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Some leading lines of dislocation in Spitzbergen.

By

GERARD DE GEER.

(With a map, Pl. 2).

As far as is hitherto known about the strike of the foliation of the Archæan rocks in Spitzbergen, it seems as if the very oldest, main tectonic lines of that country were running in about the same direction as Wijde Bay and the west coast of the land, or NNW—SSE. If it be so, the younger dislocations of Spitzbergen have, in the main, been determined as to their direction by the older lines, just as is the case in southern Sweden.¹

The first of these younger dislocations was the folding of the Silurian rocks, or the »Hekla-Hoek system». NATHORST's important discovery of lower Silurian fossils in the Hekla-Hoek rocks of Beeren Eiland and the identity of those rocks with the like named rocks of Spitzbergen, even with respect to such peculiar rock-species as the dolomitic oolite, as I have been able to establish on the most different parts of Spitzbergen, show that at least the Lower, but possibly also the Upper Silurian have taken part in that great mountain-folding which very probably was synchronous with the great post-Silurian mountain-folding in Scandinavia and Scotland.

In these countries the folding has been followed by a series of somewhat later faults, affecting strata of Devonian age.

¹ G. DE GEER, Om algonkisk bergveckning inom Fennoskandias gränsområden. G. F. F., Stockholm 1899, p. 692.

Earlier these faults were known in Spitzbergen only from the western part of the northernmost third of the country, and here NATHORST had already 1888¹ shown, that the Devonian must be limited at least to the eastern side by a great fault-line, marked upon his sketch map along the axis of Wijde Bay and bending southwards to Klaas Billen Bay. Concerning the nature of the western limit at that time nothing was yet known, and at this side there might have been a limit of erosion as well as a fault-limit.

In 1899, during a visit in Horn Sound, I recognized in the interior of this fiord the characteristic Devonian rocks, and this unexpected discovery was soon afterwards confirmed by Devonian fossils being found by TH. TSCHERNYSCHEW and myself. Yet, what attracted my greatest interest was that the Devonian evidently toward the west was limited by a gigantic fault, marked by an almost plumb vertical wall, forming the eastern limit of the Silurian rocks of the western coast region. North of Horn Sound this great fault-line runs along the perpendicular eastern wall of the *Sophie-Kamm*, and south of the fiord along the exceedingly abrupt eastern side of Hornsundstind, the highest point in southern Spitzbergen, rising, according to my measurements of 1899, to about 1430 *m* above sea level. As the faulted Devonian extends below the surface of the sea, the up-throw of the fault must probably have been more than 1500 *m*, or some 5000 English feet. It seems namely obvious that it is here, as in most other cases on Spitzbergen, the *Horst* that has been moved upwards and not the *Graben* that has been depressed.

This remarkable, quite local occurrence of thick Devonian strata also at one place in southern Spitzbergen, while they are missing as well at South Cape as at Bel Sound and at the mouth of the Ice Fiord, was, according to my opinion, scarcely explicable in any other way than by the assumption of a gigantic Devonian Graben running all across Spitzbergen,

¹ In SUSS, *Das Antlitz der Erde*, Bd. 2, Wien 1888 p. 102.

from the north end to the south, and dividing the land in two parts just as is the case with the renowned *fossa magna* in Japan, though not accompanied by eruptives as this one.

With respect to the rest of the western border of this great *fossa*, the following may here be added. In 1892 G. NORDESKIÖLD observed at Red Bay, near the north west corner of Spitzbergen, some faults, running along this bay which he considered as a *Grabensenkung*.¹ Yet, from his description as well as from all that is now known about the geology and topography in that region, it seems obvious that the fault-line at the east side of the bay is very subordinate in comparison with that along the western shore. The latter fault-line marks at the same time, as is shown on the map, the line of demarcation between the Archæan and pre-Devonian area to the west and the great Devonian region to the east.

