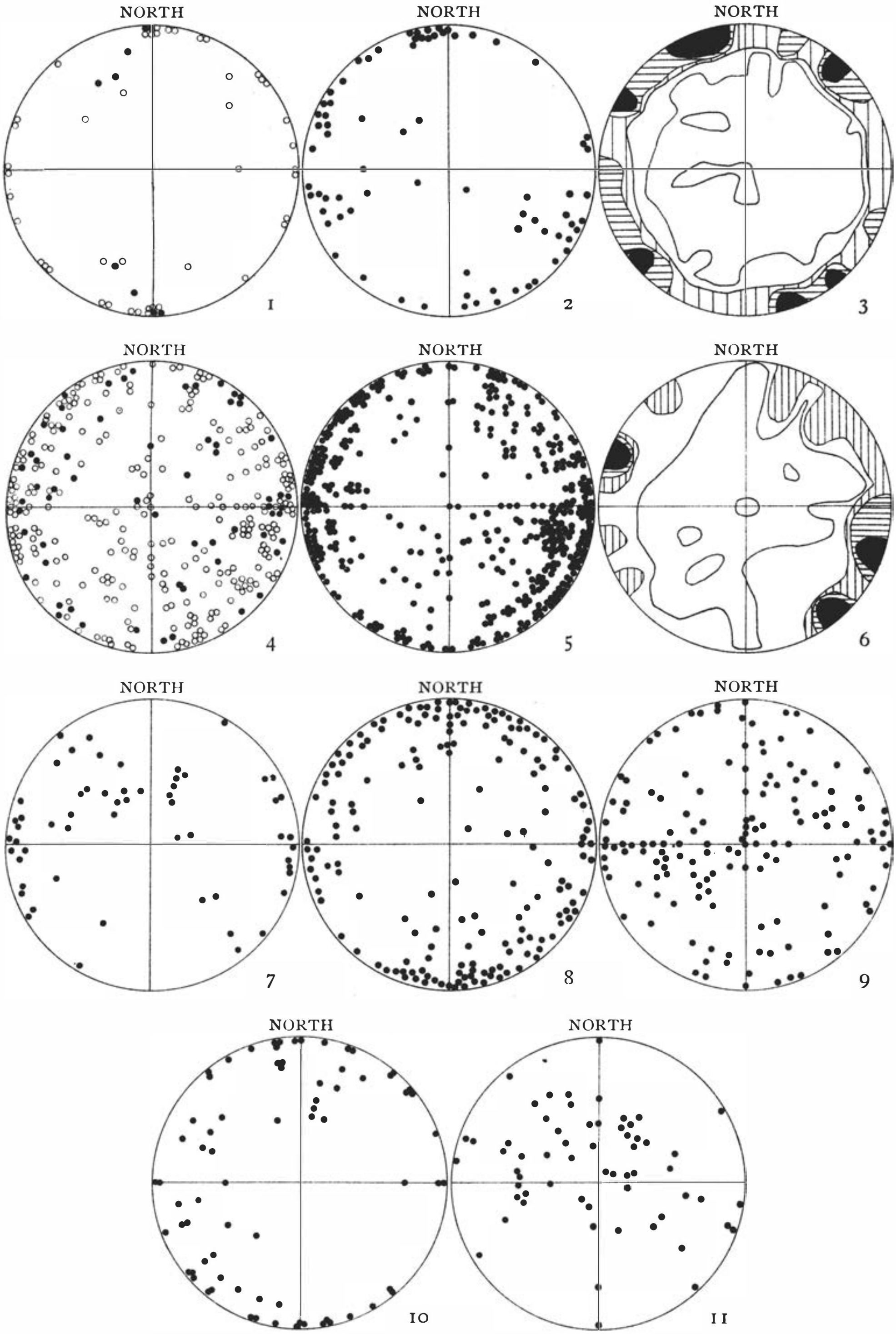

LAKES. STRIKE OF FAULTS AND JOINTS.
Joints in massive rocks and Silurian Limestone
» » gneissose » » Cambrian shales
Dolerite dikes
Hällefors and Breven dolerite dikes
A Amphibolite dikes
Breccias
Faults
Fellingsbro granite
Alkaline rocks of Almunge
Cambro-Silurian
30 km.
SALA
UPSALA
Almunge
Walloxen
Wassunda
Widbo
ENKÖPING
VÄSTERÅS
LINDESBERG
KÖPING
NORA
Blixterboda
Fellingsbro
Granholmen
Kungsör
ARBOGA
ESKILSTUNA
STRÄNGNÄS
Stocksund
Ekerö
STOCKHOLM
MARIEFRED
Hjälmsäter
Astra
SÖDERTÄLJE
ÖREBRO
LAKE HJÄLMAREN
Hälleforsnäs
Hallsberg
KATRINEHOLM
Breven
ASKERSUND
TROSA
Tvären
Landsort
NYKÖPING
Lake Vättern
Bråviken
Stora Sidus
Glan
NORRKÖPING


YOUNGER ROCKS. JOINTS.
A Dikes of amphibolite
Fellingsbro granite
Sub-Jotnian porphyries (boulders)
Sandstone
Dikes of dolerite and alkaline rocks
Cambro-Silurian
Faults causing horizontal dislocations
Faults
Breccias
Zones of joints according to lakes
30 km.
SALA
Born
Nyby
UPSALA
ALMUNGE
Wassunda
Walloxen
ENKÖPING
VÄSTERÅS
LINDESBERG
NORA
KÖPING
Blixterboda
Fellingsbro
ARBOGA
Kungsör
Granholmen
ESKILSTUNA
MARIEFRED
Ekerö
Stocksund
STOCKHOLM
Hjälmsäter
Astra
SÖDERTÄLJE
ÖREBRO
LAKE HJÄLMAREN
Hälleforsnäs
Hallsberg
KATRINEHOLM
Breven
ASKERSUND
TROSA
Tvären
Landsort
NYKÖPING
Bråviken
Stora Sidus
NORRKÖPING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