

SVEN HJELMQVIST

AN OLD EVOLUTION
AND A YOUNG 'MODEL'



STOCKHOLM 1973

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ABSTRACT

The paper compares a section of the Precambrian of Sweden with a part of the North-American Cordillera.

It must at once be declared that the term model might not be taken too literally. The intention of the author has been to point at a comparatively young area which in certain respects shows some connection with the pattern of an old region, even if there are, also, many dissimilarities. Three facts in particular have given rise to this comparison. The primary is the wide extension of well preserved Precambrian ignimbrites in central and southern Sweden with a given position in relation to an older mountain chain. The second is the repeated orogeneses which seem to have struck the folded belt outside the craton to which the volcanics belong. The third is the occurrence of massive granites which intrude the volcanics of the craton in a diapiric manner with no direct relation to any orogenetic movements. In all these respects there are similarities with occurrences in western North America.

While the development of the North-American Cordillera is well known both in regard to time and space, the chronological history of the gneissic belt of southwestern Sweden is still unknown. The radiometric age determinations hitherto made point for the most part to the latest phase of the metamorphic evolution.

As long as things are not more elucidated in southwestern Sweden it may be justified to consider the evolution of a better known territory to get an alternative basis for discussing the possible conditions regarding the geological development in time and space of the named district.

STORY

In northern Dalarna and adjacent parts of Härjedalen in central Sweden a large area is occupied by acid porphyries (Dala porphyries) which are to a large extent ignimbrites (Hjelmqvist 1966). They were earlier thought to be real lavas, an idea which did not fit in very well with their acid and, as a consequence of this, strongly viscous character since they cover very considerable areas, in round numbers 5 000 sq.kms.

The age of these porphyries is according to recent investigations (Welin-Lundqvist 1970) about 1 670 m.y. They have been intruded by granites of rapakivi type and form the base of the Jotnian sandstone in Dalarna, owing to which they have generally been called Subjotnian. Together with and beneath the porphyries both sandstones and conglomerates occur which are of the same type as the overlying Jotnian layers indicating that no sharp distinction can be made between the Jotnian and Subjotnian formations. In the main the volcanic rocks and sediments are tectonically quite undisturbed and constitute a part of a big craton in the Precambrian. Besides the well-preserved granites of rapakivi type which are closely allied to the porphyries and also show transitions to them, the volcanics are penetrated by larger granite massifs in a sometimes diapiric manner (Sorgenfrei 1971). These granites have as a rule a quite massive structure but differ from the rapakivi-like granites in their texture.

