ORIGIN AND CHARACTER OF OESSLIKE SILT IN UNGLACIATED OUTH–CENTRAL YAKUTIA, IBERIA, U.S.S.R.

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1262

Origin and Character of Loesslike Silt in Unglaciated South-Central Yakutia, Siberia, U.S.S.R.

By TROY L. PÉWÉ *and* ANDRÉ JOURNAUX

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ORIGIN AND CHARACTER OF LOESSLIKE SILT IN UNGLACIATED SOUTH-CENTRAL YAKUTIA, SIBERIA, U.S.S.R.

By TROY L. PÉWÉ and ANDRÉ JOURNAUX[1]

ABSTRACT

Loesslike silt mantles upland terraces and low plateaus throughout unglaciated south-central Yakutia but is thickest along the south side of the lower Aldan River valley and the east side of the Lena River valley. The silt is probably loess deposited during glacial advances by winds blowing southward from the Verkhoyansk Range and eastward across the broad vegetation-free flood plain of the braided Lena River.

The well-sorted uniform tan silt is well displayed along the Aldan and Lena Rivers; the thickest exposure measured, more than 60 m, is on the Tyungyulyu Terrace on the east side of the Lena River. On the west side of the valley, it is 10–25 m thick but thins rapidly to a featheredge west of Yakutsk. Almost all scarps along the south side of the Aldan River are capped by 10-35 m of silt.

The texture and mineral composition of the loesslike silt are uniform throughout south-central Yakutia, whether it overlies limestone, poorly consolidated sandstone, alluvium, and glacial outwash. All silt samples examined contained a high percentage of quartz and feldspar. The silt stands in sheer cliffs and is massive, with little or no stratification.

The origin of the loesslike silt has been ascribed to disintegration in place of country rock by a marine, estuarine, lacustrine, fluvial, residual, or eolian source, or to a combination of these processes. The marine and estuarine hypotheses have never had strong support, but the lacustrine, fluvial, and residual hypotheses have been advanced by many Soviet workers.

The most widely accepted explanation of the origin of the upland silt is that it is a combination of lacustrine and alluvial deposits formed on great flood plains and marshy plains. This origin is unlikely, however, because there are no shorelines, wave-cut beaches, deltas, mudcracks, or ripple marks. Neither distinct stratification nor an appreciable amount of clay exists in the silt. Moreover, there is no definite upper boundary to the deposits, as would be expected of lacustrine deposits.

The loesslike silt has also been described as a residual deposit formed by the breakdown, by freezing and thawing, of the underlying rocks. The silt bears no chemical, mineralogic, or textural relation to the underlying strata, however, and it is too thick to represent only breakdown of rocks in place.

The widespread mantle of uniform loesslike silt is here considered to be windblown, derived from glacial outwash in braided streams and on broad plains, because: (1) it occurs as a surficial mantle; (2) it is lithologically independent of the underlying material; (3) it is stratified indistinctly or not at all, except in retransported material; (4) it is associated with sand dunes; (5) it contains fossils of land animals; (6) its sorting and texture are similar to that of loess and windblown dust from many places elsewhere in the world; (7) its grains are angular and relatively unweathered.

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INTRODUCTION

A well-sorted uniform tan loesslike silt mantles the river terraces and low rolling uplands of much of the unglaciated part of Siberia, especially in south-central Yakutia (fig. 1), where it forms a blanket a few centimeters to many meters thick. The silt of central Yakutia, referred to in the Russian literature as clay loam, loesslike loam, dusty loam, glacial loam and, rarely, as loess, has been mentioned since before the turn of the century. During the past 75 years, workers in Yakutia have been concerned with its origin. It has been classified as a fluviatile, marine, estuarine, lacustrine, residual, and eolian deposit, and a combination of these.

Throughout this report, we shall refer to the upland sediments of central Yakutia as "loess-like silt," or "upland silt," and sometimes for brevity, as "silt."

We believe that the widespread silt on the terraces and uplands is loess and was mostly deposited during periods of glacial advance by winds blowing across outwash plains and valley trains in broad valleys. The tan silt on the ridges and hill slopes interfingers with layers of gray-to-black perennially frozen silt in drainageways and small valley bottoms. This black, frozen silt has been retransported from the hill slopes by rill wash, creep, solifluction, incorporating much organic debris, including many vertebrate remains. In a few places, two or more stratigraphic units can be recognized in the silt, but as we saw relatively few good stratigraphic exposures, it has not been possible to subdivide the silt stratigraphically; consequently the silt is treated as a single unit in this discussion.

