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PRE-CAMBRIAN MOUNTAIN CHAINS[1]

BY

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With 7 tables, 3 figures.

The existence pre-cambrian mountain chains resembling those of later geological times has been much discussed in modern geology.

The presupposition of using actualistic methods in the tackling of this problem is that the physical and chemical conditions even in those ancient times caused the geological processes to run along the same lines as later.

If this can be convincingly demonstrated, we may next compare the mountain chains as to material and architecture. Every individual mountain chain exhibits several peculiarities, distinguishing it from the other chains, but there are also common features which must be found even in the pre-cambrian deformation areas if they are to be compared with younger mountain chains.

In several respects the pre-cambrian rocks differ from those of later periods. This is the case both in regard to petrography and tectonics. The marked difference between magmatic and non-magmatic processes must in several cases be dropped. The deformation has frequently taken place in a quasiplastic manner, and because of the varying mobilities of the rocks, disconformities may be created resembling those of intrusive rocks. Due to these circumstances and to the peculiar gneissic structure of the rocks it has earlier been generally assumed that the rocks were formed under exceptional conditions.

The rocks were partly supposed to belong to the first crust of the earth, and partly to be sedimented in a hot or glowing primeval sea. Attempts were also made to explain the complexity of the rocks as a result of differentiation processes in an enormous magma chamber. But as a result of the systematic investigations of the pre-Cambrian all over the world during later years, much of the complex

[1] Read Sept. 17, 1945.

history can now be explained, and the rocks have in several respects been found to resemble those of younger formations. In the gneiss-areas are found true supra-crustals with preserved primary structures, among other conglomerates, calcareous, argillaceous and arenaceous sediments with corresponding facies-variation as found in younger formations. The chemical composition of the argillaceous sediments often correspond to recent clay, and their degree of weathering points to a cool or temperate climate. In Fennoscandia as well as in North America varved schists indicating glacial conditions have been found.[1] Glacial conglomerates also have been found in several places. (*E. g.* The tillites from the Huron series in North America and the Chuos-tillite from Damara in South Africa.)

There is no doubt with regard to the origin of all these rocks; but relic structures found in the gneisses and migmatites show that in several cases even these originated in connection with exchange of material between a pre-existing rock-complex and molecular or ionic disperse system of particles, which were presumably supplied from greater depths of the crust of the earth.

Especially through the inspiring works of Sederholm the geologists became aware of these processes. The rocks show a distinctive selective filter action, and the metasomatism may therefore have a totally different character in rocks of different composition, even when the composition of the disperse system is supposed to be the same in all cases.

The migmatite studies have clearly shown that supracrustals have a wider extension in the pre-Cambrian than indicated by the small and scanty areas of obvious supra-crustals in the migmatite areas. These areas are merely relics of more widespread formations. Probably the sedimentary formations were just as thick as in younger mountain chains.

Thus, the sedimentary cycles are not essentially different from the present ones, though some deviations in the character of the sediments have taken place. This is chiefly due to the influence of organic life. Traces of organic life are found in the upper Proterozoicum, but even in the lower pre-Cambrian traces have been found which may indicate such activity. The peculiar occurrence of disseminated graphite in several archaean argillaceous schists is hard to explain as

[1] Eskola, P.: Conditions during the Earliest Geological Times. Ann. Acad. Sci. Fennicae. Series A. Vol. 36, Nov. 1932.

caused by inorganic processes, and the content has partly been considered a result of the decay of organic substances.[1]

In Norway archaean graphite-bearing gneisses are known from Østfold and Sørlandet.

As far as we know, however, organic sediments are of no special importance until Paleozoicum, and the first great flourishing of organic life occurs in this period.

The mighty limstones of this and younger formations are scarce in the pre-Cambrian. The archean limestones are usually of smaller extension, and to what degree they are of real organic origin is unknown.

E. Kaiser has mentioned that due to the absence of vegetation and humus in pre-cambrian times mechanical weathering must have played a far more important part than nowadays, while chemical weathering must have been less effective. There certainly is a tendency in this direction, but vegetation is hardly necessary for allitic weathering. (P. Eskola.[2])

Even the composition of the atmosphere has changed since archaean times. Oxygen certainly played a less important rôle in proportion to CO_2 than it does to-day. This fact may be of importance when we discuss the mode of origin of some dolomites that seem to be primary sediments, and of the quartz-banded iron ores. Both of them have their widest distribution in Archaean and lower Paleozoicum, and are not formed nowadays.