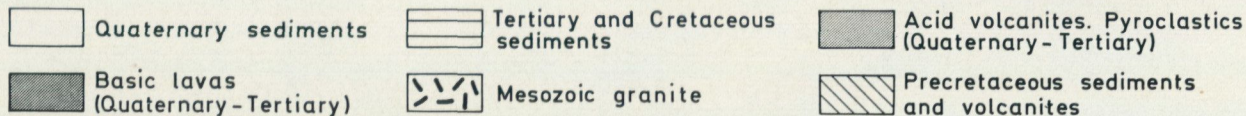
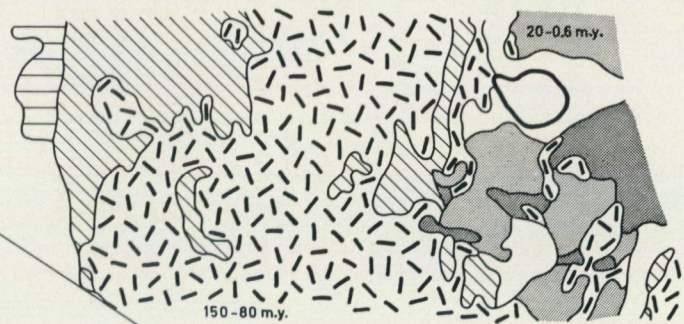
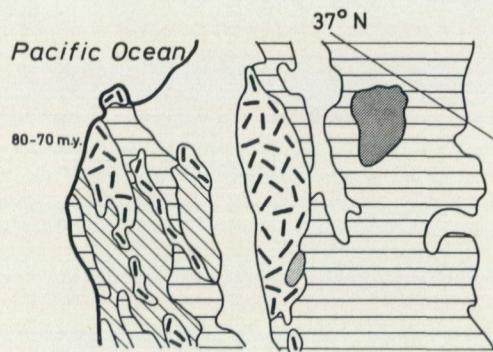
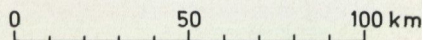
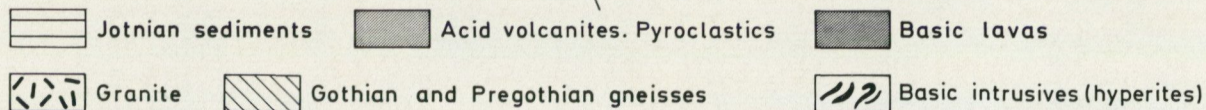
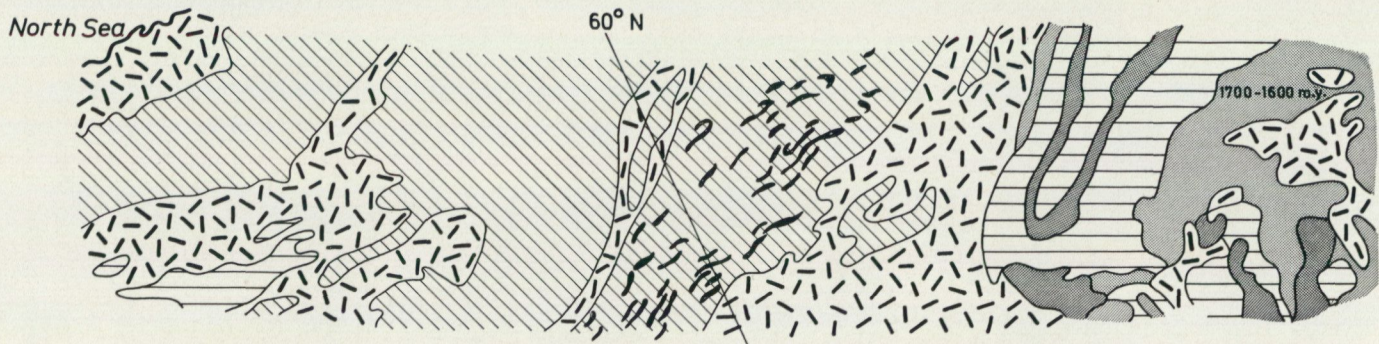


Fig. 1. Upper part: A section through southern Sweden from Dalarna to the North Sea. Lower part: A section through California from the boundary of Nevada to the Pacific Ocean.

To the west of the porphyries a broad belt of older granites and gneisses stretches in a north-south direction. This belt has been interpreted as the root of an ancient mountain chain. The interpretations have, however, been shared as to the age and significance of this folding zone. Already in a paper of 1899, G. De Geer expressed the opinion that the gneiss belt of southwestern Sweden was the rest of an ancient mountain chain the age of which he considered to be Algonkian (De Geer 1899). A similar conception of the gneiss region as the root of an old mountain building was presented by A. G. Högbom (1909), who however supposed its age to be Archaean. In the 1930s there was a lively discussion among Swedish and Finnish geologists about the granite groups and orogeneses of Fennoscandia. In a series of papers N. H. Magnusson dealt with the age relations of the Archaean of Sweden (Magnusson 1933, 1934). He showed that the granites of southwestern Sweden were younger than the late Svecofennian granites of central Bergslagen. In 1936 appeared a paper of W. Wahl about the granite groups and mountain foldings in Sweden and Finland where the author distinguishes between four separate orogenetic periods, namely the Svecofennian, the Gothian, the Karelian and the Caledonian (Wahl 1936). The Gothian orogenesis embraces southwestern Sweden and the adjacent part of southeastern Norway.

