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Principles of Geochronology.

By

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With 2 figures in the text.

Read October 12th 1938.

It seems to be proper just now to remind of the very principles of Geochronlogy. There has, namely appeared in a valuable, new text-book of geology some doubt as to the validity of teleconnections. It may be that the very able author has not had access to the papers in question, as not having referred to any one of all the publications issued after 1914, which in detail have described numerous teleconnections with conclusive proofs of their correctness. But also in other places there have occurred unproved uttrances concerning the teleconnections, which make an elucidation desirable.

In 1878, from the striking similarity between cyclical layers in the Late Glacial clay of the Stockholm region with the annual rings of the trees, the present author got the direct impression that both were registering annual variations. This was then a mere supposition, and later on I have found that there had occurred also at least three other geologists, uttering analogous suppositions. But a mere supposition is no proof. Therefore the following summer I commenced careful investigations and measurements of such a rhytmically banded clay at Ronneby in south Sweden and also I continued with scattered similar measurements in other parts of Sweden.

Still these could not be connected with each other, as not covering any synchronous series of years. Yet in 1884 I measured varves at three points, not far from each other in east and west, or along the same former ice-border near Stockholm, and these agreed very well.

At two following meetings of the Geological Society of Stockholm I now presented a plan for working out *A Chronology for the Ice Age* (»en kronologi för Istiden») by using the corresponding variations of successive varve measurements for the combination of a Time Scale registering the whole recession of the last Scandinavian glaciation. Still nobody seems to have believed in its possibility and, for my part, I thought, myself, that such an enterprise should require several generations. Finally, after exactly 20 years, I found that, in any case between neighbouring localities, varve identifications could be quite performable, if the places were practically chosen.

Having presented my plan before the Swedish Academy of Sciences, I placed out some twenty geological students, ten from Stockholm and ten from Uppsala, along a line 180 km in N—S, in order to determine, by close-connections of the annual varves at about every kilometer, the rate of ice-recession along the whole of this line. As a compensation for my twenty years' scepticism concerning the possibility of such close-connections the whole experiment ought to be, and also became, executed in only a few days.

This first clay-campaign with close-connections was a clear success, affording, by its varve measurements, greatly overlapping each other, multiple controls and at the same time giving rise to quite a crowd of enthusiastic witnesses concerning the new method.

The following year the varve line was continued southwards about to the middle part of Scania in south Sweden, while it took some years before certain gaps were filled out and a rather long time before the measurement could pass over the Danish islands to the continent.

At the opening of the International Geological Congress at Stockholm in 1910 I had the opportunity of presenting an address on *A chronology of 12,000 years*. Thereby I proposed an international use of the term *varve* for the cyclic, annual unit of deposition of what earlier had been called a clay-varve and a sandy varve. At the same time I proposed to use the term *Geochronology* for an exact annual chronology and thus not for different kinds of approximate estimations, as e.g. the interesting radium computations.

It is true that the single existing exact geochronology at present does not embrace more than about 15,000 years of late Quaternary age, but there are good chances for its extension also to comprise several pre-Quaternary stages, glacial as well as other ones, having varves climatically sufficiently well marked.

Thus Dr CALDENIUS from our Geochronologic Institute

already has worked out a time scale for some few thousand years from a Carbonian glaciation in Eastern Australia, and this no doubt will be a good starting point for teleconnections with corresponding varve series from Carbonian glaciations in other countries.

It must be emphasised, namely, that geochronology or exact time measurement, as well as time itself, of course, is not limited only to the Quaternary period, though it was started from Quaternary varves, as being the most easily accessible.

When beginning the first geochronologic investigations, I intended mainly to bring about an exact time scale, based upon melt sediments deposited in standing water off the border of the receding land-ice in Sweden and thus registering the annual ice-recession in this country.

Teleconnection.

In 1915, by comparison of such annual varve series measured at different localities, it was found and definitely certified that the remarkable similarity as to the thickness variation not at all was influenced by more or less considerable distances between such localities.

This was also nothing but natural, as no other cause to this everywhere strikingly corresponding varve variation has been found possible to suggest than the amount of melting heat during every warm season reaching the earth from the sun.

In reality it was but a quite gradual evolution from local close-connections over to more and more distant teleconnections. These were, at first, extended to the most separated localities in Fennoscandia, obviously suggesting a common universal factor.