A comparison of the archaean migmatites and gneisses with younger formations is difficult. The migmatites correspond to a deformation in great depths of the crust of the earth, while rocks deformed under such thermo-dynamical conditions rarely are exposed in younger mountain chains. But so far as it can be controlled, migmatites seem to occur in all mountain chains. They are known from the Alps (Tessiner culmination and Tauern massif). In America they constitute the "Borderlands" of the great mountain chains toward the oceans. The "Borderlands" correspond to older fold-phases of the mountains chains, and usually they are not of pre-cambrian age. In the Norwegian caledonides are also rocks exposed from the migmatite zone. They are exposed in Western Norway and in the counties

[1] Laitakari, A.: Die Graphitvorkommen in Finnland und ihre Entstehung. Geologinen Toimikunta. Geoteknilliae julkaisuja no. 40, 1925.

[2] Eskola, P.: op. cit. p. 32.

Nordland and Troms. From Stavanger V. M. Goldschmidt has described the injection-gneisses in an important work where he also introduced exact methods in the study of migmatites. On the whole, Norway is no doubt one of the countries which give the best opportunity for comparative studies of the varying types of deformation and metamorphism in different depths of mountain chains.

From the data mentioned we may conclude that actualistic methods can be used extensively in the study of the pre-Cambrian; a comparison proves, however, that there has been a slow change in the character of the sediments since the oldest geological times, — a slow, irreverisible evolution. No traces of a pyroarchaic phase have been found. On the contrary, the glacial sediments in the various precambrian formations indicate that in the oldest times known, the surface of the earth was just as cold as it has been since.

The foundation of a more extensive comparison between precambrian and younger mountain chains is therefore given, and I shall point out some main features. In all mountain chains the following three stages can be distinguished:

1. Evolutionary stage
2. Revolutionary stage
3. Detractive stage

The evolutionary or geosynclinal stage is characterized by mighty sediments of predominantly marine character. While the composition of epi-continental sediments usually vary within wide limits, the geosynclinal sediments are more uniform. Heavy mica schists often characterize the central parts, and basaltic effusives are regular.

With revolutionary stage the character of the sediments has changed. The orogene or flysch sediments show a frequent facies variation between coarse-grained, clastic sediments and finegrained, pelitic sediments.

During the further rising of the mountain chains, the detractive stage, the character of the sediments change even more. The remaining bays and channels in the geosynclinal sea disappear little by little, and at last the sedimentation chiefly takes place in marginal or central basins in the mountain chains. Accordingly we distinguish between external and internal molasse, both of which are of a clastic nature. In addition to this older molasse, which often participates in the deformation, a younger molasse occurs, lying discordant over the folded layers in the mountains and representing weathering products from the denudated parts.

As emphasized by Wegmann [1] and Backlund [2] the three stages in the evolution of the mountain chains are also found in archaean deformation areas. The gesynclinal, flysch, and molasse sediments are so characteristic for the different stages that they can be used as division base. In older mountain chains it may be difficult to distinguish exactly between the three types of sediments, as the rocks are often so highly deformed. Consequently it is necessary to consider other features which characterize the different phases, amongst others the magma activity. The basaltic effusives of the evolution stage suddenly alter to acid plutonites during the revolution stage, ultimately to be replaced by basalts.

On the division base mentioned above I shall give a short regional survey of the most important pre-cambrian areas:

In Fennoscandia Backlund [3] has tried to separate four different mountain chains:

1. Marealbides
2. Norwegosamides
3. Svecofennides
4. Gothokarelides

Little is known about the marealbides, which are separated as the oldest mountain chain. Only a comparatively narrow zone south-west of the White Sea is preserved. The strike is SW—NE, and the age of radioactive minerals from pegmatites, the youngest rocks in the district, has been measured to 1550 million years.

According to investigations by Finnish geologists the existence of the norwegosamides as separate mountain range is uncertain, while the granulites of Northern Finland, that were said to constitute the oldest rocks of the norwegosamides, belong to the upper pre-Cambrian.[4]

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[1] Wegmann, C. E.: Zur Deutung der Migmatite. Geol. Rundschau 26, 1935.

[2] Backlund, H. G.: Der Magmaaufstieg im Faltengebirge. Compte rendu, Soc. Geol. Finlande, no. 9, 1936.

[3] Backlund, H. G.: Gesteinsentwicklungen in Fennoscandia. Zeitchr. f. Geschiebeforsch. u. Flachlandsgeol. Bd. 17, H. 3, 1941, pp. 162—171.