During the arc-measurement expedition in 1901, when King's Bay was mapped in the scale 1:50 000, I could determine, that the pre-Devonian area extended somewhat farther to the east than before assumed, or at least some 12 km east of the innermost end of King's Bay. The Devonian summits in this region rise to about 1200 m. On the topographic map of ISACHSEN from 1906, together with the accompanying information and photographs, it seems established, that the western limit of the Devonian area runs in a straight line between its two above mentioned parts, at Red Bay and King's Bay, the whole way marked by a continuous, mostly glacier-filled valley. From what I have seen in many other places of Spitzbergen the demarcation line might be fixed even more precisely to the very western side of that valley, thus making only two small corners extending a few km from the main direction. The situation of this limit immediately in the continuation of the great fault along the west side of Red Bay puts it beyond all doubt that we all the way have to do with a very marked fault-limit. It is also

¹ K. Vet. Ak. Bih., Bd. 17, p. 54, Stockholm 1892.

note-worthy that this does not, as one might have earlier believed, form an angle with and intersect the direction of the western coast-line, but runs NNW—SSE, or almost exactly parallel with the great fault-line along the eastern side of Wijde Bay.

Concerning the western limit of the Devonian area in the middle parts of West Spitzbergen, where it is concealed by younger formations, it is obvious that this limit must run along or east of the limit between the Silurian and the Carbonian, the remarkable lack of Devonian in this region between the strata named surely being due to a Carbonian transgression over a *Horst* of Silurian rocks from which the Devonian was removed.

But from the direction of the great western Devonian fault-line, as well at Horn Sound as in north-western Spitzbergen, it seems likely that its intermediate part runs in the same direction, and probably just along the much younger dislocation that here marks the actual limit between the Silurian and the Carbonian.

Concerning the height of the throw of the great Devonian *fossa* the following remarks may be added.

In the Devonian region, which yet is the geologically least known part of Spitzbergen, it seems as if the strata were, as a rule, in the main horizontal, with the exception of more local disturbances along the fault-lines. Therefore, in this region the heights of the mountains would generally afford approximate figures of the thickness of the Devonian strata.

During the later expeditions the height of the mountains has been measured in a great number of places, thus permitting us at present to get an idea concerning the thickness of the Devonian strata. According to the map of Red Bay, issued by Prince ALBERT OF MONACO, the Devonian thus seems to be probably more than 900 *m* thick. According to the measurements made by N. C. RINGERTZ in 1899, when the

Swedish arc-measuring expedition visited Wood Bay and determined for the first time its extension to the south,¹ the thickness of the Devonian in this region is more than 1200 *m* and, in accordance with the map of PONINSKI and VON BOCK from 1907, there are a few summits rising to a somewhat greater height, or at one place to 1354 and at another to even about 1460 *m*. In the spring of 1906 by putting together photogrammetric material from the Swedish expedition of 1902, I found for the southern inner part of Liefde Bay, that the Devonian strata at this place were at least 900 *m*, and by the valuable mapping work of ISACHSEN and STAXRUD in 1906—07 it seems as if the Devonian region farther south of Liefde Bay should at several places reach 1200 but scarcely 1300 *m* above the sea level.

Thus it seems but fair to assume that the thickness of the Devonian in this part of Spitzbergen is over 1200 and perhaps more than 1500 *m*.

The summit of the *Horst* of pre-Devonian rocks W of the *fossa* at King's Bay, according to my own measurements, rises to a level of about 1100 *m*, and farther north, according to ISACHSEN's map, at many places to somewhat more than 1200 but never as much as 1390 *m* above the sea and is now apparently forming a basè-level plain of moderate, perhaps tertiary age and well discernible even in the coast region.

This *Horst*-summit originally forming the bed-rock of the Devonian and thus before the dislocation situated at least somewhat below its bottom or, in other words, below the surface of the sea, it seems evident, that the throw of the great fault must have been at least some 1200 *m* and probably more than 1500 *m*, and thus of the same order of magnitude as the great dislocation at Horn Sound. The same is true of the dislocation along the eastern shore of Wijde Bay where the Archæan original sub-strata of the Devonian beds now

¹ E. JÄDERIN, Rapport till Kungl. Kommittén för Gradmätning på Spetsbergen. Stockholm 1900, p. 9—10.

rise to some 1200 *m* or at Mount Chydenius, the highest point of Spitzbergen, even to about 1730 *m*, while on the west side of the fiord the Devonian reaches down below the sea-level.

