GEOLOGIE EN MIJNBOUW - 45e JAARGANG - PAGINA 125—136 - MEI 1966

THE SILJAN RING OF PALEOZOIC, CENTRAL SWEDEN: A POSTHUMOUS RINGCOMPLEX OF A LATE PRECAMBRIAN DALA PORPHYRIES CALDERA

M. G. RUTTEN [1])

SUMMARY

The Dala Porphyries, recently mapped by Hjelmquist, from a volcanic province of late Precambrian age in central Sweden, attaining a minimum volume of volcanics of 150 km^3. The Siljan ring of early paleozoics, distinguished from the early Paleozoic epicontinental cover of the Fennoskandian Shield by its thicker facies, with reef limestones, and by its peculiar, strong tectonization, occupies a ring 45 km in diameter and 5 km to 10 km wide, to the east of the Dala Porphyries.

It is postulated that the Siljan ring structure developed as a result of posthumous movements at the site of the ring-complex surrounding a caldera from which the Dala Porphyries had erupted earlier.

CONTENTS

Summary 125
Introduction 125
The early Paleozoic epicontinental cover of the Fennoskandian Shield 126
The Siljan Paleozoics 127
Tectonics of the Siljan ring 130
Siljan as a meteoric crater? 130
The Dala Porphyries 130
Dala Porphyries and volcanotectonics 132
The Dala Granite 133
History of the Dala Porphyries and the Siljan Paleozoics 136

INTRODUCTION

The Siljan Paleozoics, mainly consisting of strata of Ordovician and Silurian age, form a ring like structure situated entirely within the Precambrian of Central Sweden. The ring is between 5 km and 10 km wide, and has an inner diameter of 45 km.

[1]) Geologisch Instituut, Rijks Universiteit te Utrecht Holland.

Although situated about halfway between erosional outliers of the epicontinental Paleozoics cover of the Fennoskandian Shield to the South (250 km) and the geosynclinal Paleozoic of the Caledonian foldbelt to the north (150 km), compare fig. 1, the Siljan Paleozoics are quite distinct from both.

Although of epicontinental character, the Siljan Paleozoics differs from the „stable interior" Paleozoic cover further south in two ways. The first regards its stratigraphy, where the Cambrian is absent, but a part of the Ordovician is developed in a much thicker facies, with two reef horizons. The second regards its strong tectonization, through block faulting, tilting and related movements. The strike of this tectonization, peculiarly, is tangentional to, and follows the ring structure closely. From the Caledonian Paleozoics the Silan Paleozoics differ in being of epicontinental, not of geosynclinal facies, and in having only suffered the above mentioned peculiar type of block faulting tectonics, and no folding or nappe formation.

The Dala Porphyries, of unknown, but late Precambrian age, cover an area of some 1500 km^2, southwest, west and north of Siljan. They extend up to, and disappear underneath of, the eastern border of the Caledonian fold belt. They are overlain by the shallow syncline of the Jotnian Sandstones, of younger, but equally late Precambrian age (fig. 9, c), but else have not suffered much tectonization since their formation.

The Dala Porphyries have recently been in part interpreted as ignimbrites (Hjelmquist 1956), a view I should like not only to subscribe to, but to extend. Most of the Dala Porphyries show the massive, uniform structure, which is best explained as formed through fluid ash flows. Only a very minor part shows the characteristic turbulent laminar flow of a highly viscous lava.

The thickness of the Dala Pohrpyries is difficult to estimate, owing to the fact that a thick glacial cover leaves less than 1 % of the area exposed. In the few post-glacial fluviatile river canyons which cut through the porphyries, individual flows are, however, seen to have minimum thicknesses varying from 20 m to 30 m. An estimated minimum thickness of 100 m for the total series seems therefore to be very conservative. The actual thickness may well be considerable higher.

Even at a thickness of 100 m, the now preserved volume of the Dala Pophyries would be of the order of 150 km^3, a figure which corresponds well with other acid ignimbritic eruptions.

To my knowledge, the Siljan ring of Paleozoics and the Dala Porphyries have not been earlier brought into a causal relationship [2]. I must therefore state which characters of these seemingly so different crustal elements point to their common origin. I will begin with a short analysis of the Siljan Paleozoics, and then consider the relevant characteristics of the Dala Porphyries. Only after that a synthesis of the history of both areas can be tried. But before being able to understand in what way the Siljan Paleozoics differ from the normal development in the eipicontinental cover furhter South, we must understand the main features of that area.

THE EARLY PALEOZOIC EPICONTINENTAL COVER OF THE FENNOSKANDIAN SHIELD

This region is characterized by deposits formed on an extremely wide, and extremely horizontal, completely peneplained, epicontinental platform. Over this the most shallow of seas transgressed over thousands of square kilometers, only to withdraw after a short time over comparable distances.

This play of transgressions and regressions has already been extensively described for intervals comprising stages, or even parts of stages, where the existance of diastems and periods of non-deposition can be proved paleontologically (cf. Thorslund in Magnusson, ed. 1960). But it may well have occurred in rhythms of even shorter duration. For example, work now in progress on the island of Öland seems to indicate the existence of such oscillations between each single bed in the well known Orthoceras Limestone of the Limbata Stage of the Ordovician. Each bed of this series shows signs of karst erosion on its upper surface, indicating a regression after its deposition. This indicates a play of rhythmic transgressions and regressions of the order of each single bed, some 10 cm to 20 cm in thickness, over an area of at least 40 km in diameter.

During the early Paleozoic there has evidently reigned on the southern part of the Fennoskandian Shield, a horizontality which we have, from our present environment, the utmost difficulty to concieve.

It is, however, the kind of horizontality which we also find in other sedimentary environments. The, now almost classic, example being that of the Coalmeasure cyclothems (cf. Wanless, 1963). Another striking example has more recently been described from the Belgian Visean limestones by Michot and coworkers (Michot, et al., 1963, Pirlet, 1963).

Such horizontality seems normal for most shallow sea sedimentation basins in the geologic past, but which is quite different from our present environment.

The resason for this lies in the fact that we now live in a period which is both interglacial and post-orogenetic. This has resulted on the one hand in the drowning of all shelves by the eustatic sea level rise since the last glaciation. Whereas on the other, the Quaternary is characterized by strong vertical crustal movements, which have not yet by far been equalized through erosion, peneplanation and sedimentation.