[4] Eskola, P.: Erkki Mikkola und der heutiger Stand der präkambrischen Geologie in Finnland. Geol. Rundschau 32, 1942, pp. 452—483.

Table 1.

	Eastern and Southern Finland	Northern Finland
Detractive phase 700—500 Mill years	Jotnian Hoglandian	
Gotho—Karelides 1000—700 Mill. years	Serkinematic granites	Nattanen granite Red granites Granulites, charnochites
	Synkinematic granites	Hettagranite Kumpu—Oraniemi { Kumpuquartzite, Sirrka conglomerate }
	Kalevian . . . { Kalevian facies (phyllites, micaschists) Jaurakko facies } Flysh formations	
	Jatulian . . . . { Upper marine Jatulian (vulcanites, micaschists) Sariolian facies (conglomerates, quartzites) } Epicontinental formations	Lapponian . . { Carbonate rocks, quartzites, micaschists, sedimentary iron ores, Sillimanite gneisses }
	Ladogian . . . (micaschists, dolomites) { Geosynclinal formations }	
Svecofennides 1200—1000 Mill. years	Postkinematic granites: Åva, Lemland Onas Bodom etc. Serkinematic granites: Migmatite granites Synkinematic granites: Oldest gneiss granites, the Central granite etc.	
	Bothnian . . . { conglomerate, sandstone, Uralite porphyre }	Tuntsa—Savokoski series.
	Svionian . . . { Acid to basic vulcanites, Cordierite leptite, kinzigite, varved schists }	argillaceous sediments, granites etc.
Norwego—samides?		
Morealbides > 1500 mill. years		

Table 2.

	Sweden		
Gotho—Karelides	Dalasandstone, Rapakiwi		Younger molasse
	Dalagranite	Sorsele-, Rätan-, Lina granite	
	Dalaphorphyre	Upper Noppi } Vargfors Formation	
		Lower Noppi } Vargfors Formation	
	Dalformation	Upper Loos } Vargfors Formation	Older molasse
	Småland—Fillipstad Granite	Risberg granite	Synorogene granites
	Småland porphyr		
		Lower Loos	Flysh- and geosynclinale Formations
	Ramsberg—Västervik quartzite		
		Sub Loos	
	Åmåls- and Västanå Formation		
Sveco-fennides	Stockholm and Fellingsbro granite		Postorogene granites
	Greenstone		
	Urgranite		Synorogene granites
	Leptite Formation { Sediments, Leptites, hälleflinta, Sörmland Series		Flysh and geosynclinale Formations

Far more is known about the two younger mountain chains. The svecofennides strike E—W from Finland to Central Sweden, and comprise also parts of the Kongsberg-Bamble formation in Southern Norway. The various areas occur totally enclosed in the gothokarelides. They constitute great anticlines of older pre-Cambrian in the younger chain.

In Finland the geologists distinguish two divisions in the svecofennides: The Svionian and the Bothnian. Attempts have been made to divide between evolution, flysch, and molasse sediments (Table 1).

The gothokarelides in Finland are probably the pre-cambrian mountain range which is best known. Evolution, flysch, and molasse sediments can be separated. The basaltic volcanic plutonites of the evolution stage alter during the orogenesis to granitic plutonites, which finally alters to basalts once more. By a thorough tectonic analysis Wegmann has found several similarities with the Alps, and he has been able to demonstrate overthrusts.

In Sweden (Table 2) the rocks of the leptite formation have been considered as flysch formations of the svecofennides. The swedish geologists divide between the bottom svionic series, consisting of leptites alternating with metamorphic sediments, and the upper Saxå—Grythytte—Larsbo series, consisting of sediments. H. Backlund supposes these rocks to be underlain by evolutionary sediments represented by the rocks of the Sörmland series.

In the gothokarelides of Sweden evolution, flysch, and molasse sediments are also distinguishable. According to investigations by Mikkola the rocks of Northern Sweden and Northern Finland closely correspond to each other.

The Woronesch massif in Ukraina are of great interest when we discuss the pre-cambrian geology of Fennoscandia. An old complex, probably corresponding to the svecofennides, can be seperated. In several aspects the rocks may be compared to those in Kongsberg—Bamble formation. The Bug series, for instance, is closely related to the arendalites in Southern Norway.