As the annual variations of the air temperature within formerly glaciated regions were found to correspond, I supposed and certified, by quite a number of direct varve measurements, at first in North America and later on, by cooperators from our institute, in all the five parts of the world that the so-called Swedish Time Scale had a world-wide application and, at last, had afforded a universal registration from the sun in so far as it reaches the earth.

This was indeed the main problem for the solution of which all the transmarine expeditions were sent out.

Out of the great material of varve measurements I have published, during the last twenty years, several teleconnected

varve series, comprising together about 8,000 annual varves, and exhibiting long sequences of characteristic varve constellations practically identic with corresponding rows of constellations in the Time Scale in Sweden and its filials in other countries

Even the exactly corresponding intervals between such correlated constellations have certified, long ago and beyond any reasonable doubt, that only a common cause can have produced such a striking similarity, in some cases over more than 1,000 annual varves.

Against one objection that there might be rhytmic iterations in the variation of the varves, which possibly could explain such similarities without any synchronism I have published parallel graphs, covering the last 7,000 years, conclusively showing that no such iterations do exist.

As another reason for doubts the great distance between several of the teleconnected varve-series sometimes has been emphasised, though no one has been able to deny the radiation from the sun as the essential cause of variation in the amount of ice-melting and varve thickness, whereby, in comparison with the enormous distance from the sun, the location of the compared varve-series on the earth is totally irrelevant.

This fact seems conclusive and makes it *a priori* probable that normally developed varves everywhere on our planet ought to show similar variations. Though this has been directly shown to be the case there still seems to exist some people who neither have really studied the matched varves, nor reflected on their mode of origin. As such undue scepticism might be able more or less to postpone a much needed use of teleconnection, it may be appropriate here to mention an example clearaly proving the possibility of teleconnection even at very long distances and at the same time between the northern and the southern hemisphere, thereby indicating that their glaciations were synchronous and not alternative.

Cross-teleconnection from the North to the South Hemisphere.

As I have already mentioned, Dr CALDENIUS some ten years ago sent to me from his measurements in Argentina a varve diagram, comprising 560 varves, and asked me to make a comparison with the Swedish Time Scale.

CALDENIUS supposed that these varves might belong to the later part of the last glaciation, and this assumption also was confirmed by a detailed comparison, which revealed a

most remarkable similarity between about 80 % of all the varves along a great number of constellations. The similarity was so great that it was possible to state, in my printed report sent over to Argentina, that a few, exactly dated varves must have been overlooked at the measurement.

Somewhat later, at another locality farther south in Argentina, Dr CALDENIUS really found all the six missing links, of which five had been correctly predicted, exactly at their right years.

A better proof of teleconnected, real identity than this telecorrection, being published in advance and afterwards confirmed in the field, scarsely can be imagined, but still it has been totally ignored by some opponents.

In Fig. 1 the main part of this transequatorial teleconnection is reproduced, whereby the great majority of variations, identified from both sides of the equator, are marked by double, heavy lines, which denote correspondance between the northern hemisphere and the southern one. Biennic variations are marked by round dots and triennic ones by hooked lines or nooks and combined by a light shade.

It is noteworthy with respect to certain years that, sometimes, in one of the hemispheres there is a lagging of one year, but the dominating marked conformity makes it probable that this exception is only apparent and depending thereof that the natural delimitation of the thermal year somewhat deviated from that of the civil year.

In good accordance with the transequatorial correspondence of the varves is the result of a comparison between direct thermometric determination of the annual temperature of the air on the two hemispheres in question, in accordance with the climatic registration by annual tree-rings from New Zealand (Fig. 2), determined by EBBA HULT DE GEER.

Here the time-coincidence is exactly known by the year and thus the transequatorial coincidence of the climatical variations undeniable. One year's exceptional lagging between both of the hemispheres is quite analogous to that of the varves, and the whole comparison seems to be a very good example of the universal application of the Swedish Time Scale. This fact being admitted, a careful study of teleconnections already performed seems well justified and rather desirable for a more effective use of the method in question.

Short periodic varve variations.