Thus it seems that this gigantic »*Graben*«, with a breadth of 65–70 *km* and a throw of probably more than 1.5 *km* or 1 Eng. mile, cuts straight across the whole of Spitzbergen with an astonishing regularity and really deserves to be called a *fossa magna*.

The Archæan *Horst*, east of the *fossa*, is limited also to the east by a great fault running along the west side of Treurenberg Bay and further to SSE, parallel with Wijde Bay and forming the limit between folded Silurian strata to the east and the Archæan plateau to the west. E. of Mt Chydenius it was mapped by H. BACKLUND. Even this fault is, no doubt, of Devonian age, though the Devonian strata were in this region removed before the Carbonian transgression.

If it be granted that the Devonian *fossa* is not restricted only to the regions where the younger dislocations do not occur, but extends as far as these and is strikingly coincident with them, it seems highly probable that the location of the younger displacements was determined partially just by the extension of the great Devonian *fossa*.

After the formation of this *fossa* the Devonian strata, resting on its uplifted margins, were totally removed and base-levelled before the end of the Devonian period, the very regular base-level plain being in many places well exposed and transgressively covered with Culm-strata. Upon these follow Carbonian, Permian, Triassic, Jurassic, and lower Tertiary strata seemingly without more conspicuous discordances. Still there must have been at least two important breaks in the sedimentation, one before the deposition of the Jurassic strata which, on Franz Joseph's land, seem to rest directly upon the Archæan plateau which, no doubt, forms the same axis of upheaval as northern Spitzbergen, the intermediate formations

here being at that time already destroyed by erosion. At Horn Sound it is also obvious that the same erosion has been at work on the old *Horst* along western Spitzbergen. The other break represents the whole Cretaceous period which all over Spitzbergen is found only on Kung Karls Land, thus making it evident that, during the period named, the rest of Spitzbergen was land, or in every case at the end of the same period uplifted above the sea-level and intensely eroded so as to leave no remnants of any Cretaceous formations. This great upheaval of land was accompanied by considerable outbursts of basic eruptives including effusive basalts and intrusive diabases. By the same upheaval it seems that the extended Devonian *Horst* along the west coast was uplifted anew, the Tertiary strata here being in several places found resting immediately upon different older rocks of Silurian as well as Carbonian age, the intermediate Triassic and Jurassic strata being removed before the deposition of the Tertiary ones. This seems to be the case at Cape Lyell at the mouth of Bel Sound as well as at King's Bay and the northeast side of Prince Charles Foreland, on the Silurian ground of which Tertiary strata recently have been found by W. S. BRUCE.

After the last great transgression of the Tertiary sea followed a new considerable upheaval by which the Tertiary strata in Central Spitzbergen were raised at least 1000 *m* above the sea-level, while the old *Horst* along the west coast was once more uplifted to a still considerably greater height. At the same time, and evidently in connection with this great upheaval, the earth-crust of the region was exposed to a tangential pressure from the sea-side, clearly manifested by beautiful plications, over-folds, and over-thrusts, most strongly developed along the narrow *Horst* at the west coast but also farther inland, especially in Oscar II:s Land, while even south of the fiord very noteworthy over-thrusts have been observed at several places, as at Kol Bay and Sassen Bay. At the

same time the Silurian ridges at Kings Bay, Prince Charles Foreland, and Cape Lyell seem to have been pushed up above the Tertiary strata.

With respect to these younger displacements it may for the present purpose be enough to accentuate that their location principally seems to have been determined by the pre-existent Devonian *Horsts*, which on repeated occasions were in a similar manner affected by the pressure from below which, according to my opinion, must have originated from subcrustal displacements of magmatic matter, caused by the great collapses of the adjacent sea-bottom. Thus, for example, in the later part of the Tertiary period the central region of Spitzbergen was uplifted more than 1200—1400 *m*, this being the height of the upheaved, almost horizontal Tertiary strata, while the western horst was very much more uplifted. In the same way northern Spitzbergen and Franz Josephs Land have bulged up and become eroded already in Jurassic time and, very likely, also later on, probably in connection with the sinking in of the great sea-depression around the North Pole.