Younger than this complex is a mountain chain striking N—S, the folds of which are inverted eastward. The rocks correspond to those of the gothokarelides in Finland, and it is probable that a continuous mountain chain formerly connected the two areas (S. v. Bubnoff, Fig. 1).

Thus, the gothokarelides form a mountain chain in the modern sense of the word. As regards the breadth, the frame effect found in younger chains is less marked in this deeply eroded chain, and the breath has not yet been exactly determined.[1] But even if it reaches from Karelen to the Telemark formation, it is not broader than what the case may be in post-cambrian chains.

In Greenland and on the Labrador coast Wegmann [2] and Kranck [3] have found traces of two mountain ranges (Table 3).

The ketilides in Southern Greenland correspond to the labradorides on the Labrador coast. According to Kranck the oldest rocks in the labradorides are geosynclinal sediments, while the Aillik formation is intepreted as flysch.

The Mugford and Ramah series of the younger cycle have geosynclinal character, while the rocks of the Gardar formation, which

[1] Backlund, op. cit.

[2] Wegmann, C. E.: Geological Investigation in Southern Greenland, Part I. Meddelelser om Grønland, Bd. 113, no. 1, 1938.

[3] Kranck, E. H.: Bedrock Geology of the Seaboard Region of New Foundland, Labrador. N. Foundland Geol. Survey, Bull. 19, 1938.

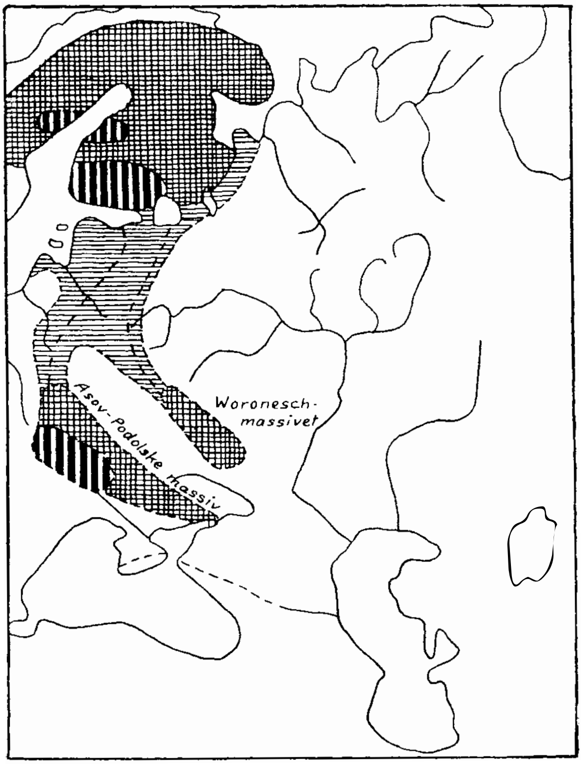

Fig. 1 (repr. after v' Bubnoff.)

are comparatively undeformed, probably correspond to Jotnian in Fennoscandia. It is natural to correlate the two chains with the svecofennides and the gothokarelides; yet the age cannot be decided with certainty until absolute age determinations have been carried out.

The North American shield is the best known pre-cambrian area outside Fennoscandia. As demonstrated in Table 4 various orogene cycles have been separated. According to age determinations the laurentian and the huronian cycles are generally correlated with the svecofennides and the gothokarelides. The huronian cycle is probably a little belated in proportion to the gothokarelian. Two orogene phases can be distinguished in this cycle. Yet, it is a problem whether they

Table 3.

	Greenland		Labrador coast
Gardar Formation	Alkali rocks		Alkali rocks
	Rapakiwi Granite		Rapakiwi Granite
	Vulcanites		
	Igaliko Sandstone		Double Mer Sandstone
			Mugford Series
			Ramah Series
Ketilides (strike: NE—SW)		Labradorides (strike NW—SE)	Granites and Syenites
	Julianehaab granite		Makkovik Granite (palingene) Anorthosites
	Arsuk Series		Aillik Formation (quartsites, gneisses)
	Sermilik Series (micaschists, quartzites, congl. pyroxene gneisses)		Micaschists, caleareous- and arenaceous sediments, effusive greenstones
	Gneiss granites		Gneiss granites

are really phases of the same mountain chain or belong to two independent chains: the algoman and the huronian.

According to age determinations two older mountain chains have also been separated in North America; however, little is known about them (cfr. Holmes [1]).

