PLEISTOCENE GLACIATION OF SIBERIA.

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ABSTRACT.

Field work done by Russian geologists during the last decade has shown that, contrary to previous views, most of Siberia was totally glaciated during the Pleistocene with the exception of large driftless areas in Central Siberia whose history is uncertain as yet. In contrast with Europe and North America the Siberian glaciers moved in all directions from a multitude of relatively small ice-centers rather than from a single huge one. Large scale faulting of the northern shore of Siberia, said to be penecontemporaneous with the Riss-Würm interglacial stage is described as well as several marine "boreal" transgressions and a complicated series of fluvio-glacial sediments including horizons of fossil ice. As a result of their work many Russian geologists are prone to favor the idea of an ice-free Arctic Ocean even during the glacial epochs, an ocean which possibly was kept open by warm currents (the Gulf Stream?) in the same fashion as such warm currents are flowing toward the pole today.

Less than ten years ago it was generally believed that the northern part of Asia had been left practically untouched by Pleistocene glaciation. A radically different view, claiming almost total glaciation of Siberia north of the 61 degree parallel was presented to the attention of Western geologists by Obrutchev in 1930.[1] In the following years a considerable amount of field work by other Russian geologists confirmed that at least two-thirds of this enormous territory (Western and Eastern Siberia) had been indeed totally glaciated as far south as the 61° or 62° parallel. The glaciation of the remaining third—Central Siberia—still remains a disputed subject among Russian geomorphologists.

Two major ice advances, correlated with the Riss and Würm stages and separated by an important interglacial marine transgression (the " boreal" transgression) are now postulated for Western and Central (?) Siberia. As many as four glacial stages somewhat doubtfully dated are said to be recognizable in certain parts of Eastern Siberia.

This latest information has been summarized in a recent Russian symposium.[2] The present discussion is based mainly

[1] Obrutchev, W. A.: "Die Verbreitung der Eiszeitspuren in Nord- und Zentralasien," Geol. Rundschau, 21, 243-283, 1930.

[2] "Geology and Mineral Resources of the North of the USSR, Vol. 1—Geology" (in Russian); a symposium with articles on the following subjects of Siberian geology: Stratigraphy by W. A. Obrutchev; Geomorphology by J. S. Edelstein; Ancient Glaciation by N. N. Urvantsev; Tectonics by N. S. Shatsky, and a discussion of Shatsky's paper by M. M. Tetiaev. "Responsible editor" of the symposium: N. N. Urvantsev. "Technical editor" (i. e. secretary) P. T. Stepanov. Published by the Administrative Board of the Arctic Seaway ("Glavsemorputi"). 175 pp., 2 maps; Leningrad, 1935. This book has been referred to by F. P. Shepard in a recent article (see footnote 7) as P. T. Stepanov, "Useful Minerals of the North USSR," Vol. 1, Geology, Moscow (1935) (in Russian).

upon this publication. No startling discoveries have been made since Obrutchev's *aperçu* of 1930, but the subsequent confirmation of many of his claims makes it now possible to present to American geologists a reasonably authentic picture of what took place in Northern Asia during Glacial time.

In order to understand properly the Pleistocene glaciation of Northern Asia, it is necessary to remember that Siberia can be divided into three very different natural provinces: Western, Central, and Eastern Siberia, each of which is characterized by its own peculiar stratigraphy, structure, and geomorphology.

The Western Siberian Lowland, between the Ural Mountains and the Ienisei River, is a flattish constructional plain, rising to less than 350 feet above sea level. It is dissected by river valleys 30 to 150 feet deep, and is blanketed by a thick mantle of Pleistocene sediments: marine, lacustrine, glacial and fluvioglacial. The Pleistocene is underlain by almost horizontal, undisturbed Tertiary and Mesozoic formations. There is very little Paleozoic and Pre-Cambrian in this area.

In the northern part, marine sediments of the interglacial boreal transgression cover the surface, rising in places to elevations of 250 feet above sea level. Farther south a mighty series of end moraines, up to 225 feet in thickness, which extends as far south as the 60° and locally even to the 59° parallel, leave little doubt as to the continental glaciation of the area.