In the discussion after the paper of Wahl, Magnusson emphasized that three geological cycles can be distinguished in the Swedish Precambrian, namely the Svionian, the Gothian and the Karelian cycles in order from the oldest to the youngest (Magnusson 1936 a, b). The gneisses and granites of southwestern Sweden were assigned to the Gothian cycle, whereas the better preserved sediments of the Dalsland series were classed among the Karelian. Backlund pointed out that the name Svionian had to be exchanged for Svecofennian (Backlund 1937 a) and, moreover, grouped the Gothian and the Karelian cycles into one Gotho-Karelidian cycle comprising both the gneiss belt of southwestern Sweden and the sediments of the Dalsland series as well as the Karelian belt of eastern Fennoscandia (Backlund 1936 a, b, 1937 b). Parenthetically it can be mentioned that the distance between the two limbs of the Gotho-Karelidian folding zone, which enclose the interjacent Svecofennian area, is about the same as the distance between the Sierra Nevada and the Rocky Mountains. In 1963 Magnusson maintained that the Karelian cycle should be in respect of age closely connected to the Svionian (Magnusson a.o. 1963). The Gothian cycle was thought to be younger. As an older formation Magnusson – in accordance with Lundegårdh (Lundegårdh 1956) – detached a Pregothian suite embracing the gneisses of southwestern Sweden, which were said to be either older than the Svecofennian or of the same age. The granites were still interpreted as Gothian. For the folded sediments of the Dalsland series Magnusson introduced an independent cycle, the Dalslandian (the name originally given by Sederholm 1932), representing the youngest Precambrian of southwestern Sweden.

In later recapitulations concerning the geology of southwestern Sweden the gneisses are divided into Pregothian and Gothian although the relations between these are not always interpreted in the same way by different authors (Larsson 1958, Lundegårdh 1958, Gorbatshev 1971).

A mere glance at a geological map of Sweden shows the sharp boundary between the gneiss belt of southwestern Sweden and the region east of it. The gneisses constitute a geotectonical unit which is clearly separated from the area to the east. In spite of the gneissic character it is possible to distinguish in it better preserved supracrustal rocks, strongly folded, which are intersected by granites. Obviously southwestern Sweden has been subjected to repeated orogenesis. The folding zones move westerly the younger they are: Hammarö complex – Åmål complex – Dalsland complex.

East of the gneisses a big massif of Gothian granite stretches north-south from Norway to the Baltic with a length of about 600 km. In its eastern part this granite is intersected by porphyries belonging to the Subjotnian. Farthest west in the gneiss belt a younger granite occurs (the Bohus granite) which is associated with pegmatites. In connection with the folding processes tectonic movements: faults and overthrusts have affected the area on a large scale (Magnusson 1937, Larsson 1956, Gorbatshev 1971).

In the eastern part of the gneiss belt there is a multitude of basic intrusives, the black dolerite-like hyperites, which can be followed on a length of 600 km within a 20–40 km wide zone from the Norwegian border to Scania in the south (see Fig. 1). In accordance with the conception of plate tectonics the occurrence of these rocks can be connected with the moving of a basic crust perpendicularly to the border of the gneiss belt on the granite.

Kyanite has been found in at least four places in the gneiss belt of southwestern Sweden but nowhere in the Svecofennian area. This indicates a high pressure metamorphism as distinguished from the low pressure – high temperature metamorphism of the Svecofennian orogenic belt (Zwart 1967).

The chief purpose of the present paper has been to point at a young area characterized by acid volcanics of great extension, which display some apparent similarities with the acid porphyries of Dalarna. When looking for a region with extensive acid volcanics the western part of the United States offers an imaginable possibility of comparison. Here large areas of acid and semi-acid ignimbrites of Tertiary or later age occur in the Great Basin to the east of the Sierra Nevada. Their situation adjacent to an older mountain chain has a certain similarity with the conditions in central Sweden.

Fig. 1, upper part, represents a belt of western Sweden from Dalarna to Bohuslän compiled from the geological map of the Kopparberg county in the scale 1:200 000 (Hjelmqvist 1966) and the general geological map of Sweden in the scale 1:1 000 000 (Magnusson and collaborators 1960) with some complementary addition (Gorbatshev 1971). Fig. 1, the lower part, is a generalized

map of a part of California compiled from the map sheets Santa Cruz (Jennings and Strand 1959), Mariposa (Strand 1967), Walker Lake (Koenig 1963) and San Jose (Rogers 1966) in the scale 1:250 000. The figures of the age are taken from late publications (Dalrymple a.o. 1965, Evernden a.o. 1970, Huber a.o. 1967, King 1969). Both maps are represented in the same scale. One reason of their placing together is the desire to give an idea of comparable distances and areas in the two cases.