Africa is certainly the continent where pre-cambrian rocks are of greatest importance. The shape of the continent was practically established as early as pre-cambrian time. Krenkel has separated four mountain chains of different ages: proto-afrizides, meso-afrizides, older and younger neo-afrizides (Table 5).

The meso-afrizides have several features in common with younger mountain chains and are comparatively well known. According to investigations by Cloos it is possible to demonstrate thrusts in higher zones, and a plastic deformation tectonic in lower zones of the chain.

[1] Holmes: The Age of the Earth, London 1937, p. 200—209.

Table 4.

North America	
Huronian Cycle	Keweenawan
	Duluth gabbro
	Post Huron granite (743—786 mill years)
	Huron, Animikian Cobolt Series Bruce Series
	Algoman granite?
	Knife Lake, Steeprock
	Ironformation, Sudburian (tillite)
Laurentian Cycle	Laurentian granite (1027—1050 mill. years)
	Gabbro, anorthosite, Buckingham Series
	Temiskaming Hasting Series
	Keewatin
	Coutchiching Grenville Series
Great Bear Lake	Granites, pegmatites (1210—1334 mill. years)
Athabasca	Beaverlodge Series
Black Hill Cycle	Tazin Series
Manitoba Cycle	Granites, pegmatites (1750—1670 mill. years)
	Rise Lake Series

Whether the older and younger neo-afrizides are really different mountain chains or just represent different phases of the same cycle, is as yet not settled. The younger phase also comprises parts of early palaeozoic formations.

In Table 5 the main features of pre-cambrian geology of South America are indicated in comparison with those of Africa.

Owing to the important ore deposits in Australia the pre-cambrian geology of this continent is well studied (Table 6). Three orogene

Table 5.

Cycle		South Africa		West Africa	South America
Katanga Cycle		Younger Neo-afrizides		Namaides	
		Bushveld Complex { granite, gabbro			
	Transvaal series	Pretoria Series (with tillite)			
	Transvaal series	Dolomite Series		Nama Formation	
		Older Neo-afrizides		Konkipides	Older Brasilides
		Ventersdorp Series (mica schists)		Konkip Series	Itacolumy Serie with itabirite
		Witwatersrand Series (micaschists quartzite, tillite etc.)			
Damara Cycle		Meso-afrizides		Domgranite	Minas Geraides
		Upington granite			
		Kheiss Series		Bastard Series (effusives, micaschists and limestone	Minas Series with itabirite
		Oldest granites		Salem granite	
			Damara Series	Karibib (marble, conglomerate, tillite, iron formation)	
		Barberton Series sediments effusives plutonites	Damara Series	Khomas (quartzite, mica shist)	
Abbabis-Cycle		Proto-afrizides		Mylonite granite,	Archaides
		Swaziland—Namaqualand Series		Abbabis Series	

Table 6.

Australia	
Nullagine-Adelaide Cycle	Platau basalts, micaschists, quartzites, tillite Vulcanites
Yilgarne Kalgoorlie Cycle (Mosquito cycle)	Granites, regional granitization Basic intermediate eruptives Sediments and effusives
Darling Cycle	Arunta and Darling Complex Flinders: sillimanite gneiss Hutchison: micashists, hyperstene gneiss

(A. Holmes op, cit. and E. de C. Clarke:
Reg. Geol. d. Erde. Bd. 1, abschnitt VII)

cycles are distinguishable, which in regard to architecture as well as age correspond to those in Africa. The old Darling complex comprises mica schists, sillimanite- and hypersthene gneisses, and in several features it is reminiscent of the Kongsberg-Bamble formation of the svecofennides. In the Broken Hill district the hydrothermal or sedimentary nature of several quartz rocks has been much discussed, just as in Southern Norway. During recent years the sedimentary nature theory seems to be favoured.

Rocks resembling those in the Darling complex are also regular in the Antarctic. Both mica schists, hypersthene gneisses, and charnockites of the same type have been described.

• The next cycle in Australia, the Yilgarne-Calgoorlie system, has several features in common with recent mountain chains, and the mighty sediments which have been found are of geosynclinal character. The rocks of the youngest cycle are comparatively undeformed.

In India the same three cycles can be distinguished as in the other southern continents (Table 7): (1) a pre-Dharwar complex, (2) the Vedic series corresponding to the Yilgarne-Calgoorlie system in Australia, and to the meso-afrizides in Africa, and (3) the algonkian Purana system corresponding to the Adelaide series in Australia. »The

Table 7.