The more normal circumstances during geologic history were, however, those of the much longer periods that were both non-glacial and a-tectonic (Rutten, 1953). During such periods the horizontality mentioned above was normally arrived at, because crustal movements were easily offset by erosion and sedimentation, and hence an equilibrium situation was normally installed. It is, however, difficult to visualize such circumstances from our present experiences, a thing always to keep in mind, when applying the concept of actualism (Lafitte, 1949; Rutten, 1949).

For the epicontinental cover of early Paleozoic on the Fennoskandian Shield this horizontality implies that we have to abstract ourselves also from our present notions of a coastline, of near-coastal and the like. The coast at any time

[2]) Asklund has, in 1936, shortly mentioned the possibility of a volcanotectonic origin of the Siljan ring, but failed to indicate where the volcanics erupted from this structure were to be found.

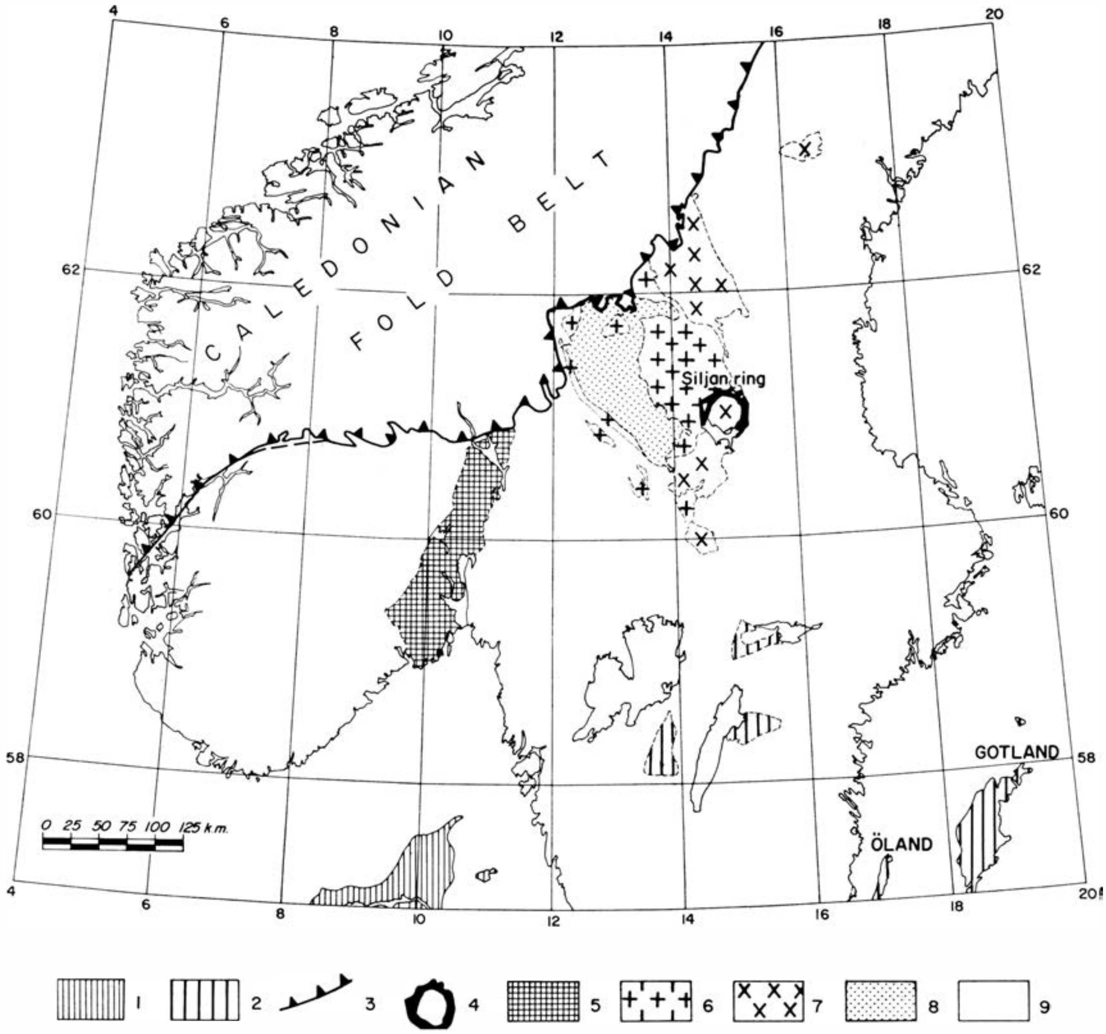


Fig. 1 — Index map of part of Skandinavia.
1: Mesozoic. 2: Epicontinental Paleozoic cover. 3: Eastern border of Caledonian fold belt. 4: Siljan Paleozoics. 5: Oslo Graben. 6: Dala Porphyries. 7: Dala Granite. 8: Jotnian Sandstone. 9: Earlier Precambrian.

formed no constant line across the shield, nor can it be said that for instance Central Sweden was farther from the coast than Southern Sweden, Instead, the coast line swept back and forth over most of the area, if not over all of it, with every rhythm of regression and transgression. This is attested by the fact that not only the various paleontological stages, but also many of the sedimentation breaks, so patiently worked out by the Swedish stratigraphers, can be followed over most, or even all of the area.

THE SILJAN PALEOZOICS

The Siljan Paleozoics have been carefully studied, amongst others by Thorslund and his school. A good introduction to the area is found in Thorslund & Jaanusson, 1960. A major difficulty lies in the fact that a large part of the structure is covered by Lake Siljan and by several other lakes. Moreover, as professor Thorslund writes: „Almost everywhere the beautiful Paleozocic rocks are hidden by a dirty Quaternary cover". Good exposures are mostly limited to the quarries opened in the reef limestones, and to occasional road and railway cuts. It follows that, whereas the stratigraphy of the Siljan Paleozoics is known in great detail, albeit from many scattered observation point, the structure of the Siljan ring is known only schematically.

