MEMOIRS OF THE MUSEUM OF COMPARATIVE ZOOLOGY AT HARVARD COLLEGE; VOL. XLVII, NO. 1: SEASONAL DEPOSITION IN AQUEOGLACIAL SEDIMENTS

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ROBERT W. SAYLES

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SEASONAL DEPOSITION IN AQUEO-GLACIAL SEDIMENTS.

BY
ROBERT W. SAYLES.

WITH SIXTEEN PLATES.

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SEASONAL DEPOSITION IN AQUEO-GLACIAL SEDIMENTS.

1. INTRODUCTION

ALTERNATIONS between coarse and fine sediments in a regular rhythmical banding have been noted by geologists for many years. To the different types of banding, various causes have been ascribed. That seasonal variation in deposition does not account for all kinds of banding is perfectly clear. In this paper only the banding in clay sediments associated with glacial deposits will be discussed. It is suspected that the banding in many slates, without associated glacial deposits, may be due to variations in seasonal deposition, but until the banded glacial sediments have been thoroughly studied, and the criteria fully determined, it is inadvisable to discuss these other well-banded sedimentary rocks.

I wish to acknowledge my appreciation of the helpful advice and encouragement given me in this work by my colleagues, Profs. W. W. Atwood, J. B. Woodworth, and E. C. Jeffrey. Professor Atwood carefully examined the slate at Squantum with me in November, 1915, and also visited the section of the clays at Woodsville, N. H. Professor Woodworth very kindly read my manuscript and gave invaluable criticism. To Professor Jeffrey I am much indebted for the photomicrographs, Plate 16. Mr. Frank B. Taylor spent two days with me on the Squantum tillite and slate formations, and favored me with his opinion on the problem of seasonal banding in the slate at Squantum.

2. LITERATURE ON SEASONAL BANDING IN GLACIAL CLAYS

For many years geologists have noted the strikingly even lamination of glacial clays. Some observers have attributed such regularity to seasonal deposition, but only recently have geologists felt confident that this regularly alternating deposition of coarse and fine sediment could be used as a means of recording past time.

The first mention that has come to my notice, of the idea that these regular layers might mean years, was made by Edward Hitchcock in **1841**. He wrote:

"The layers of our diluvial clay rarely exceed half an inch in thickness in the valley of the Connecticut. In each layer the coarsest part of the materials is invariably placed at the bottom; and there is a gradual diminution of fineness upward, until at the top it is exceedingly fine clay. This arrangement is just as we might expect from deposition in water; and it shows perfectly quiet water. Probably each layer marks the annual deposit; or the result of a freshet." E. HITCHCOCK, 1841, **2**, p. 359, 360.

These words were written just before Hitchcock accepted the theory of the Glacial period as expounded by Agassiz and Charpentier in **1836**. It is sufficient to realize that the regular layers were considered at an early date.

In Europe, during **1878** de Geer noted the regular banding in the glacial clays of Sweden and attributed their regularity to annual or seasonal deposition. To de Geer more than to anyone else we owe the firm foundation on which the theory of seasonal or annual deposition in these glacial clays rests. He was the first geologist to explain the origin of the banding and also the first to prove the truth of his theory. For many years he worked toward the solution of the problem and he gave a preliminary account in a lecture before the Geological Society of Stockholm in **1884**. Not until **1912**, however, did he publish his results in detail.

At the International Congress of Geologists at Stockholm in 1910 de Geer read an impressive paper, A geochronology of the last 12,000 years (de Geer, 1912), a paper so important that I quote significant parts of it here:

"Geology is the history of the earth, but hitherto it has been a history without years. It is true that many attempts have been made to obtain time-computations for certain parts of that history, but none of them has been capable to stand a closer trial. Thus, the very able authors [Chamberlin & Salisbury] of one of our lately published textbooks of geology say (1): 'The desire to measure the great events of geological history in terms of years increases as events approach our own period and more intimately affect human affairs. The difficulties attending such attempts are, however, formidable, and the results have an uncertain value. At best they do little more than indicate the order of magnitude of the periods involved. Geological processes are very complex, and each of the co-operating factors is subject to variations, and such a combination of uncertain variables introduces a wide range of uncertainty into the results.'

"Under such circumstances it may be suitable here to place briefly before you a new, exact method of investigation, through which it is possible, by actual counting of annual layers, to establish a real geochronology, for a period reaching from our time backwards some 12,000 years.

"As a basis for this chronology have been used certain late glacial and postglacial, periodically laminated sediments in which the deposition for every single year can be discriminated. By actual countings and successive combinations of a great number of sections

with regular intervals along a line extending from the southernmost to the central part of Sweden it has been possible not only to sum up the whole series of centuries it has taken for the ice-border to retire this distance, or some 800 km, but also to estimate the length of the postglacial epoch after the disappearance of the ice and up to our days.

"Of the late glacial sediments the most important is a glaci-marine clay, the "*varvig lera*" (hvarfvig lera), so called from its "*varves*" (2) or its periodical laminæ of different colour and grain.