India	
>500 mill. years	Upper Vindhyans
	Karnuls
	Semri Series (Lower Vindhyans)
Purana	Malani Series
Cycle	Granites
	Guddapahs, Bijawar
	Erinpura Gravite
	Dehli Series
	Raiala Series
895 mill. years	Glosepet Granite
	Charnoekite Series
	Peninsular Gneiss
Vedic	Champion Gneiss
Cykle	Upper Dharwar (mica schists, ironores)
	Lower Dharwar (marbles, mica schists, khondalites, manganiferous ores)
	Pre Dharwar Complex

(A. Holmes op. cit. G. de P. Cotter Reg. Geol. d. Erde. Bd. 1, Abschn. VI.)

Purana era was certainly characterised by mountainbuilding movements in Raiputana where the Aravelli range, a tract at least 400 miles long by 30—60 miles wide, was folded and base-levelled in pre Vindhyan times« (G de P. Cotter op. cit.). Outside this belt of orogenic folding the Purana system consists of rocks which are very little disturbed by orogenic movements.

The regional survey shows that traces of at least two pre-cambrian mountain chains can be distinguished in the northern continents:

an older one, with the svecofennides, the ketilides, and the laurentian chain, and a younger one, with the gothokarelides and the huronian chain. According to Holmes the lengths of the orogene cycles correspond to those of the younger chains, while it would be natural to expect a shorter rhythm in ancient times if the crust of the earth had been especially cooled during the geological history.

The gothokarelian cycle can be closely matched in the southern continents and is represented by the Damara, Yilgarne-Kalgoorlie and Vedic cycles. The svecofennian cycle probably correspond to the Abbabis, Darling and pre Dharwar cycles; but due to the lack of age determinations this correlation is rather vague.

Whether the different pre-cambrian areas in ancient time were connected by continuous mountain chains, extending over long distances along the margins of the continents of that time is unknown. We have no knowledge of the division between land and sea in those times. Possibly bigger massifs have existed, later on having burst or floated away from each other in the same way as that demonstrated by Wegener for later periods. On the other hand it is also possible for the continents to increase by a compression of marginal geosynclines around older archaean cores. Fig. 2, reproduced after Stille, demonstrates how the younger mountain chains in North America here always follow the borders of pre-existing continents.

In the Canadian shield Ruedemann has drawn the old archaean strike directions (Fig. 3). The map is a little schematic, as we have to deal with various mountain chains; yet it is evident that the strike of the younger chains depends upon the older structures (the grain of America), and that the pre-cambrian mountain chains followed the edges of the continent of that time toward the ocean.

Thus we encounter the problem of invariability of the continents even in the oldest geological times known. Obviously these can decrease through breaking up as well as increase by a compression of marginal geosynclines. This latter process would occasion an increasing thickness of sial during the geological history.

In several respects the problems of pre-cambrian geology are, thus, the same as in later periods. There is no sharp division between archaean and post-archaean mountain chain research. The difference is chiefly due to the fact that the upper zones are usually exposed in younger chains, while the lower zones are exposed in ancient ones.