As stated already in the introduction, the Siljan Paleozics differ in two ways from the epicontinental Paleozoic cover of the Fennoskan-

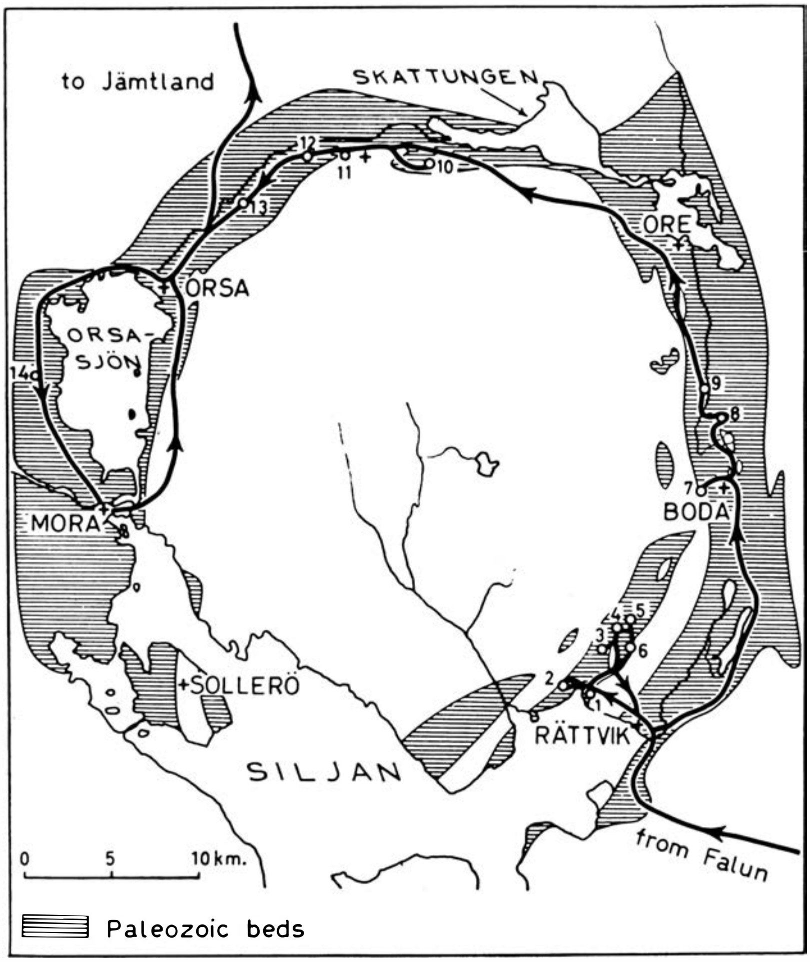


Fig. 2 — Generalized map of the Siljan Paleozoics.
From Thorslund, in Thorslund & Jaanusson, 1960.

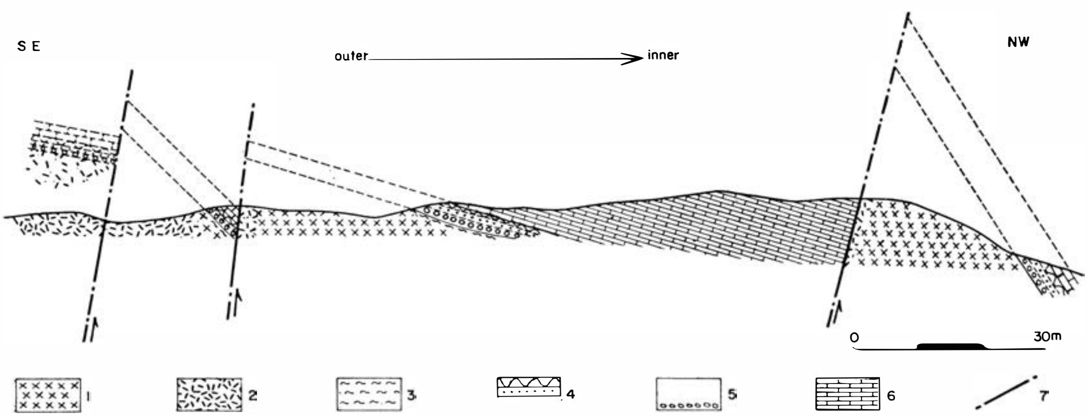


Fig. 3 — Radial section through part of the south-easterly portion of the Siljan Ring, near Sjurberg (stop 1 of fig. 2.) After Thorslund, in Thorslund & Jaanusson, 1960.

1: Fresh Precambrian granite. 2: Brecciated granite. 3: Weathered granite. 4: Basal Arenigian beds. 5: Tremadocian conglomerate. 6: Orthoceratite limestone. 7: Fault.

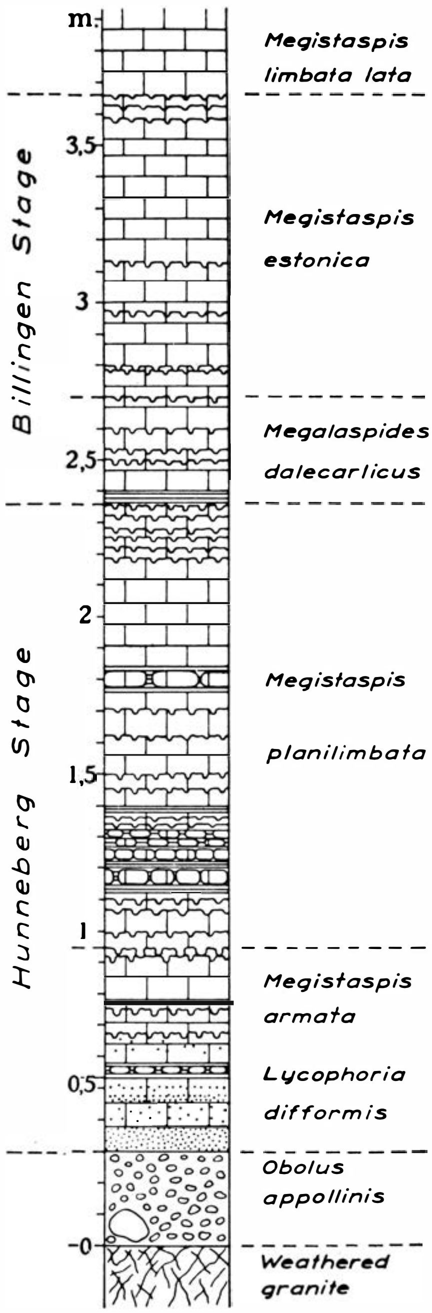


Fig. 4 — Stratigraphic section of the basal beds of the Paleozoic near Sjurberg. Compare fig. 3. After Tjernvik in Thorslund & Jaanusson, 1960.
The Cambrian is missing, as elsewhere in Siljan. The part of the Ordovician exposed here belongs to the Lower Ordovician and lies below the reef limestones that formed during the Middle and the Upper Ordovician. It is developed in the same facies as in the epicontinental cover further south, characterized by extreme thinness of individual stratigraphic stages (of the order of a meter), and by the numerous larger and smaller gaps and diastems indicating repeated periods of non-sedimentation.

