Geology. — *Major geological cycles.* By PH. H. KUENEN. (Communicated by Prof. F. A. VENING MEINESZ.)

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It is well known that the major activities of geological forces are not distributed arbitrarily through time, but that distinct pulsations can be detected. These rhythms are partly of short duration. Thus in sedimentary series yearly rhythms or pulsations of several years or thousands of years are often evident. Probably clymatic cycles are the major cause of these phenomena. But there are also more leasurely recurrences, to be measured in millions of years. Stille and Grabau are the chief exponents of this point of view and Umbgrove [1]) has recently summarised what is known concerning these matters. The present author [2]) attempted to show that internal, deepseated causes must be held responsible for the rhythmic transgressions and regressions resulting in the repeated sedimentary cycles.

Finally there is the longest and grandest cycle of all, that consists of general geosynclinal sedimentation, followed by orogenetic activity and closing with magmatic intrusion and elevation. The Calcedonian, Hercynian and Alpine cycles have long been distinguished and have proved to be of worldwide importance. Of latter years, however, there has been a tendency to divide these into the shorter periods mentioned above and doubt has arisen whether the major cycles can be upheld as separate units. May it not be that arbitrary clusters of shorter cycles have been united to form the major cycles, in a time when geological knowledge was not yet far enough advanced to show the complex nature of such an orogenetic period?

The soundest argument in favour of upholding the major cycles would be to show, that they can also be distinguished in the earlier history of the earth. This demonstration would be of the greatest importance in finding an explanation of the major rhythms and moreover it would furnish indications as to whether the earth is ageing in a dynamic sense.

Amongst Scandinavian geologists Sederholm has ranked foremost in demonstrating the cyclic nature of the orogenetic and magmatic activity in the Pre-Cambrian. Nevertheless the impossibility of correlating the cycles of widely separated area's of ancient rocks, has hampered the development of a system of general applicability and therefore of demonstrating that for the Pre-Cambrian the major cycles also extend over the entire world.

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[1]) On rhythms in the history of the earth. Geol. Mag., Vol. **76**, 116—129 (1939).

[2]) Quantitative estimations relating to eustatic movements. Geologie en Mijnbouw, 194—201 (1939).

The correlation of these ancient happenings has entered a new phase now that radioactive determinations of age are gradually accumulating. In 1937 HOLMES in his booklet "The Age of the Earth" brought together the reliable radioactive age determinations then available. He was able to show that the ages of European and American minerals are concentrated in a number of periods of intrusion, divided by barren epochs in which intrusive activity evidently slumbered. He was even able to place the ages of minerals from these districts in the cycles distinguished by geologists, thus giving a first tentative correlation between American and European orogenetic cycles of the Pre-Cambrian.

It appears worthwhile pushing these investigations further, because of the great theoretical importance of establishing Pre-Cambrian cycles over the whole world. It is hoped that the following attempt to do so, will induce a specialist on radioactivity to take the matter up.

To form an estimate of the value of the available data not only the European and American, but *all* the determinations given by HOLMES have been brought together in our table and the ages given by NIER [1]) since then have been added. In fig. 1 they are shown graphically. A few technical remarks must be made. The ages have been rounded off to the nearest 5 million. When several determinations are available on the same kind of mineral from the same locality they have been averaged, but where different kinds of minerals have been investigated from the same locality they are given separately. The determinations by NIER are in thick print and are given irrespective of the same mineral having been listed by HOLMES, because of a different method having been followed in the examination. A question mark is affixed to the less trustworthy determinations.

In the right half of the figure the periods of intrusive activity are marked in black, the barren stretches being left white. The ages with a question mark in the table are given on the left side of the neighbouring time-line, the more trustworthy figures on the right.

It will be seen that 5 of the 61 ages listed, fall outside the active periods as assumed. As some of the minerals examined may have been formed in bodies that were intruded between orogenetic periods and as the accuracy of the determinations is not assured in all cases, we could hardly expect all the points to fall within the active periods.

It might be supposed, that an arbitrarily chosen set of ages would always show clusters and could therefore be divided into cycles, without any deeper meaning than that they were due to the rules of probability. For the cycles with only a few determinations this might well be the explanation. But the clusters between 10 and 11 or 8 and 9 hundred million years can hardly be attributed to mere chance.

Moreover, the fact that a cluster occurs both in the Calcedonian period between 3 and 4, and the Hercynian between 2 and 3, goes far to show

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[1]) Report of the Comm. Measurement of Geol. Time, 76—81 (1938—1939).