Hans Stille

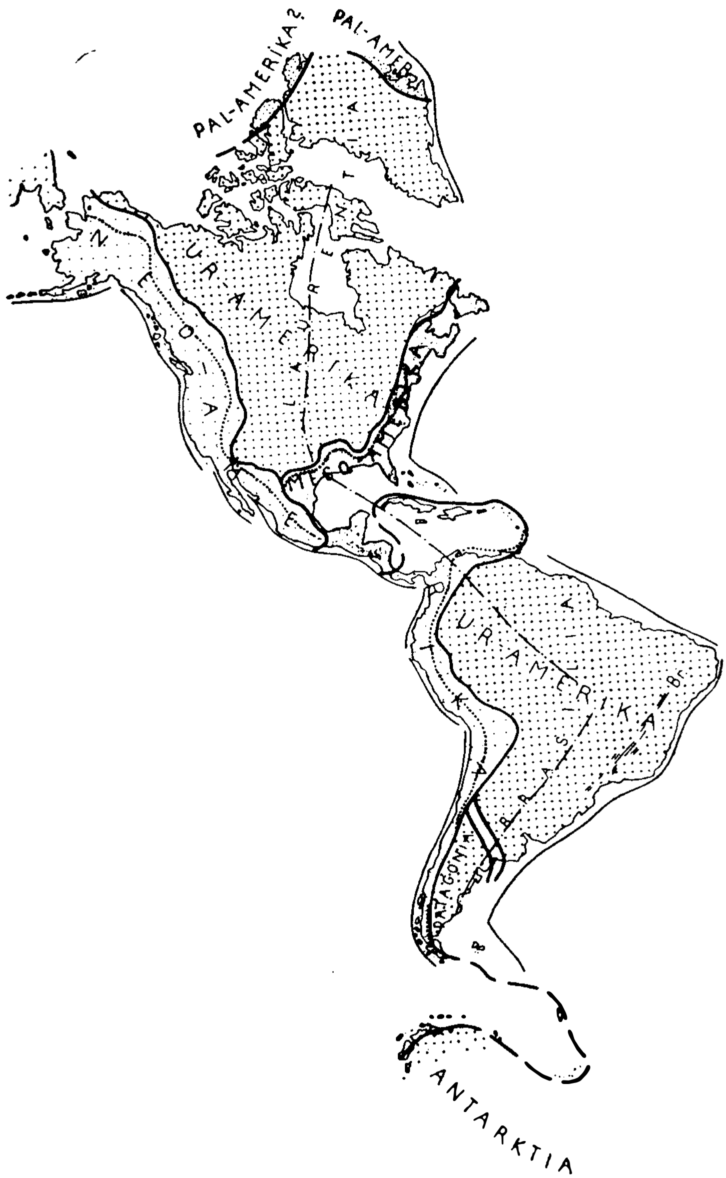

Fig. 2. (Repr. after H. Stille.)

As a synthesis of such a comparison between mountain chains where different zones are exposed, it is possible to get a general view of architecture and deformation of the mountain chains.

All mountain chains show a difference in architecture between the marginal and the central areas. The mountain chains therefore usually have been divided in various zones characterized by their rock succession, tectonic and magmatic activity; this division, however, does not give a complete picture of the architecture, and for the present it is only adapted for the upper zones. It seems natural to suppose that in lower zones the deformation style changes. During an orogenesis the rocks do not have the same possibilities to escape under the influence of compression as in higher strata.

According to Wegmann it is natural to divide the mountain chains into the following three depth zones:

Upper zone (Oberbau).
Transition zone.
Lower or migmatite zone (Unterbau).

The Upper zone is the place of thrusts and is characterized by a low metamorphism. The transition zone is the place of folded and thrusted nappes. Synkinematic eruptives are regular and the zone is usually characterized by a strong regional metamorphism. These two zones especially have been the subject of previous studies, and the nomenclature and division known from post-archaean mountain chain research are especially adapted for these zones.

The migmatite zone is characterized by the build and tectonic known from the pre-Cambrian. The exploration of this zone is now a central problem in the study of mountain chains, and the results attained by the archaean geologists have already been used to a great extent. The knowledge of the deformation style is among the most important results. The rocks have been folded in a plastic manner, and, as mentioned before, the difference between magmatic and non-magmatic processes cannot be maintained in the same way as in the upper ones. As pointed out by Wegmann the deformation manner is disharmonious in relation to the upper zones. The border between them, the migmatic front, is a movable surface. During the orogenesis it will be displaced upwards, and rocks originally occurring in the upper zones will, therefore, be deformed in the migmatic zone in a later stage.