As already mentioned, I have noted some short variations in the thickness of the varves, comprising respectively two,

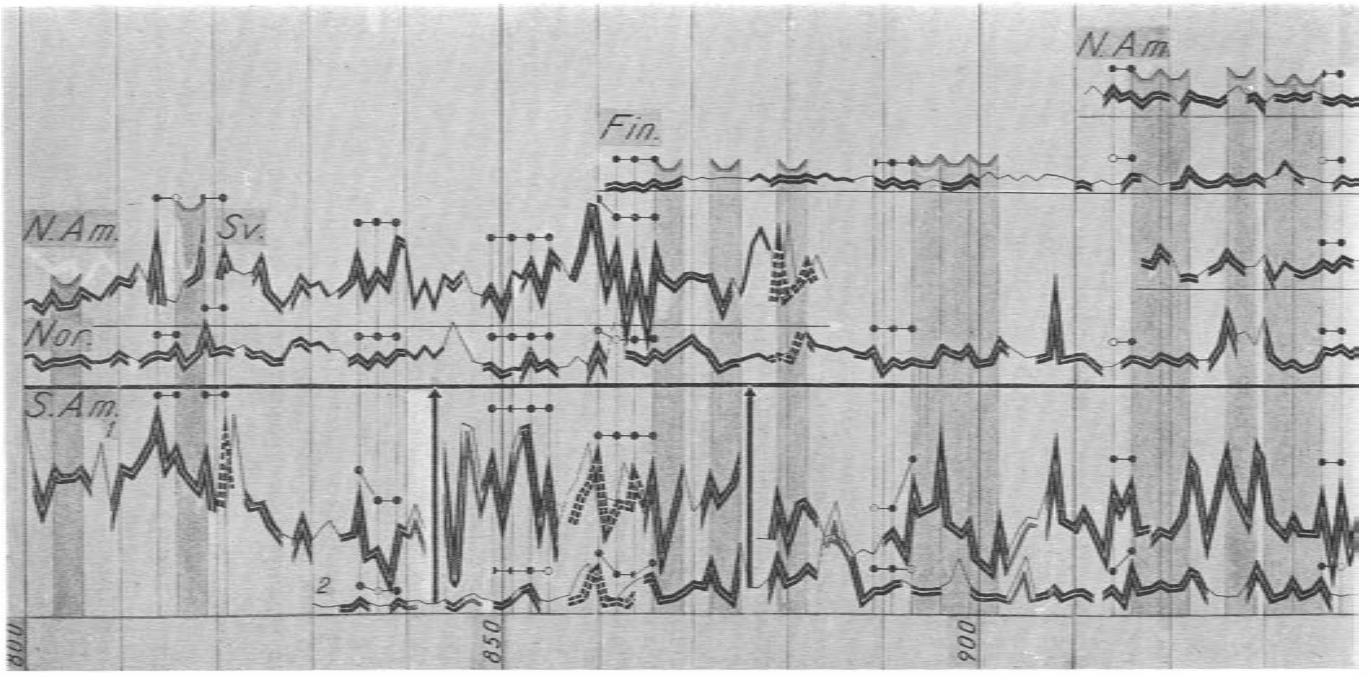
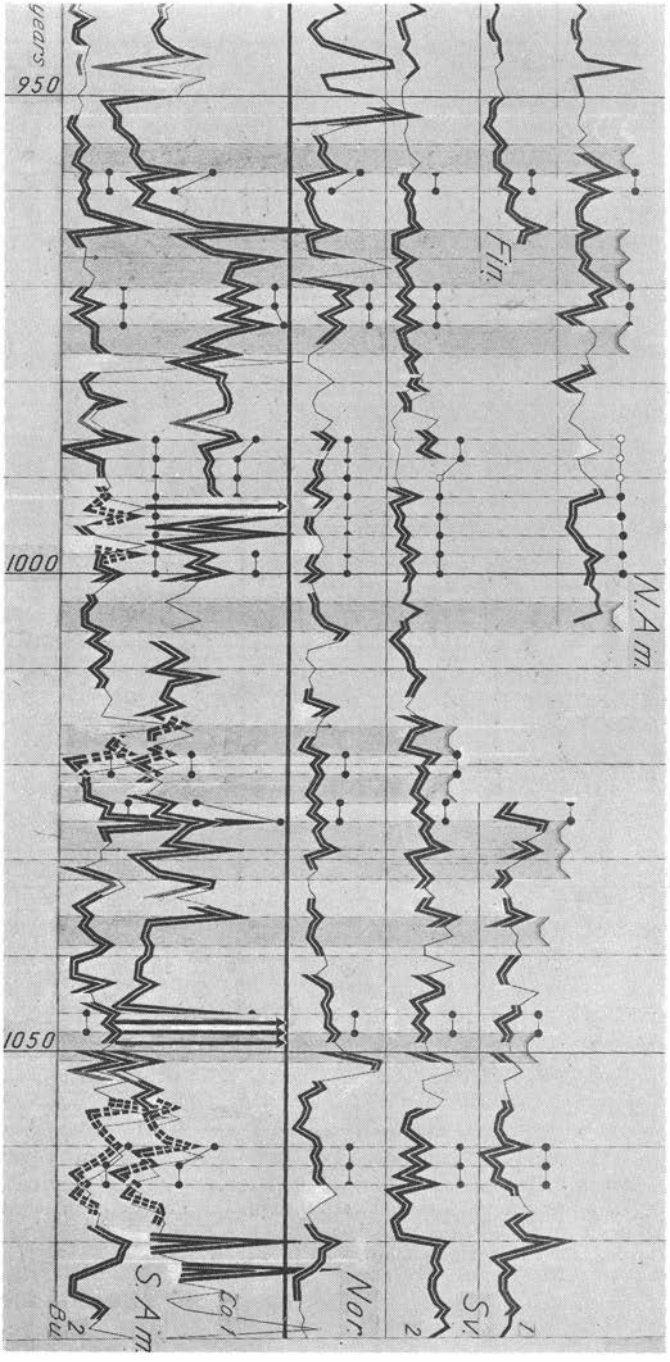