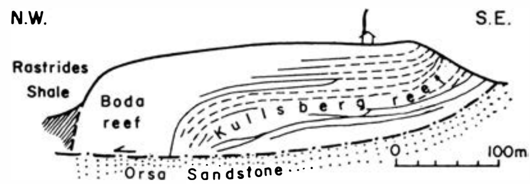


Fig. 5 — Section through the Osmundsberg reefs in eastern Siljan (stop 8 of fig. 2). After Thorslund, in Thorslund & Jaanusson, redrawn).
A local overthrust has developed beneath the thick lenses of reef limestones.

dian Shield, i.e. in the development of reef limestones and in their tectonization.

Taking first into consideration the Siljan reef limestones, it is to understand their paleogeographic significance that I have in the preceeding paragraph stressed so much the difference between the paleogeography of normal, non-glacial and a-tectonic periods with our present geography, dominated by the effects of postglacial eustatic sea level rise and of post-orogenetic crustal movements.

Reefs at present, apart from atolls, only grow in near coastal conditions. This has generally been extrapolated as indicating near coastal conditions for the Siljan Paleozoics too. From the foregoing it follows that I think this extrapolation is erroneous. There has been no more or less stable coast during the Ordovician and Silurian. Instead, both the Siljan district and the more southerly areas were entirely submerged during periods of transgression, and fell dry during the regressions which led to the breaks in sedimentation. Only during the Cambrian the coast remained south of Siljan, as sedimentation in this area only began with the Ordovician. For the rest of the time, continental and marine conditions succeeded each other in rapid succession, without leaving a trace of the fleeting coast line.

The importance of the Siljan reefs lies in quite another direction. They indicate local extra subsidence in Siljan, stronger than that found elsewhere on the stable areas of the Fennoskandian Shield.

In the shallow seas characterizing the early Paleozoic in this part of the world, one must have a crustal subsidence of 100 m to form a

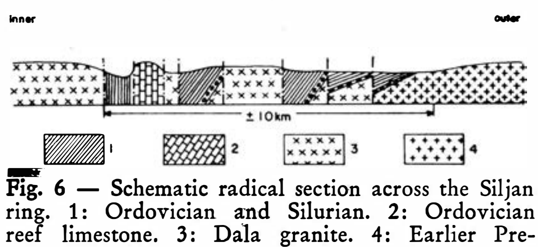


Fig. 6 — Schematic radical section across the Siljan ring. 1: Ordovician and Silurian. 2: Ordovician reef limestone. 3: Dala granite. 4: Earlier Precambrian.

reef 100 m thick. But outside Siljan, the various stages of the early Paleozoic epicontinental cover only developed thicknesses of the order of meters, before sedimentation was halted by the next regression. It follows that outside Siljan there was not enough crustal subsidence, no space, for thick reefs to develop. Even in somwhat more mobile belts, such as in the Silurian fo the island of Gotland, reefs reach thicknesses of the order of ten meters only (Rutten, 1958) [3]).

Reefs consequently did not develop as a function of their near-coastal situation, a notion meaningless at that time and place, but as a function of extra crustal subsidence.

Now the queer thing is, that only in the Siljan ring reef limestones of a thickness of the order of 100 m could develop during two stages of the Ordovician, when outside Siljan the thickness of the deposits laid down during the same time in the normal epicontinental cover was limited to the order of meters by the extremely meagre crustal subsidence.

The reef limestones developed during the Middle and Upper Ordovician in the Siljan ring consequently indicate local extra crustal subsidence. This must be due to local tectonics contemporaneous with the sedimentation. Such a picture of local extra subsidence, restricted to the ring structure, correlates well with the later tectonic history of the Siljan ring.

TECTONICS OF THE SILJAN RING

This brings us to the tectonics of the Siljan structure. I is characterized by a peculiar type of blockfaulting, in which the strike of the faults, of that of the tilted blocks and even of that of a number of smaller overthrusts accompanying the faults, is roughly tangentional to the ring, and follows it all the way around.

Owing to the meagre exposures, no general section across the Siljan ring had ever been published. The tectonic style follows, however, from many smaller local sections, such as that figured in fig. 3.

Starting at the outer zone of the ring, one finds a number of successive blocks, all tilted inwards, and bounded by antithetic faults. The blocks consist of a basement of the Precambrian Dala Granite, covered by Ordovician. The throw of the antithetic faults is such that the basement is repeatedly brought to the surface. This explains the detailed structure of concentric rings of basement and Paleozoic in several parts of the Siljan ring.

The further inwards, the steeper the tilting of the blocks becomes. In the centre of the ring, both the position of the sediments of the tilted blocks and that of the antithetic faults separating the blocks, is normally subvertical. Towards the inner border of the ring, overturned positions may even occur.

As an additional feature, overthrusts are locally found beneath the rigid blocks of reef limestone, owing to lack of space in the subsiding blocks (fig. 5).

From these local sections, which supply an internally coherent picture of the style of tectonic deformation in the Siljan ring, fig. 6 is drawn as a schematic cross section. The main point is, that it shows tectonic movements due to subsidence of crustal blocks and accompanied by tilting, that occur only within the ring and in its immediate surroundings. This is a local tectonication, that does not occur, either within, or without the structure.

The age of these tectonic movemens cannot be fixed beyond the fact that they are post-Silurian and pre-Quaternary.

Taking into consideration the extra subsidence that led to the formation of the reef limestones, we consequently have at least two periods of extra subsidence within the Siljan ring, that are not found outside this structure. One is of Ordovician age, and consists of two subsequent movements, leading to the formation of two superimposed groups of reef limestones. The other, probably more important, led to the tectonization of the Siljan ring. The latter is post-Silurian. The latter may, of course, be well be composed of many separate smaller movements, occurring over a long time interval.

SILJAN AS A METEORIC CRATER?

In these space conscious days, every ring structure on earth sollicits explanation as a meteoric impact crater. Siljan has, in fact, suffered the same sort (cf. Wickman, et al 1963, p. 209, Frederiksson & Wickman, 1963, p. 128, 129). Because of the fact that the tectonic movements were spread over at least two different periods, whereas during the first period reef limestones developed, indicating continuous crustal movement, such an origin seems completely impossible for Siljan.