As might be expected from the analogous geographical situation of Spitzbergen compared with that of Scandinavia there seem to be several interesting analogies between the tectonic structures of these two lands. After the completion of the post-Silurian or Devonian mountain folding, the bulging of the land continued, though after that time only accompanied by ordinary faults. During the same Devonian period the very thick Silurian desposits in Spitzbergen were in several places completely removed, the Devonian strata being deposited immediately upon the Archæan bed-rocks, afterwards faulted along the *fossa magna*, and, finally, at both sides of this *fossa* totally removed, although they had a thick-

ness of some 1500 *m*, all this happening before the end of the Devonian period and the great transgression of the Culm strata. This being settled, it seems very allowable to make the assumption, as I ventured to do some years ago, that the *fossa* of lake Vättern in Sweden together with its Visingsö-formation is of Devonian age and only a continuation of the somewhat earlier but also Devonian = post Upper Silurian faultings in the immediately adjacent regions of Sweden. The conditions in Spitzbergen seem to show that the Devonian period lasted much longer than the time required for the erosion of the relatively thin Silurian strata which rested on the ledge of Archæan rocks upon which the Visingsö-formation, according to the above mentioned assumption, was deposited during a later stage of the Devonian period.

Other interesting analogies between the geology of Spitzbergen and that of Scandinavia may be spared for another place than this preliminary note.

Resumé.

Så vidt man hittills känner, synes parallellstrukturen inom Spetsbergens urberg framgå i ungefär samma hufvudriktning som senare dislokationer och har därför sannolikt verkat bestämmande på dessas förlopp. Den äldsta af dessa yngre dislokationer utgöres af de siluriska lagrens veckning, som antagligen inträffat under början af den devoniska tiden liksom i Skandinavien. Efteråt afsatta, mer än 1500 *m* mäktiga devonlager hafva sedermera genomskurits af förkastningar, om hvilkas betydande både språnghöjd och utsträckning man numera kan göra sig en ganska god föreställning. Devonlagren finnas i vår tid bevarade endast inom en väldig »fossa magna», som går tvärs igenom hela landet och på ömse sidor begränsas af horstar, hvilka blifvit upplyftade åtminstone 1500 *m*. Denna stora dislokation jämte fullständig bortdenudering af de upp-

lyftade devonlagren hade också hunnit försiggå under devontiden eller före den stora transgressionen af kulmlager. Under följande perioder hade inträffat en betydande landhöjning med åtföljande erosion före jurallagrens afsättning. Såväl Frans Josefs land och norra Spetsbergen som höjningszonen vid detta lands västkust synas hafva deltagit i denna höjning. Likaså inträffade under krittiden en betydande höjning, som åtföljdes af ansevärliga diabas- och basalteruptioner. Den omfattade största delen af landet. Den sista mera betydande höjningen inträffade under tertiärperioden, då landets hufvudmassa upplyftades mer än 1000 m och horsten utmed dess västra kust ännu betydligt mycket mera, hvarvid äfven flerstädes ett ganska betydande tryck gjorde sig gällande utifrån hafssidan, såsom framgår af vackra veckningar och öfverskjutningar, hvilka särskildt äro utpräglade inom Oscar II:s land just innanför Prince Charles' Foreland, som antagligen till en del har samma rörelse att tacka för sin uppkomst.

Anmärkningsvärdt är, att i Skandinavien lika väl som på Spetsbergen den postsiluriska eller devoniska bergveckningen åtföljts af omfattande devoniska förkastningar. Förhållandena på Spetsbergen bevisa därjämte tydligt nog möjligheten däraf, att under loppet af den devoniska tiden så föga mäktiga lager som mellersta Sveriges kambro-silurbildningar mer än väl hunnit bortdenuderas samt att ofvanpå det härvid blottade urberget hunnit afsättas yngre devoniska lager, dit förf. velat hänföra Visingsö-serien, samt att slutligen också dessa genom sprickförkastningar, tillhörande samma dislokationssystem, blifvit skyddade mot fullständig förstöring.