This report is in part the result of a cooperative project proposed by Péwé to the Academy of Sciences of the U.S.S.R. and the National Academy of Sciences of the U.S.A. Péwé and Journaux visited the Lena-Aldan area in 1969 while participating in the excursion of the Periglacial Commission of the International Geographical Union. Because of the striking similarity of the distribution, character, and stratigraphy of the loesslike silt exposed in central Yakutia to the perennially frozen Quaternary silt exposed in unglaciated cen-

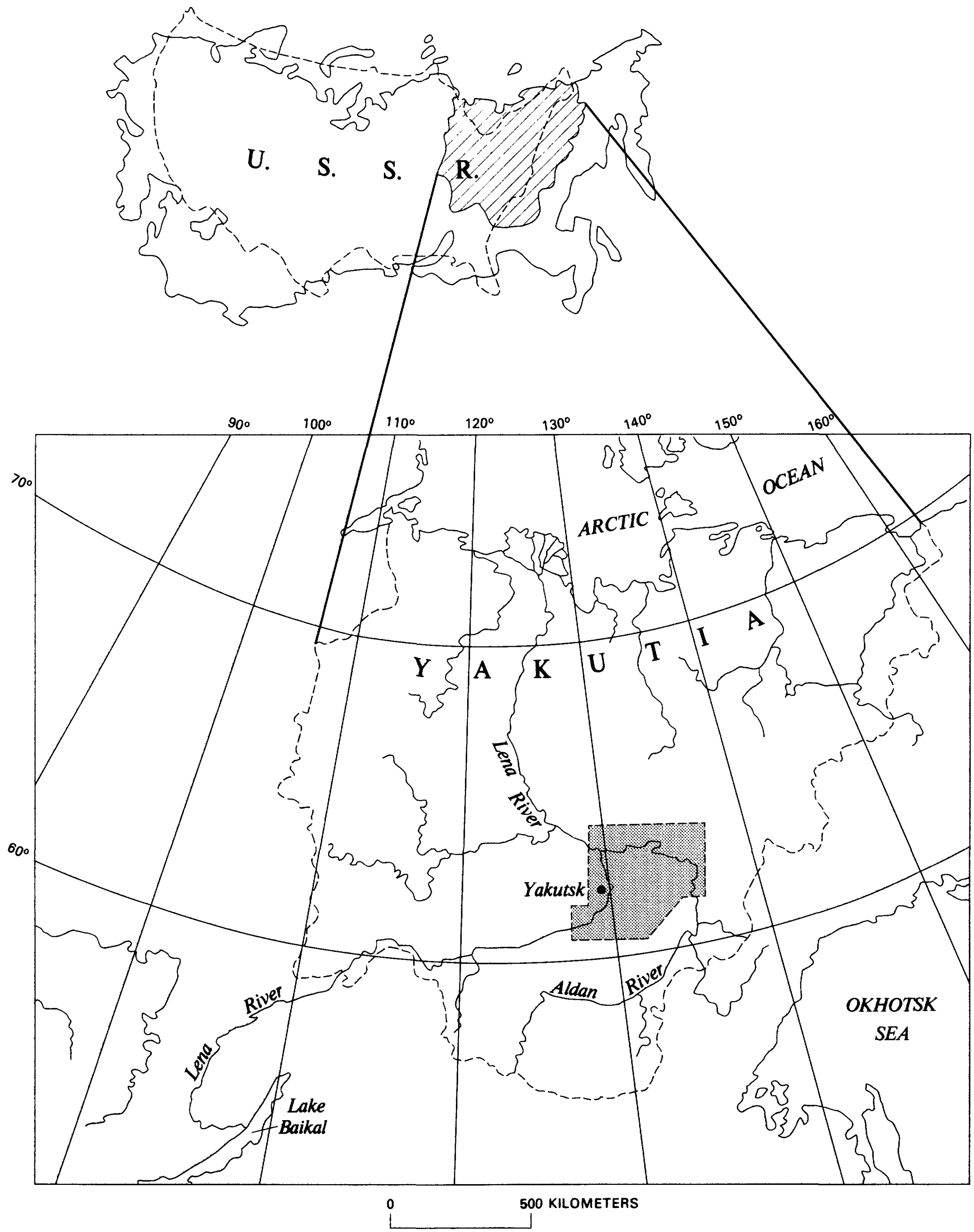


FIGURE 1.—Index map of Yakutia, U.S.S.R. Area of field research near Yakutsk (shaded area) represented in physographic diagram of figure 3.

tral Alaska (Péwé 1955, 1975a,b), Péwé returned in 1973 to make further observations and to collect silt, paleontological, and radiocarbon samples. The 1973 visit was in part made in connection with the Second International Conference on Permafrost (Péwé, 1973a,b,c). In order to understand more fully the origin, distribution, and characteristics of the silt, the exposures examined by Péwé and Journaux in 1969 were revisited and more samples collected. In addition, observations were made and samples collected west of Yakutsk and as far as 100 km east and northeast of Yakutsk. Field work was conducted along the Lena River upstream from Yakutsk for a distance of 250 km. For comparison with the Yakutian silt, loess deposits were examined in western and southwestern U.S.S.R., central Europe, New Zealand, and North America.