THE DALA PORPHYRIES

Turning now to the Dala Porphyries, a recent map of the area (Hjelmquist, 1965), which will shortly be followed by an extensive description, gives us a good insight in their

[3]) The strong, local subsidence of a small basin in Skåne in southern Sweden during the Silurian, leading to clastic sedimentation of the order of many hundreds of meters thickness, is left out of consideration here.

Fig. 7 — Two of the rare exposures of a somewhat thicker section of Dala Porphyries, showing the massive, uniform structure typical for ash flows.

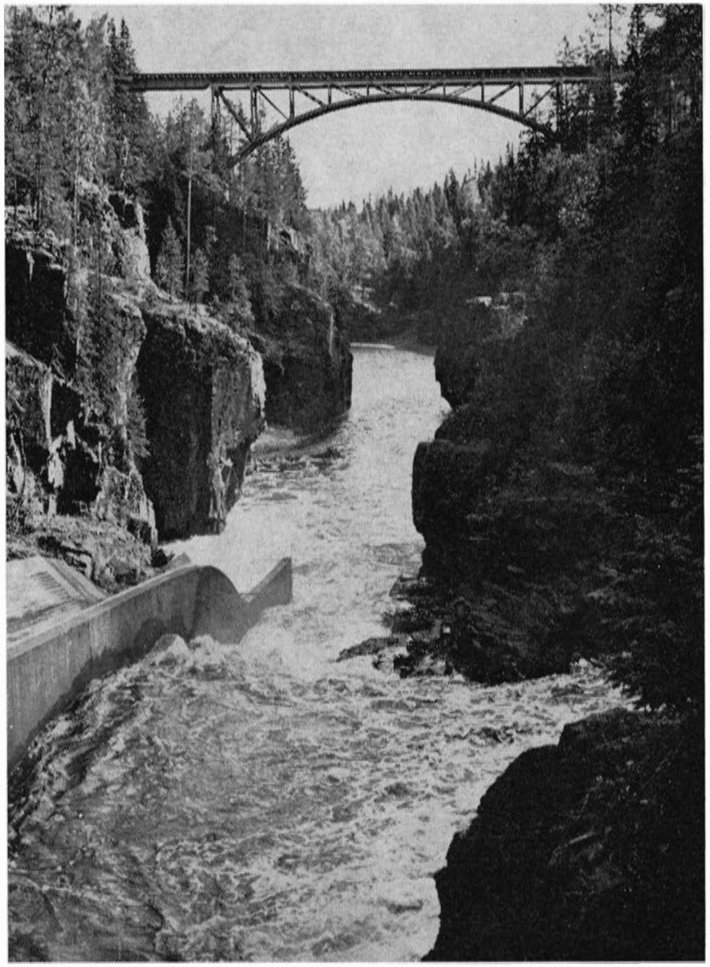


Fig. 7a — Storstupet Canyon, north of Orsa. Massive rock, without fluidal lamination, of the Upper Dala Porphyries.

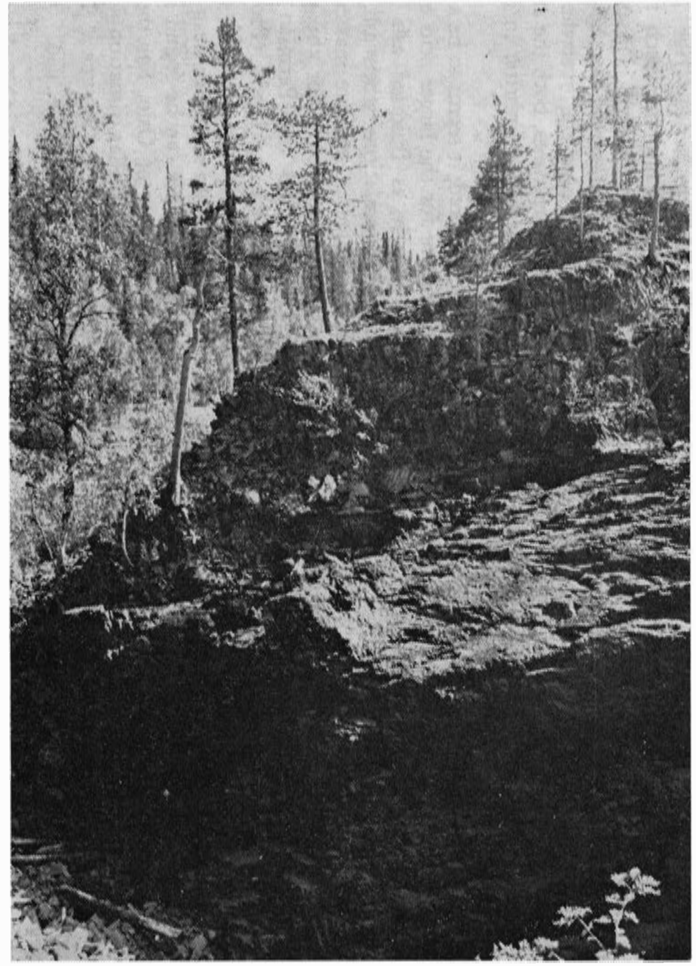


Fig. 7b — Exposure at Kälkastupet northwest of Älvdalen. Bredvadporfyr of the Upper Dala Porphyries, with some sligth fluidal lamination apparent through weathering.

development. Although no sections are available due to the excessive glacial cover, a lower and an upper series can be distinguished on the ground that the former contains quartz phenocrysts, the latter not. But apart from that, there is great similarity between the various types recognized.

A conspicuous difference lies in the fact that some menbers are more streaky and tuffaceous, others more massive. According to Hjelquist (1958), the first type, his „slirig porfyr" should represent ignimbrites or ash flows, the more massive types lava flows.

I can follow Hjelmquist in the explanation of the more streaky porphyries as due to ash flows, but think that the massive types were formed in the same way. They also indicate extreme fluidity at the time of their formation. The thick flows are entirely homogeneous, whilst they only rarely show a faint fluidal lamination. This is parallel, subhorizontal, and of a type similar to that found better expressed in the "slirig porfyr". This is altogether unlikely for a rhyolitic lava flow, which must have been of a very viscous nature, developing strong fluidal lamination, which, moreover, must be, at least in part, of a strongly turbulent pattern.

As a matter of fact, such structure has also been found in a single Dala Porhyry flow, near Limedforsen, in the lower series. (figs. 7, 8). This proves on the one hand that such fluidal lamination of a turbulent pattern is preserved over longer time spans. Whereas on the other hand it helps indicating that the overwhelming majority of the Dala Porphyries, both the streaky and the massive types are ignimbritic in origin (Rutten, 1963).