The Central Plateau, between the Ienisei and Lena rivers, is a flattish, dissected structural tableland, usually less than 2,000 feet high, although in its northwestern part it reaches an altitude of 5,000 feet. The tableland is fractured by several major grabens and dissected by very wide river valleys. It is underlain mostly by moderately disturbed Paleozoic rocks, although the Pre-Cambrian is also fairly well represented. Mesozoic formations are found only locally, and there is almost no Tertiary. The most important rock of the region is the so-called "Siberian trap," a series of basic igneous rocks of Permian age possessing a similar composition, but variable texture, and ranging from gabbros through dolerites, diabases, and basalts, into tuffs. They cover an area in excess of 300,000 square miles. Although at some places the trap occurs as lava flows and tuff layers, the fundamental type of occurrence seems to be the sill. Individual sills reach 500 feet in thickness, and have been followed continuously for 60 miles

or more. There are from five to seven superimposed sill horizons, and single horizons have been traced for over 200 miles at a time.

The alternation of resistant trap horizons with weak Paleozoic sediments accounts for the geomorphology of the tableland, the mesa-like character of certain of the interfluves and the precipitous step-by-step descent of many river-valley walls.

Innumerable signs of ice action are found in Central Siberia. They include numerous erratics, up to 15 feet and more in diameter, especially along the valleys; scratched and striated pebbles; boulders of foreign derivation in the valleys of many smaller streams; so-called tills or boulder clays as far south as the 61° parallel; numerous polished, scratched and striated rock surfaces; "finger" lakes reaching a length of 60 miles with a width ranging from one to eight miles and a depth up to 700 feet; and finally the presence of fossil ice, or ice as a rock formation, an amazing and peculiar feature of Central Siberia even in latitudes as low as the 62° parallel.

These features are considered by many Russian geologists, led by Obrutchev and Urvantsev, to be proof of a former continuous ice mantle. A much more cautious view is that of Edelstein, who refers to these phenomena as "pseudoglacial." According to Edelstein the erratics, striated pebbles, polished and grooved rock surfaces and the so-called boulder clays are caused by river ice. On the large Siberian rivers, such as the Ienisei, the spring thaw assumes cataclysmic proportions, and all these pseudoglacial phenomena, including the transport of boulders ten feet in diameter, are directly observable during that time. The fact that most of these features are generally confined to river valleys supports Edelstein's hypothesis. The presence of foreign boulders in the valleys of the smaller rivers is explained by Edelstein as due to river capture rather than to a till mantle. This view cannot be confirmed or disproved until much more field work is done in this little-known region. The larger trap erratics along the Ienisei and other major valleys are considered by Urvantsev to have been brought by the glacier from the north and by Edelstein by river ice from the south. Inasmuch as trap is universally present in Central Siberia, the problem appears to be insoluble, at least for the time being.

Furthermore, Edelstein claims that no positive evidence of ice action has yet been found on the interfluves, citing as his example the relatively well described course of the Tunguska

River. Here the higher slopes of the tableland are hidden under a thick talus of trap fragments, and a trap regolith blankets the tundra-covered flattish interfluves. Finally, individual, vertically standing, prismatic columns of trap are not infrequently found, a positive proof that the higher Tunguska tableland was never glaciated. Urvantsev admits that in southern Central Siberia the ice sheet may have dwindled to less than 1,500 feet as compared with a thickness of 3,500 feet farther north, and that nunataks, some of them possibly of extremely large dimensions, may have been numerous. Hence, even if Urvantsev's views are accepted, the presence of a very extensive "driftless" area must be conceded at a distance of 100 to 150 miles north of Urvantsev's Central Siberian ice-front.

On the Taimyr peninsula, the north-western extremity of Central Siberia, the presence of huge end-moraines, 500 feet high, is considered by both Urvantsev and Edelstein to be sufficient evidence for the glaciation of that part of the region. The finger lakes in the Norilsk region, south of the Taimyr peninsula, are not satisfactorily explained by Edelstein, and hence may be an indication of a more extensive southward ice advance. Finally farther southeast between the Lena and Aldan rivers (i.e. between the 62° and 65° parallels) there is a region of abundant fossil ice.