Fig. 1. *Varve teleconnections between N. and S. Hemisphere,* N: above and S: below the heavy line. Years: before the final year of the Ice Age. Broken curves: moved one year. Dots: biennic varve combinations. Nooks: triennic varve combinations Vertical spears: telecorrected varves.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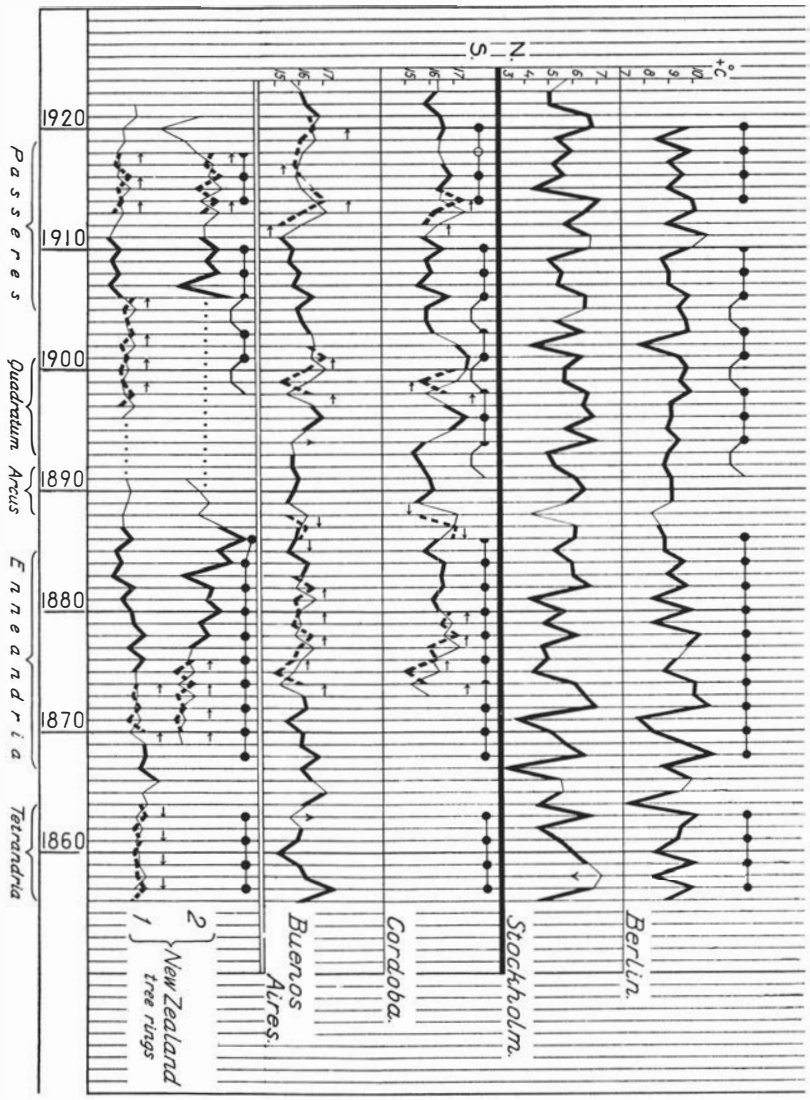

Fig. 2. *Annual Temperature teleconnections between N. and S. Hemispheres and tree rings from New Zealand;* 1: White pine = Podocarpus dacrydioides; 2: silver beech = Nothofagus menziesii.