Parenthetically remarked, it seems to be a more or less normal feature for the larger acid eruptions, to extrude mostly as fluidised ash flows, but to show rare intercalations when ash, tuff-breccia and lava erupted in separate masses. We know this to be the case both for the young Cenozoic Yellowstone and the Permian Estérel volcanics (Rutten, 1963). Professor Oftedahl recently showed me a similair occurrence for the Permian Oslo volcanics near Ramnes, whilst another example can be found in the Glittrevan Cauldron west of Oslo. For the Precambrian, we found a similar situation in the Malani Rhyolites in Rajasthan (Rutten, 1965), and now for the Dala Porphyries.

DALA PORPHYRIES AND VOLCANOTECTONICS

Regardless of their mode of eruption, the very volume of the Dala Porphyries, of at least

Fig. 8a — Detail of the Bredvadporfyr at Kälkastupet northwest of Älvdalen. Compare fig. 7b. In a freshly quarried wall, to allow better transport of trees along the river, hardly any trace of fluidal texture is apparent in the fresh massive rock.

150 km^3, presumably poured out over a relatively short period, must have had volcanotectonic reactions. According to a notion widely spread in literature, ignimbrites erupt from fissures. This is, however, erroneous. Amongst other examples, the young Cenozoic ash flows from the mid-Italian volcanoes can, for instance still be physically followed into their central volcanic eruption sites (Rutten, 1959).

Scanning the new map of Dalekarlia (Kopparberg Lan) by Hjelmquist (1965), the only structure which seems to qualify for volcanotectonic origin seems to be the Siljan ring. It has the dimensions of a major caldera, whilst it is situated at the border of the Dala Porphyries' area.

The structure we observe now, cannot, however, be the remnant of the actual caldera. For the eruption of the Dala Porphyries dates back to the late Precambrian, whilst the formation of the Siljan Ring in its present state goes back only to the early Paleozoic.

But it is a well known fact that calderas are often related to ring dikes along their periphery (Reynolds, 1956). These ring dikes may, moreover, be emplaced at a later date than that of the major caldera subsidence. Together with the concentric subsidence faults, they form the ring-complex.

It is my contention that such valcanotectonic movements may even extend posthumously over a much longer time period. In this way the Siljan Paleozoics would owe its presence, both in its sedimentation and in its later tectonization, to such posthumous movements along the ring-complex surrounding a caldera, or the caldera, from which the Dala Porphyries had earlier erupted.

THE DALA GRANITE

Another feature of the geology of Dalekarlia still deserves mentioning, i.e. the dala Granites. These are coarsely granular granites, of which two varieties occur; the reddish Siljan type and the whitish Järna type. Apart from this, these granites are extremely homogenuous over all of their area. They differ from truly intrusive granite batholiths in two ways. Firstly they do not show any signs of cooling rims along their contacts. The rock may become more pophyritic, towards its border, but such variatons are of a very general nature. Secondly, they do not possess a „Ganggefolgschaft", an accompanying dike complex, either inside or outside their area.

Because of their consanguinity with the Dala Porphyries, I believe we are justified in assuming that the Dala Granites are no normal intrusive granite batholiths, but to postulate that they

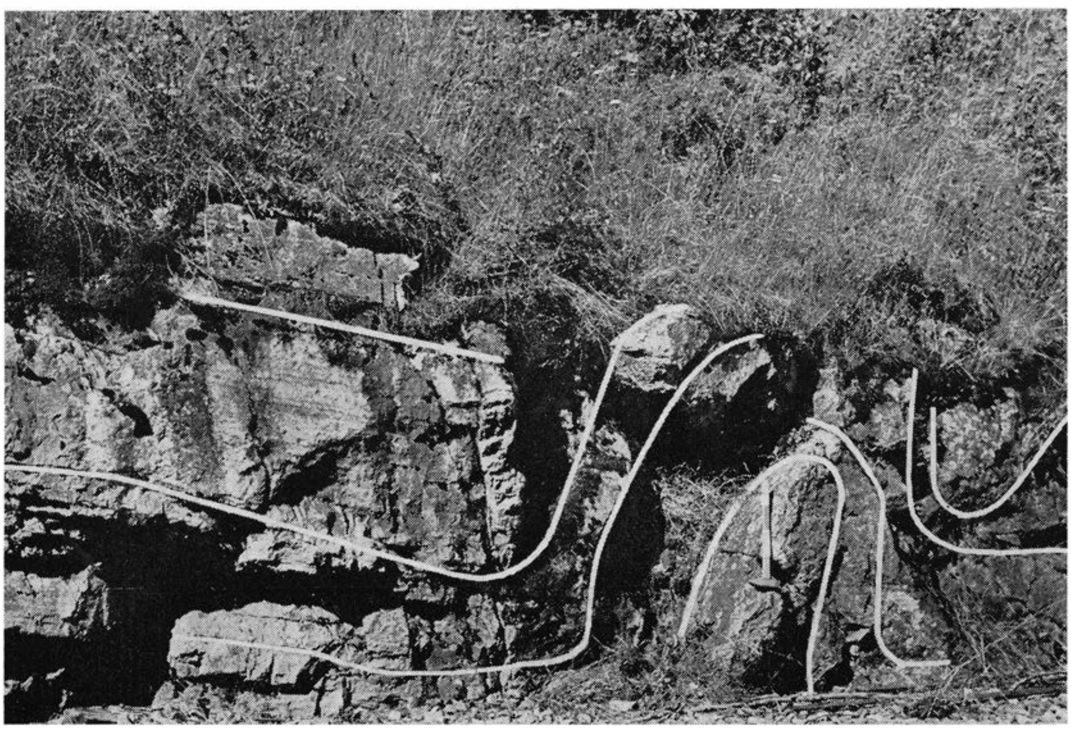
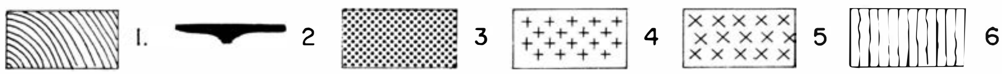


Fig. 8b — Lavaflow intercalated in the "Strökornsrik porfyr" of the Lower Dala Porphyries, west of Limedforsen. The rock shows strong fluidal lamination, which is regular and dipping slightly in the lefthand part of the picture, and very irregular in the right hand part.