The ice horizon, present at many places in Central Siberia, reaches a maximum thickness of 200 feet near the shores of the Arctic Ocean. It is sandwiched between normal sands, silts, and gravels. Ice dikes penetrate the sediments and clastic sandstone dikes cut across the ice horizon. In the Lena-Aldan area, fossil ice is much thinner, usually from 35 to 100 feet in thickness or even less. The country is covered with many kettles and small lakes, due to thawing of the ice and slumping. While admitting that some of the smaller ice bodies may be the remnants of frozen Pleistocene lakes, Urvantsev considers that the main ice beds are the actual remnants of the Pleistocene glacier, dead ice left by stagnation and rapidly covered by glaciofluvial sediments. Edelstein maintains that the Lena-Aldan ice is due to the recrystallization of large snow or firn fields which accumulated in the non-glaciated valleys during the Pleistocene, and have been buried later by ordinary fluvial deposits. The stability of snow-fields is questioned by Urvantsev, who says that they would be readily dissipated by ablation or converted into real moving glaciers,

especially under the influence of the large masses of ice which were descending at that time from the East-Siberian glaciers nearby. Obrutchev, however, in his 1930 paper also endorsed the firn-field hypothesis. Apparently more field work is required before we can decide in favor of one of these two rival theories.

The East Siberian Highland consists of numerous high mountain ranges, and reaches an altitude of 8,000 to 12,000 feet. The geology is very complex. All the geologic systems from the Pre-Cambrian to the Tertiary, are present. Igneous rocks of all types are abundant. The strata have been repeatedly folded, the last major orogenesis having occurred during Alpine time.

The region teems with evidences of glaciation. In the north, the glaciers apparently were of the continental type, with moraines occurring as high as 6,500 feet above sea level. In the south, the glaciation had a more Alpine character.

In conclusion, it seems that possibly all of Siberia north of the 61° parallel, and certainly at least two-thirds of it, was covered with Pleistocene ice which coalesced east and west with the American and European glaciers, forming, according to Urvantsev, a "gigantic ice ring" within the northern hemispheres. An impartial evaluation of the evidence, however, shows that in Central Siberia this "ice ring" must have been rather thin and probably at some places discontinuous.

Two ice stages are recognized west of the Lena River (i.e. in Western and Central (?) Siberia).

The first and most important ice advance, of Riss age, had a large-scale, continental character. A major difference must be noted between the glaciation of Europe and that of Siberia. In Europe the continental ice-sheet spread out from one large ice-center, Fennoscandia. In Siberia many smaller centers of glaciation were active simultaneously, with coalescing glaciers spreading from these centers in all directions. This was recognized by Obrutchev in 1930[3] and has been entirely confirmed since.[4] The principal centers of glaciation were the Urals, the highlands of the Northern Ienisei (?) and apparently a series of high points in the north, which now have sunk below the

[3] Op. cit., p. 275.

[4] This is not in harmony with the view recently expressed by F. P. Shepard ("Daly's Submarine Canyon Hypothesis," This Journal, 33, pp. 369-379, 1937) that (p. 379): ". . . . recent discoveries of Soviet geologists that the ice moved up out of the Arctic basin and spread well south over the entire northern part of Siberia and Russia may be mentioned. . . . . ."

surface of the Arctic Ocean. The evidence for this last supposition is partly based on the direction of striae covering hundreds of miles on the Taimyr peninsula all of them pointing back to a common center, in the Nordenkiold archipelago, which is now only 160 feet above sea level. Ice movements are traced from this archipelago toward the Byrang region, 200 miles to the south and now over 2,400 feet above sea level. Directions of ice movement, which are indicated on the adjoined map (after Urvantsev), show this dispersal from common centers of glaciation.[5]

Similarly, in the Urals, on Mt. Rai-Iz erratics are found at an elevation of 4,000 feet, which are correlated with a much lower-lying region farther north. All of this, according to Urvantsev, indicates that during Riss time the relief map of Northern Siberia was entirely different from the present, and that the bottom of the Arctic Ocean within the 200 meter (100 fathoms) line was well above present sea level with the Severnaya Zemlia, the Nordenskiold, and the New-Siberian archipelagos being a part of the continent. This is in harmony with the Russian concept that the Siberian shore of the Arctic Ocean has been molded not only by eustatic and epeirogenic movements but mainly by large-scale faulting during the Pleistocene, a concept supported by the presence of enormous Quaternary grabens and rift valleys all over Siberia, Lake Baikal being the classic example. Previous to that down-faulting, a high land mass extended almost to the 80° parallel. This land mass contained many of the large centers of glaciations. An ice-free Arctic Ocean north of the 80° parallel provided the necessary moisture to feed these centers of glaciation, with the main ice movement taking place southward. Obrutchev[6] in discussing the probable drainage of the great Siberian rivers during Glacial time, comes to the conclusion that they were not deflected into the Caspian Sea, but followed the ice border until some point in Central Siberia, where they managed to

[5] Due to the small scale of the map, the centrifugal effect (which is not a north-south movement) is not as clearly shown as, for instance, on the detailed large map published by Urvantsev in 1931 (N. N. Urvantsev "Quaternary Glaciation of Taimyr," Bulletin de la Commission pour l'étude du Quarternaire, No. 3, 23-47, 1931). This map (on page 25) shows clearly the radiation of ice from the Nordenskiold archipelago. The arrows on the map (Fig. 1) hence, are really "synthetic" ones and are meant to show the "average" direction of ice-movement, which, although it possessed a notable north-south component, was essentially one from the highland ice-centers towards the lowlands (see also footnotes 4 and 7).