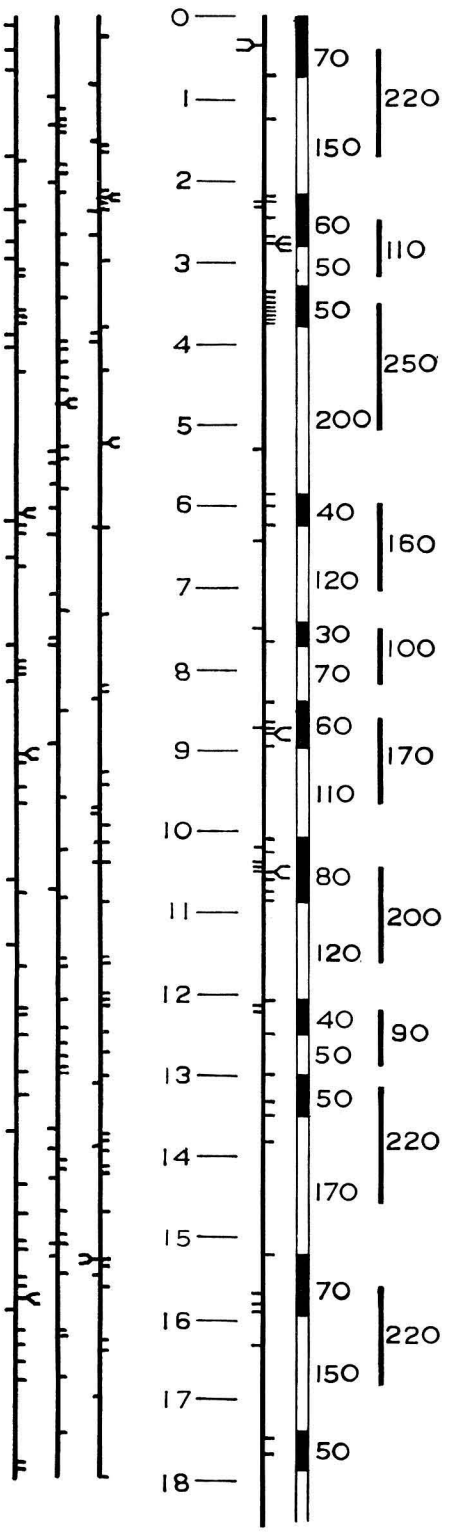

Fig. 1. Graphic representation of the radioactive ages, showing division in active and dormant periods. On the left three groupings found by a roulette-system of chance.

TABLE OF RADIOACTIVE AGES.

Europe	Africa	Asia	Australia	America	Active periods
		125		35? 35? 70	0?—30?—70
220 225? **225** **245** 270				230? 280 280 280	220— 280
				335 **340** 350 355 **360** 365 370 375	330— 380
	565 **600** 620	530? 645?			580— 620
				750? 765	740— 770
840 865	880	895	870	870? **880**	840— 900
1010 1020? 1045? 1060 **1085**			1050?	1025 1040? 1050 1050 **1075**	1010—1090
			1215? 1225?	1210 **1250**	1210—1250
				1300 1335 1350 1385	1300—1350
1520 1590?				**1570?** 1585? 1635?	1520—1590
				1750 1770	1740—1790

Ages in millions of years. From data by HOLMES and NIER.
The ages by NIER are in thick print. Less trustworthy figures with a question mark.

that the radioactive ages are definitely concentrated in orogenetic periods.

Still, in order to make sure, three tests were made in each of which 61 arbitrarily determined points [1]) were drawn on a time-line, 18 of these on the left. The results are shown on the left of our figure. It will be seen that although there are clusters and open spaces, the points are far more regularly spread than of the minerals, thus emphasizing the high probability that some factor controls the spacing of the radioactive ages.

Once this principle is accepted the cycles that are founded on only a few data appear more trustworthy, although their length and exact number of course remain questionable.

The existence is thus demonstrated of definite periods of intrusion divided by inactive periods of greater length and this bears on fundamental problems in geology and geophysics.

Although the Post-Cambrian major cycles can be each divided into shorter cycles, the fact that the larger units extend right back into the youth of our earth, shows them to be not merely an arbitrary cluster, but the fundamental rhythm of our earth's dynamic evolution.

For the Post-Cambrian cycles it has long been established, that the orogenetic activity awakens over widely separated area's simultaneously and that intrusion of larger bodies was limited to the same active periods. This rule is now seen to hold good for all periods. The magmatic period of just over 1000 million years is marked by eleven determinations and these come from minerals from Europe, Australia and America. The following period has 7 points derived from Europe, Africa, Asia, Australia and America. In the Pre-Cambrian orogenetic and magmatic activities are evidently not only periodical, but also world-wide in the same manner as in the Post-Cambrian period.

This fact clearly shows, that the ultimate cause must lie below the crust and must be world-embracing. We cannot conceive of an intercrustal mechanism, which brings about orogenetic activity simultaneously in the granitic continents, divided by basaltic oceans, that are several thousand kilometers across, while the thickness of the crust is only a few dozen kilometers. Neither can a theory be satisfactory, that attributes diastrophism to a local cause, no matter whether the substratum of the crust is thought to play a part in the explanation or not. If a theory is such, that the length of a cycle would depend on locally varying factors (resistance, temperature, chemical composition, dimensions, etc.) this theory is either incomplete or fundamentally wrong.

Another important point is the absence of any indication that the earth is ageing in a dynamic sense. In the first place the fact, that from earliest

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[1]) As there are 360 possible ages of 5 years between 0 and 1800 the revolving stage of a microscope could be used, by turning a large and varying number of times, in both directions without looking and then taking the reading. The first 18 of these were used as "less trustworthy" on the lefthand side of the time-line.

times intrusive activity was limited to definite short periods, goes far to establish the absence of ageing. The general picture obtained from studying basement complexes is that of a thin and highly mobile crust, almost constantly invaded by granits or convulsed by diastrophism. Sederholm's conception, that a limited number of cycles have occurred is amply confirmed by the data on radioactive ages. But the picture derived from the latter goes even farther, for not only are there cycles in the Pre-Cambrian but they are no shorter in duration than the more recent cycles. True there are accidental variations in length, but no progressive lengthening.

Finally it is of importance to note, that the eleven periods of activity are of an average length of 50 million years, the longest being 80. The intervening periods on the other hand are no less than 120 million years on an average, varying from 50 to 200. (Where there are only very few points in an active period the length is arbitrarily fixed).

Summary.

It is shown in extension of HOLMES' correlation of Pre-Cambrian cycles, that for the whole length of time covered by the data, radioactive ages — and therefore times of intrusion — are limited to short active periods, divided by longer periods of quiescence. The periods of activity are of worldwide importance. There is no apparent lengthening of the cycles thus established, or any other indication in the data of an ageing earth.