The geological history of the named section of the United States is roughly as follows (essentially after Gilluly 1963 and King 1969).

The western part of the present Cordillera was from Cambrian to Devonian time a geosyncline, while the eastern part was shelf. Enclosures of older rocks of Precambrian age are very fragmentary. Notable orogenies occurred in Carboniferous, Permian, Triassic and Jurassic time. The main folding was the Nevadan orogeny which took place in Jurassic time. Volcanic rocks older than Carboniferous and as old as Silurian and Devonian occur in Sierra Nevada.

Most granites of the region were emplaced during or shortly after the main orogeny of the fold belt in Jurassic time with a maximum in the Cretaceous but there are also granites and granodiorites which show that the emplacement reached over a long period from Triassic to upper Cretaceous. The rocks of the Sierra Nevada batholith were emplaced essentially in upper Jurassic and Cretaceous time. The granite of the Coast Ranges is somewhat younger (upper Cretaceous).

After the climax of the Nevadan orogeny layers of clastic rocks accumulated in the coastal belt of California from latest Jurassic to Pleistocene filling the Pacific geosyncline which is characterized by late orogenic and volcanic activity. The Cenozoic deposits of the Coast Ranges of California have undergone several orogenic deformations of which those in Miocene and in Pleistocene are the most important.

Whereas there are on the whole no granites in the Paleozoic and the Cordilleran plutonism reached a maximum in the Cretaceous the volcanic activity extended from Cambrian to Pleistocene time. Siliceous products are common in Silurian and Tertiary time, else the volcanism was mainly basaltic. In the craton to the east of the fold belt large masses of volcanic rocks covered the older formations. Siliceous ash flows of Cenozoic age are particularly abundant in the eastern and southern parts of the Great Basin but occur also farther west. The volcanites are intruded by small plugs of acid and basic rocks.

In the reactivated parts of the craton east of the Mesozoic plutons there are large granitic bodies which have had no direct relation to any generation of magma in the eugeosynclinal area to the west. They are autochthonous and are believed to derive from deep levels of a crust that had been weakened and broken by many orogenic events (King 1969).

Summing up we have thus a picture of a mountain chain, the Sierra Nevada, composed of Paleozoic and Mesozoic rocks, which were folded mainly in Jurassic time and were then the centre of the emplacements of granites chiefly during Cretaceous time. It contains, *inter alia*, enclosures of older volcanites of Silurian and Devonian age. Farthest to the west a somewhat younger granite occurs. In the craton east of the folding belt there are abundant siliceous ash flows of Cenozoic age. These pyroclastics extend from Miocene to Pleistocene over a period of about 20 m.y.; in the area represented in Fig. 1 the Cenozoic volcanites essentially date from Pliocene and Pleistocene. Besides the pyroclastic rocks among which welded tuffs play a conspicuous rôle there are both rhyolites and basalts. Plugs of plutonic rocks of Tertiary age intrude the volcanites, and in reactivated parts of the craton large granite plutons occur which derive from deeper levels of the crust. In the far west a younger mountain chain composed of Jurassic to Pleistocene rocks, was folded and uplifted in Cenozoic time mainly during Miocene and Pleistocene epochs, respectively. During Cenozoic large parts of the Cordillera were disrupted by block faulting, partly coinciding in time with the volcanism but continuing later.

If we turn to southwestern Sweden we find there the roots of an old mountain chain of uncertain age, mainly consisting of gneisses and granites but with enclosures of better preserved supracrustal rocks older than the granites. The few existing age figures of the granites indicate by their uniformity that the latter have with all probability been subjected to a regional activity, which is possibly several million years later than the formation of the rocks. It is probable that the eruption of the granites covers a long space of time. It is important in this connection to notice the rather wide gap between the oldest and youngest granites of the massif of Sierra Nevada.