[6] *Op. cit.*, p. 276, 1930.

break through the thin glacial cover and flow northward into this ice-free Arctic Ocean.[7]

The idea of an open ice-free Arctic Ocean almost entirely surrounded by continental glaciers may at first appear to be somewhat improbable. However, it must be remembered that there is no conclusive evidence of a continuity of the ice barrier between Greenland and Europe and that through this gap a warm current (such as the Gulf Stream) may have flowed into the Arctic Ocean and kept it open even during the glacial stages. That this is not entirely idle speculation is shown by the existence of such a warm current which apparently reaches the North Pole at the present time. This fact, suspected for some time by the Royal British Meteorological Society, was proved only in June, 1937, when members of the Soviet Polar Station discovered at the pole, between the depths of 300 and 1,000 meters below sea level the existence of a warm current ". . . . apparently flowing from the Atlantic . . . ." and carrying a warm water fauna.[8]

[7] These two Russian concepts, viz., the existence of a former high northern border of Siberia and of an ice-free Arctic Ocean do not coincide with the interpretations advanced by F. P. Shepard in his references to the symposium which forms the basis of this discussion. The reader is referred to footnote 4 and also to F. P. Shepard's "The Underlying Cause of Submarine Canyons," Proc. Nat. Acad. Sci., 22, 496-502, 1936. In the latter publication a greatly simplified version of Urvantsev's 1935 map (p. 500) ". . . . . showing the direction of the ice movement in Northern Russia and Siberia" is offered as ". . . . . one of several lines of evidence favoring the Arctic ice-cap" (p. 501) which is said to have grounded ". . . on the relatively shallow margins of the Arctic basin."

In this connection Professor Shepard (letter of June 16, 1937) wishes to state the following: "I should like to suggest that you make it a little clearer in your footnotes that the map which I copied in my National Academy paper contained the information regarding ice movements which was shown on the Soviet map (if this is the case) but that as I was unable to translate the text my interpretations of the meaning of these directions of ice movement did not coincide with those of Urvantsev." The writer concurs with Professor Shepard in admitting that without a translation of the full legend of the map and especially without a knowledge of the text of the book, an interpretation similar to that arrived at by Professor Shepard is very likely to result from an inspection of the map (see footnote 5).

This discussion should not be construed as an attempt to take sides in the controversy concerning the origin of submarine canyons. It is simply desired to show that the present status of Russian geologic knowledge concerning the glaciation of Siberia does not make it possible to draw from it any inferences favorable to the possibility of large scale eustatic changes in sea level.

[8] This discovery, as reported in a preliminary radiogram from Krenkel and Papanin of the Soviet Polar Station, was published in Russian newspapers on June 10, 1937. As this is written (according to the same newspaper notice) chemical analyses of this 700 meter thick layer of warm water are being made and its fauna studied in order to establish its exact relationship to the Gulf Stream.

The first major ice advance was followed by an interglacial stage during which the glaciers did not disappear entirely, but merely wasted back towards the mountain tops. This interglacial stage was punctuated by the huge boreal transgression,