Fig. 9 — Schematic genetic cross sections through the Dala Porphyries and the Siljan Paleozoics, on the 61th parallel. 1 : 1.000.000.



1: Paleozoics of the Siljan structure. 2: Trapp basalts. 3: Jotnian Sandstone. 4: Dala Porphyries. 5: Dala Granites. 6: Earlier Precambrian.

The series of main events that led to the present structure are as follows:

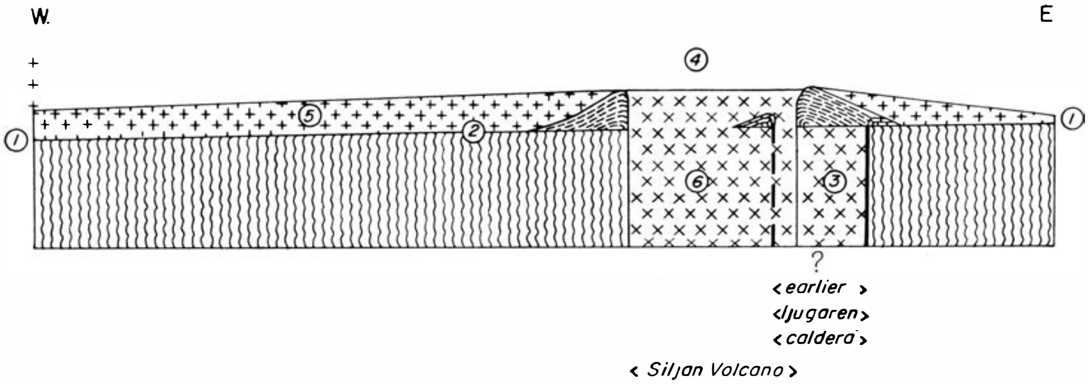


Fig. 9a — 1: Westward tilting of late Precambrian, pre-Dala peneplain. 2: Deposition of continental (?) Digerberg clastics (not shown). 3: Formation of Ljugaren volcano (?). 4: Formation of Siljan volcano, largely obliterating the Ljugaren structure. 5: Westward effusion of highly mobile ash flows during low explosivity eruptions: Dala Porphyries. 6: At eruption's end, secondary melting of fluidised ash contained in crater vent (rheo-ignimbrite), crystallizing as a granular, pseudo-hypabyssal or pseudo-abyssal rock: Dala Granites.

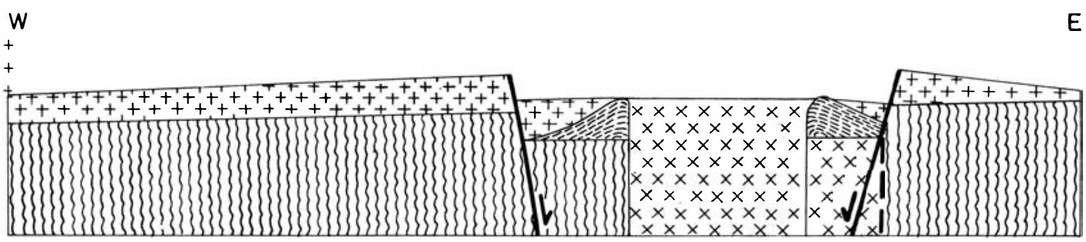


Fig. 9b — Collapse of Siljan Caldera.

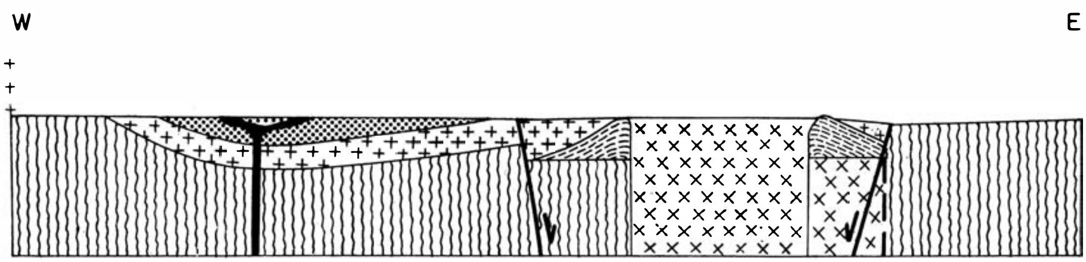


Fig. 9c — Regional faulting and slight subsidence, leading to deposition of Jotnian Sandstones and intercalated basalts.

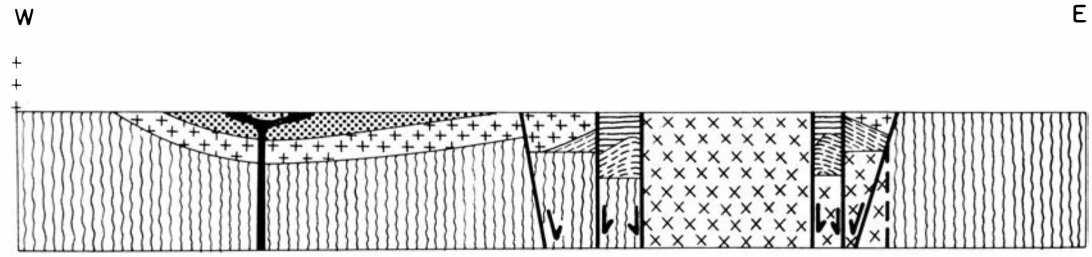


Fig. 9d — Posthumous ring-complex movements, leading to deposition of Ordovician, with reef limestones, and Silurian.

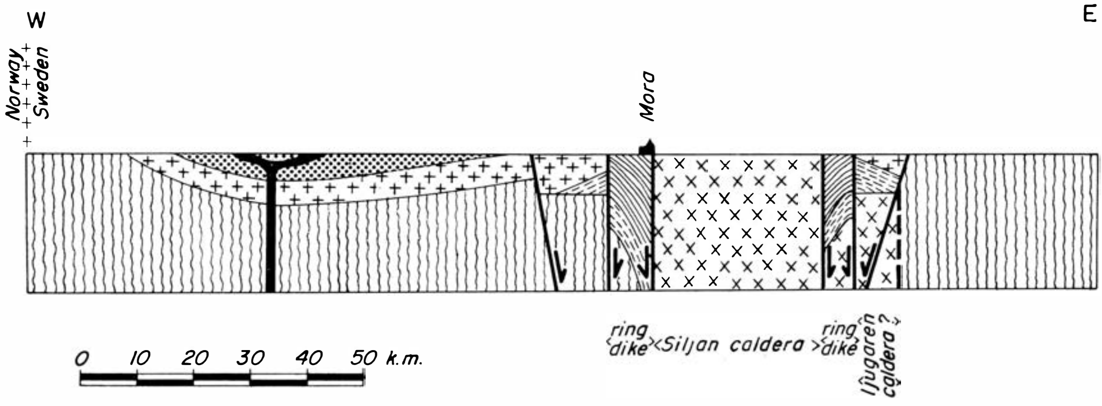


Fig. 9e — Further subsidence within the ring-complex, leading to tangentional tectonization of the Siljan ring of Paleozoics. Slight tilting, with relative rise of the western part of the area. Perhaps only in Plio-Pleistocene times, in relation with the general rise of the Skandinavian Mountains. Erosion, glaciation, etc.

represent rheo-ignimbritic masses (Rittmann 1958), related to the eruption of the Dala Porphyries.