In the gneiss belt there are signs of foldings at different times. The youngest folding zone is situated farthest west and has affected the geosynclinal Dalsland complex which has a thickness of about 2 000 m. The Dalslandian orogeny is supposed to have taken place about 900–1 200 m.y. ago and might be compared with the orogeny of the Californian Coast Ranges which were folded in Miocene and Pleistocene times. In addition the Dalslandian fold belt is characterized by mighty breccias and overthrusts.

In the craton east of the folding belt there are abundant siliceous volcanic rocks which generally show only local or no tectonic disturbance. They are distinctly younger than the granites to the west against which offshoots of them exhibit intrusive contacts (Hjelmqvist 1966). To a large extent the siliceous volcanites are still recognizable ignimbrites. At the southwestern contact they are locally upraised and pressed. Within a large area the porphyries are covered by Jotnian sandstones with intercalated basaltic layers.

According to Welin the Dala porphyries belong to the concluding intrusion and deposition period of the Svecofennian orogenic zone (Welin 1970). The

same idea is expressed by T. Lundqvist who on the basis of the existing age determinations of Subjotnian porphyries maintains that the post-orogenic Subjotnian igneous activity has occurred in relatively close connection with the Svecofennian orogeny (Lundqvist 1968). A gradual development from Svecofennian to Subjotnian and still younger formations moving from SE to NW in Dalarna has been emphasized by the present author (Hjelmqvist 1966).

There is, however, reason to discuss also another possibility. The porphyries in question are geographically distributed along the eastern border of the gneiss belt of southwestern Sweden. Furthermore, if northern Sweden and the Kiruna porphyries are taken into account, the young volcanics are arranged in a roughly north-south-stretching zone which, however, over great distances is interrupted by the Caledonian mountain chain. In addition to the porphyries anorogenic granites are met with in the same zone. In relation to the gneisses of southwestern Sweden the Subjotnian and Jotnian rocks constitute a sunk area while the gneiss belt has risen. According to Rittmann the eruption of ignimbrites is caused by the rise of anatectic magmas in a sinking field which under the influence of tectonic stress and high vapour pressure force their way to the surface during the post-orogenic stage (Rittmann 1960).

The ignimbrites of Dalarna are posterior to the Gothian granite in SW and this in its turn is younger than the late Svecofennian granite of central Sweden. If the ignimbrites of Dalarna should be connected with an orogeny it seems plausible to consider, at first hand, the orogenic zone of southwestern Sweden, the late movements of which have affected not only the porphyries but also the Jotnian sandstone, which in its western part has been upraised and even turned over. At some distance from the Gothian granite a faint folding of the sandstone is sometimes noticeable, the fold axis being parallel with the granite boundary (Hjelmqvist 1966). The fact that the movements of the Jotnian of Dalarna are connected with the tectonic activity in southwestern Sweden is a contributive argument for associating also the Dala volcanites with the development of southwestern Sweden.

When comparing the ignimbritic porphyries of Dalarna with the Cenozoic ash flows of eastern California and Great Basin it is interesting to consider the age relations in both cases (see Fig. 1). The age of the porphyries of Dalarna is about 1 600–1 700 m.y. The Gothian granite, if compared with the Sierra Nevada, could then very well be 50 or 100 m.y. older than the porphyries without implying for this reason a cease of the geotectonic influence.

The porphyries are intruded by granites of rapakivi type which also show transitions to porphyries indicating a close affinity between these rocks. In addition conglomerates from the lower part of the volcanic series contain pebbles of a very similar granite proving that there must have been more than one generation of rapakivi-like granite. There are in the craton east of the fold belt also large granitic bodies with a massive character and intrusive

against the porphyries. They have possibly been pushed up in a diapiric manner from deeper levels of the crust in the same way as has been maintained concerning the big Tertiary granite plutons east of the Sierra Nevada (King 1969). If two Russian potassium-argon determinations of Järna granite are correct (1 880 and 1 860 m.y., Magnusson 1965), these granites of Dalarna must contain an older kernel and have probably then been emplaced at a rather low temperature. Better possibilities to judge of all these things are obtained when more absolute age determinations have been made.

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