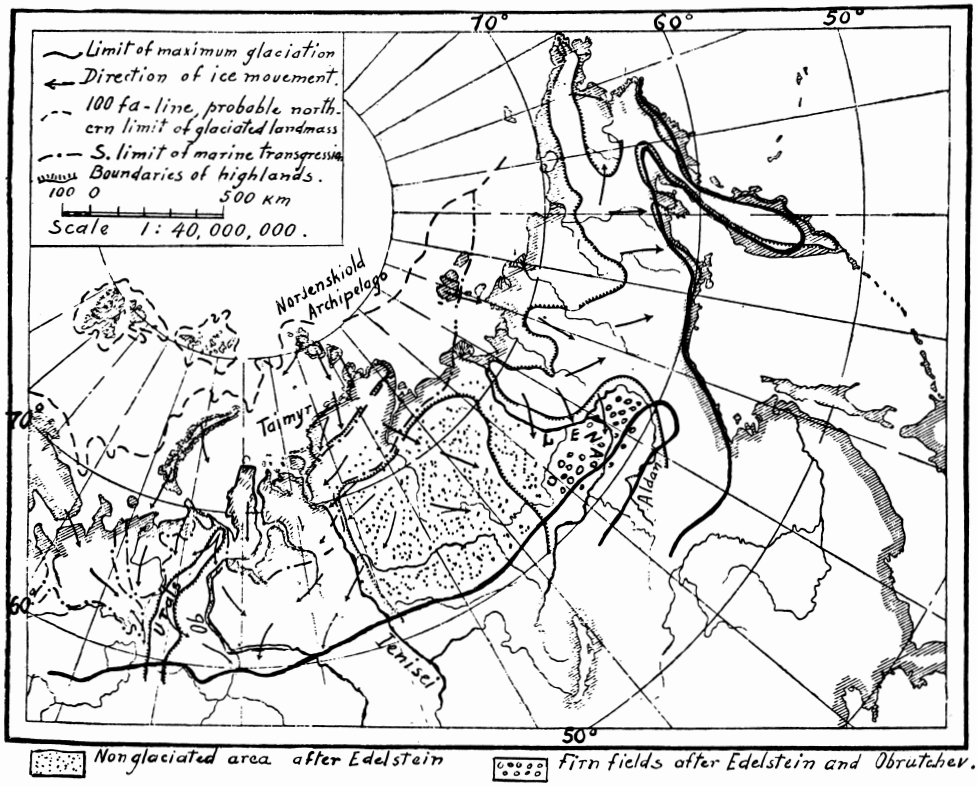

Fig. 1. Pleistocene glaciation of Siberia after Urvantsev (1935), with modifications after Edelstein (1935).

and it was caused not only by climatic changes, but also by the colossal down-faulting which brought under water the northern extremity of Siberia, destroying the northern centers of glaciation and flooding Western Siberia with such rapidity that no fossil ice could be formed there.

Climatic changes and epeirogenic movements brought into being the second (Würm) glacial stage. Glaciers were much less extensive than before, being generally of Alpine character, coalescing in the valleys (Malaspina type).

Finally, epeirogenic movements resulted in a second, albeit very minor, postglacial marine transgression, after which the present shoreline and climate were established. This climate was apparently milder in the beginning, judging from the fact that many trees and plants have retreated from 120 to 300 miles southward since early postglacial time.

East of the Lena River, the Pleistocene history is much less well known. As many as four separate ice stages are said to be recognizable on the Tchukotsk peninsula, with both climatic changes and large scale faulting and epeirogenic movement being of genetic significance.

At the present time all the northern coast of Siberia is slowly emerging at the rate which on the Taimyr peninsula equals 2.0 cm. per year: the shallow shoals mapped there by the Middendorf expedition of 1843 are now low islands of identical outline 1 m. above sea level. A peculiar feature of this emergence is that the fossil-ice horizon is brought to the surface and subjected to wave action and temperature changes. As a result, on the New-Siberian archipelago, although the surface is rising, the perimeter of some islands is decreasing (at a rate which may reach 120 feet of inland retreat per year) because the weak ice horizon does not resist well marine abrasion and thermal attack.

The general impression left by the 1935 symposium is one of thorough work by competent investigators. In this respect it stands out as a welcome addition to the huge output of geologic literature, enormous in quantity, but very uneven in quality, which has been coming out of Russia during the past few years. Much remains as yet to be learned about the Ice Age in Northern Asia, especially about the puzzling driftless areas and firn-fields (?) of Central Siberia. Nevertheless, the main events have been discovered. A point of special interest appears to be the peculiar combination of climatic changes and faulting which seems to have caused many of the features of the Siberian Pleistocene. Students of tectonics and sedimentationists will join geomorphologists in waiting hopefully for further information which the Russians may produce on this interesting subject.[9]

[9] A study of faulting as a controlling factor of glaciofluvial and glaciomarine sedimentation would be a most welcome addition to the study of the influence of faulting upon fluvial sedimentation recently published by C. R. Longwell ("Sedimentation in Relation to Faulting," Bull. Geol. Soc. Amer., 48, 433-442, 1937).

ACKNOWLEDGMENTS.

The writer wishes to express his thanks to Professors Flint and Longwell of Yale University for helpful suggestions and criticism during the preparation of this discussion, and to Professors Dunbar and Knopf for reading the manuscript.

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