"Already at my first field-work as a geologist, in 1878, I was struck by the regularity of these laminæ, much reminding of the annual rings of the trees. The next year, therefore I commenced, and during the following years pursued, detailed investigations and measurements of these laminæ in different parts of Sweden. The laminæ were found to be so regular and so continuous that they could scarcely be due to any less regular period than the annual one. I therefore ventured in 1882 to advance the view that there might be a close connection between the periodical laminæ of the clay and the annual ablation of the land-ice (3). Two years afterwards the investigations had proceeded so far that, being confirmed in my opinion that the laminæ were really annual, and having found out a way for correlating annual layers at different places by means of diagrams, I could, in a lecture read before our Geological Society in Stockholm, indicate the way by which a real chronology for the last part of the Ice-age could be obtained (4). A few months afterwards I also succeeded in finding the first correlation between the clay-layers at three points, though not very far from one another. In 1889 I found — and mapped — in the neighborhood, NW of Stockholm, a thereto [hitherto] overlooked kind of certainly quite small, but very characteristic terminal moraines, which proved to be periodically arranged in rows with somewhat regular intervals of about 200–300 m. This led me to point out the possibility that these ridges might correspond to the stop in the recession of the ice-border, which was probably caused by each winter, and that this might be ascertained by investigation of the successive annual clay-layers between some neighbouring ridges (5). This kind of moraines has since that time been found to be quite common in the lower parts of the land, and at first I had therefore the intention of pursuing the chronological investigations by means of a careful mapping of the annual moraines.

* * * * *

"By detailed studies of some oses, especially at Stockholm and Uppsala, and, later on, also at Dal's Ed it had turned out that also the oses are of a pronounced periodical structure, marked by centres of coarser material, on their southern side gradually passing into finer gravel and sand. This led me to a new explanation of their formation as successive submarginal delta-deposits, formed in the glacier-arches of the receding land-ice, and probably corresponding to the annual "*varves*" of the finest, clayey sediment and to the annual moraines (6).

"Finally, in 1904, I happened to get a very good correlation between two clay-sections 1 km apart from each other, and now I determined to make an earnest attempt to realize my old plan for a clay-chronology.

"By investigating some forty points in the Stockholm region it was soon found that the clay-correlation offered less difficulty than thereto suspected and was — the localities of observation being well chosen — as a rule performable at distances of 1 km. This being ascertained, I secured the assistance of a number of students from the universities of Stockholm and Uppsala, ten from each, and after some training they went all out on a summer morning in 1905, each of them to his special part of a line about 200 km. long, running, as seen from the map Pl. 1, past Stockholm and Uppsala through the Södermanland-Uppland peninsula, from the great Fennoskandian moraines at its southern end to the river Dalälfven to

the north, and going as nearly as possible in the direction of the ice-recession. The main work was performed in four days; though the filling up of some lacunæ at difficult points could be performed only after several repeated attempts.

"Among the different results it may suffice here to mention, that I now finally got the conclusive proofs for the assumption that the individual "*varves*" had a very wide distribution. Thus it was shown that it often exceeded some fifty km, and that the cubic-mass of the "varves" must be measured by millions of m^3. This together with their regular structure definitively showed, that they could not be due to any local or accidental cause of smaller importance or less pronounced periodicity than the climatic period of the year. On the other hand, it seems equally impossible that every sharply marked *varve* should correspond to any hypothetical and, in every case, indistinctly limited series of years without showing any registration of the in fact so sharply accentuated period of the single year. Indeed, it seems to me quite as improbable that the melting-season of the land-ice should not put its stamp upon the annual sedimentation, as that this should not be the case with the annual period of vegetation in relation to the annual rings of the trees.

"In the following year, with the assistance of partly the same staff of co-operators, the investigation was extended to the rest of the line 800 km in length between Skåne (Scania) and that point of the late-glacial ice-shed — in S. Jämtland — where the last ice-remnant first became divided into two parts. Also this campaign was successful, though at several places lacunæ had to be left for the moment.

"However, the main thing was that the plan had been found to be quite performable even under such highly varying conditions as had been met with along this extended line, and that it now evidently was only a question of labour and patience, gradually to work out the chronological and climatical record almost as far into detail as might be wished.

"In my later completion and correlation work it was a great pleasure to me to find how able and enthusiastic in their work my numerous young collaborators had been, and how good and reliable were their results. Never lacunæ were left, where the difficulties had not really been too serious for the time available.

"The natural conditions upon which the plan for the whole investigation was founded are the following. When the late-glacial land-ice receded from Sweden, the lower parts of the land were still depressed below the surface of the sea, and during the warm season of every year the melting-water from the surface of the great land-ice sank down through its crevasses and found its way along the bottom of the ice, where it was pushed forward under strong hydrostatic pressure, thereby sweeping away considerable masses of moraine-matter which were transformed into water-worn sediment. Where these overburdened rivers, at the steep border of the land-ice, reached the stagnant water of the sea, the subglacial river-tunnels widened rapidly into glacier-arches, and at the same time the rapidity and transporting power of the water slackened, thus causing a deposition of the great cobbles and the coarsest material at the innermost, proximal part of the arch, while, further out, smaller pebbles and gravel and ultimately almost only sand was deposited at the more distal part of such a submarginal delta in the very mouth of the arch. Still farther out in the sea off the ice-border the sand becomes thinner, finer, and more and more interstratified with clay-layers, which ultimately become dominant and free from sand.

"Thus every ose-centre is nothing else than the proximal glacier-arch portion of an annual layer and, if this be compared to a fan, corresponds to the very handle of it.

"Every year, by the melting during the warm season, followed also a recession of the steep ice-edge with the glacier-arch and its river-mouth. This retreat, on the whole quite dominating, was during winter-time somewhat counter-acted by a slight advance, at many places wonderfully well registered by the small, but well-marked winter-moraines.