For the Dala Granites within the Siljan ring this seems a plausible explanation indeed. They would then represent the represent the fluidised magna, filling the crater vent at the time when the eruption stopped. It was at that time so hot, that it melted secondarily, when its movement died out. Upon cooling, it then crystallized as a granular, pseudo-plutonic rock. Dependent upon the level reached within the crater vent, some of this material had already come into contact with the contemporaneous atmosphere, and had become oxidized. This later became the red Siljan type. Material from a lower level in the crater vent, on the other hand, still retained its original less oxidized state, and later crystallized to the whitish Järna type.

A similar genesis has been proposed earlier for the so-called „central pluton" of the Permian Ramnes volcano of the Oslo district (Rutten & van Everdingen, 1961), and might well apply to many other of the subvolcanic granular Oslo rocks.

The relation of the Dala Granites outside the Siljan ring to the Dala Porphyries is less clear. A roundish area around Lake Ljugaren, situated to the southeast of the Siljan ring, and about 12 km in diameter, might well be formed by another, smaller, and probably earlier caldera. The main difference with the Siljan ring being that it did not undergo the posthumous ring dike movements, which, in attracting Paleozoic sedimentation and in causing its later tectonization, make the Siljan structure so eminently visible.

In a similar way, the somewhat more complicated area south of the Siljan ring, in which Dala Granites are found over a region measuring about 40 km by 40 km (fig. 1), might well be formed by a number of overlapping volcanic vents, whose borders are not now visible. In a better exposed area, it would probably be possible to trace the ring complex proper. But the extensive and thick glacial cover of Dalekarlia will presumably prohibit for always a better understanding of this southern part of the Dala Granites area.

HISTORY OF THE DALA PORPHYRIES AND THE SILJAN PALEOZOICS

To conclude, the history of both the Dala Porphyries and of the Siljan Paleozoics might be summarized very schematically as follows, from the series of genetic sections of fig. 9.

BIBLIOGRAPHY

Asklund, B. (1936) — Discussion of a paper by P. Thorslund. Geol. Fören., Stockholm, Förn. **58**, 385-387.

Frederiksson, K. & Wickman, F. E. (1963) — Meteoriter. Svensk. Naturvetens. Stockholm, p. 121-**157**.

Hjelmquist, S. (1956) — On the occurrence of ignimbrite in the Pre-Cambrian. Sveriges Geol. Unders., Ser. C, no. 542, Arsbok **49**; 1-12.

—— (1965) — Berggrundskarta över Kopparbergs Län. 1 : 200.000. Sveriges Geol. Unders, Ca nr. 40.

Lafitte, R. (1949) — Sédimentation et orogénèse Ann. Hébert et Haug **7**, 239-259.

Magnusson, N. H. (ed.) (1960) — Description to accompany the map of the pre-Quaternary rocks of Sweden. Sveriges Geol. Unders., Ba nr. 16.

Michot, P., et. al. (1963) — Sédimentologie des formations viséennnes du Synclinorium de Namur, dans la vallée de la Meuse. Livret-Guide, Exc. G, 1ière Partie, 6ième Congr. Int. Sédimentologie, Bruxelles, 22 p.

Pirlet, H., 1963: Sédimentologie des formations du Viséen supérieur, V3b, dans la vallée du Samson (Bassin de Namur, Belgique). Ann. Soc. géol. Belge **86**, M 1-41.

Reynolds, D. L. (1954) — Fluidization as a geological process and its bearing on the problem of intrusive granites. Amer. J. Sci. **252**, 577-641.

—— (1956) — Calderas and ring-complexes. Verh. K. Geol. Mijnbk. Gen., Geol. Sectie 16, 355-379.

Rittmann, A. (1958) — Cenni sulle colate di ignimbriti. Boll. Acad. Gioenia Sc. Nat., Catania, **4**, 4, 10, 524-533.

Rutten, M. G. (1949) — Actualism in epeirogenetic oceans Geol. & Mijnb. N.S. **11**, 222-228.

—— (1953) — Shallow shelf sea sedimentation during non-glacial and a-tectonic times in geological history. CR, XIX Cong. géol. Intern., Alger, 4, 4, 119-125.

—— (1958) — Detailuntersuchungen an Gotländischen Riffen. Geol. Rdsch. **47**, 359-348.

—— (1959) — Ignimbrites of fluidised tuff flow on some Mid-Italian volcanoes. Geol. & Mijnb. N.S. **21**, 396-399.

—— (1963) — Acid lava flow structure, as compared to ignimbrites. Bull. Volcanol. **25**, 111-121.

—— (1965) — Tectonics of Late Precambrian ignimbrites in western Rajasthan, India. Geol. & Mijnb. **44**, 316-319.

Rutten, M. G. & van Everdingen, R. O. (1961) — Rheo-ignimbrites of the Ramnes volcano, Permian, Oslo Graben. Geol. & Mijnb. **40**, 49-57.

Thorslund, P. & Jaanusson, V. (1960) — The Cambrian, Ordovician and Silurian in Västergotland, Närke, Dalarna and Jämtland, Central Sweden. Guide Book, Exc. A 23 & C 18, XXI Int. Geol. Congr., Kopenhagen, Geol. Survey, Sweden, 51 p.

Wanless, H., et. al. (1963) — Mapping sedimentary environment of Pennsylvanian cycles. Bull. Geol. Soc. Amer. **74**, 437-486.

Wickman, F. E. et. al. (1963) — Isotopic constitution of ore lead in Sweden. Arr. Min., Stockholm **3**, 193-257.