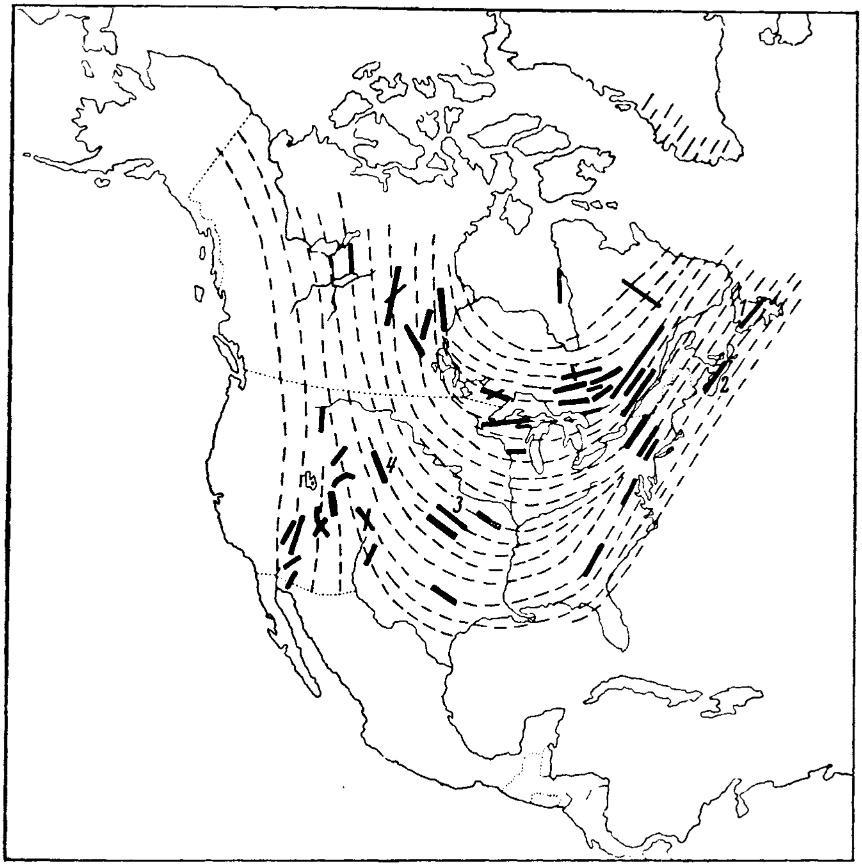

Fig. 3. Grain of America (after H. Ruedemann).

In some places the front goes no higher than to the crystalline basement, while in other places it extends into the geosynclinal sediments.

The depth to the migmatite zone is rather varying. In the Alps the Tessiner culmination probably corresponds to a depth of 15 kilometres. In the caledonides of Greenland and Western Norway and in the svecofennides in Finland, however, the front begins at a depth of 5—6 kilometres, according to the investigations of Wegmann.

The rocks of the migmatite zone have a typical flow structure. Displacements in the isostatic equilibrium of the great sial blocks will effect a rock flow in the migmatite zone, thus bringing about a supply or carrying off of material until equilibrium is retained. Thus the sial blocks flow upon the migmatite zone, and not, as commonly assumed, upon sima (Wegmann). This important conclusion must be considered in connection with all geotectonic questions.

The border between the migmatite zone and the sial blocks is characterized by a special mobility. Magmas mobilized at great depths have often been intruded and enriched in this zone. In the Arendal district the hyperite phacolites were also intruded near the migmatite front, and the inrusion was separated from the regional granitization by a short space of time only.

The deformation in the migmatite zone is the result of a compression similar to that taking place in higher strata. The material is compressed to a smaller horizontal breadth, and will try to escape in all possible directions. It will be pressed as diapires upwards in the anticlines of the overlying strata, and will partly intrude as synkinematic eruptives along deformation zones in these layers.

The peculiar deformation style is often reflected in the topography. Fold axes and other tectonic elements with special linear or parallel structures are seldom constant over longer distances. Therefore the ground is usually uneven and characterized by dome-shaped hills and ridges, as commonly found in the Kongsberg-Bamble formation and in Telemark in Southern Norway. In another paper [1] I have discussed the genesis of the peculiar, onion-shaped diapire granites in Setesdalen which often protrude steeply from the bottom of the valleys and were formed by an uneven granitization of the pre-existing gneisses.

These diapires demonstrate how a plastic flow in the migmatite zone may effect an active vertical pressure in the mountain chains, and it is probable that such movements will explain several folds differing from the normal. Certainly vertical undulations in the mountain chains may be caused by plastic flow as well as migration of dispersed particles in the migmatite zone.

The migmatite studies in the pre-Cambrian have totally altered the views on the magma activity and its cyclic course. It is now generally assumed that most of the granites in the mountain chains originated in the same way as the palingene archaean granites. They are only to a small extent supposed to be differentiation products of a basic mother magma. Nearly all granites (except some sub-volcanic alcali granites) occur in mountain chains and were formed during the revolu-

[1] Bugge, J. A. W.: The Geological Importance of Diffusion in Solid Rocks. Vid.-Ak. Avh., I. Mat.-Nat. Kl. 1945, no. 12, p. 52.

tion stage. Therefore it is natural to regard the formation of granites in connection with the special conditions in the migmatite zone during the orogenesis, and to conclude that they were formed in connection with a differential anatexis in this zone.

Wegmann's application of Alpine tectonics in the Archaean of Finland is of the utmost importance for the study of the Archaean, and to an increasing extent corresponding views and methods are being employed by archaean geologists all over the world. On the other hand, the archaean geology has contributed much to the general exploration of mountain chains. The results already attained show that a comparative study after the principles I have tried to demonstrate in this paper should be an important method in the study of mountain chains.

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