Years: A. D. Other signs mainly as in Fig. 1.

three, and four years, and being designated as biennic, triennic, and quaternic cycles. Out of these the biennic cycles are by far the most common and most easily distinguished. By extracting those biennic cycles from the general graphs and plotting them into special ones, teleconnections are essentially facilitated.

With respect to my suggested explanation of such variations, it seems natural that the assumed clouds of meteoric dust possibly at the intervals in question may have absorbed some part of the sun radiation, and must circulate around the earth in the plane of the ecliptic. This may indicate a co-telluric origin of that material. But as yet it seems too early to make any further suggestions concerning their different periods of circulation and the successive origin of the cycles named.

Still it may be worth mentioning that while the biennic cycles during the late Quaternary period sometimes could cover 50 % of all the varves, it generally did not reach more than some 20 %. The same I have found from Permocarbonian varves, measured in Australia by Dr Carl Caldenius and reaching very nearly the same percent. Similar was the case with Eo-Cambrian varves photographed in N. Sweden by Dr O. Kulling, both published in the last number of Geol. Fören. Förh., Sthlm.

From these preliminary figures it seems as if the frequency of biennic variations might have been about the same as well during the Quaternary Period as some 200 and more than 340 *milli* ago, if the assumed unit for radium datings may be thus designated, instead of by millions of years.

Various application of varve connection.

Datings of ice-recession afford a valuable registration of climatic evolution where the influence of iceberg fracture can be eliminated.

Thus our success of determining a rapid ice-recession in middle Sweden explained why in that region the ordinary pine, instead of arctic plants searched for in vain, represented the first floral immigrants as following in the traces of the ice.

In the same way the rapid ice-recession in the Mälaren region proved that *Portlandia (Yoldia) arctica* was here an expiring relict and not at all, as previously believed, a witness of an arctic climate.

On the other hand, excessive ice-recession, especially in large valleys, as in the Baltic one and most strikingly in its deepest Bothnian part, has been shown to be due to a rather unrivalled amount of fracturing.

It goes without saying how important exact datings will be concerning certain stages of the immigration of the forest vegetation according to the remarkable pollen investigations as well as of the evolution of the land and water-fauna, of the diatoms and, ultimately, of prehistoric Man himself.

Likewise the new method of exactly dating, how long a time at different places the soil has been free from landice- and water-covering at last affords a reliable means of fixing the evolution of various kinds of soil, namely as well the vegetable mould of CHARLES DARWIN and HAMPUS VON POST as also the eluvial processes of Nikitin, including the *Podsol* of the Russians, the *Ahl* of the Danes, the *Auslaugung* of the Germans, and the *Gumbotil* of the Americans.

If specimens for such comparisons are carefully secured from appropriate localities, it will be possible to study in detail these eluvial processes from different stages, comprising together more than 15,000 years, and it is easy to imagine the importance of such a quantitative knowledge concerning the natural evolution and most rational use of the soil for crops as well as forests of most suitable kind.

Microdistal varves.

On the plains of middle Sweden the upper part of the varve-clay generally is eroded away during the land upheaval, making the bottom varves more accessible. Still at some places remnants of the top varves have been accidentally protected, for an example by down-slidden ose-sand. Such top varves, being sometimes less than 1 mm thick, got the name of micro-distal varves, and several specimens were, long since, preserved in our collections. Recently I commenced measuring them magnified by 20 and plotting them into graphs. Thereby the thickness variation exhibited a great resemblance with that of ordinary, proximal varves.

Such graphs of the new measured, microdistal varves were moved along the part of the Time Scale derived from northern Sweden, but did not show any similarity until at a considerable distance north of the locality in question.

Thus microdistal varves deposited in the Stockholm region were found with certainty to have their proximal continuation and their corresponding ice-border as far northwards as in Jemtland, a distance of up to 170 km, no doubt a record of exactly determined sediment distribution.

These tiny and uniform varves were sometimes rather well defined by utterly thin laminæ of whitish, very fine silt.

Where these were more or less lacking, repeated measurements had to be used for a control. Eventual errors from sliding had to be eliminated by control measurements on samples from other localities.

With these two exceptions microdistal sedimentation seems to be free from all other sources of error which impinge upon the proximal shallow-water facies.

Thus the microdistal varves have afforded a new and very promising means of working out normal curves, registering the mean annual ice-melting and its climatical cause.

When a sufficient number of control measurements have been performed also in different countries, this no doubt will mark an important step forwards and an evolution of certain parts of geology into exact geophysical investigations.

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