ACKNOWLEDGMENTS

The authors deeply appreciated the cooperation and aid of the many persons in various countries who made this study possible. P. I. Melnikov, corresponding member of the Academy of Sciences, U.S.S.R., arranged the cooperation of the Academy and offered the use of the facilities of the Permafrost Institute of the Siberian Division of the Academy in Yakutsk, of which he is Director. Felix Are and E. M. Katasonov, of the Permafrost Institute, graciously aided in many of the logistics problems in the field and vigorously discussed the origin hypotheses both in the field and in the office. Robert M. Dillon, formerly of the Building and Research Advisory Board of United States National Academy of Sciences, aided in preliminary arrangements. Péwé's visit in 1973 was in part funded by the U.S. National Academy of Sciences as chief United States delegate to the Second International Conference on Permafrost. Part of his participation in the study was funded by a grant (No. GA38598) from the National Science Foundation of the United States. Katasonov collected silt samples U and V from Churapacha. Duwayne Anderson, formerly of the U.S. National Science Foundation, kindly provided satellite imagery for the region, and the late R. J. E. Brown of the National Research Council in Canada provided some Soviet literature and translations. George Soleimani, U.S. Geological Survey, helped translate the Russian literature. Jaromir Demek, former Director of the Institute of Geography of the Czechoslovakian Academy of Sciences (C.S.S.R.), kindly had the Pleistocene mollusks identified. J. Pellerin, Deputy Director of the Centre de Geomorphologie (C.N.R.S.), Caen, France, guided the mechanical, mineralogical, and chemical analyses of the silt samples, made at the Centre de Geomorphologie under the direction of André Journaux. Radiocarbon analyses of samples collected by Péwé were made at the Smithsonian Institution Radiation Biology Laboratory under the direction of Robert Stuckenrath. James T. Bales, under the direction of Roger Slatt, formerly Professor of Geology at Arizona State University, calculated the statistical parameters of the sediment samples.

Finally, the authors appreciate the helpful suggestions of D. M. Hopkins, U.S. Geological Survey, and A. L. Washburn, former Director, Quaternary Research Center, University of Washington, Seattle, Wash., U.S.A., both of whom visited central Yakutia in 1969; Oscar J. Ferrians Jr., U.S. Geological Survey, who visited central Yakutia in 1973, 1975, and 1976; and the late Roger J. E. Brown, of the National Research Council, Ottawa, Canada, who visited central Yakutia in 1966 and 1973.

PHYSICAL SETTING

PHYSIOGRAPHY AND GENERAL GEOLOGY

Unglaciated south-central Yakutia lies almost 200 km south of the Arctic Circle in the largest Siberian republic and, with an area of 3,077,900 km^2, is the second republic in the entire U.S.S.R. The area under consideration lies in the central Yakutian lowland, at an elevation of 50–400 m (fig. 2); it is drained by the Vilyuy, Lena, Amga, and Aldan Rivers. To the south, the lowland grades into the Prelensko Plateau; to the north, it is bounded by the towering Verkhoyansk Range. The mountains, sculptured by past glaciers, reach 2,295 m above sea level; small glaciers still exist in the east end. Crescentic terminal moraines lie on the sloping outwash plain that extends from the mountains southward to the Aldan River (fig. 3).

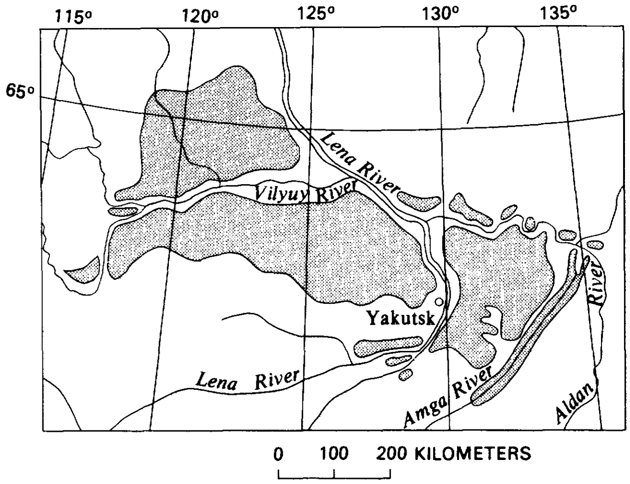


FIGURE 2.—Central Yakutian lowland (shaded area), a region of well-developed alases, thaw depressions that form in areas of thick ice-rich silt deposits. From Solov'ev (1959, fig. 1).

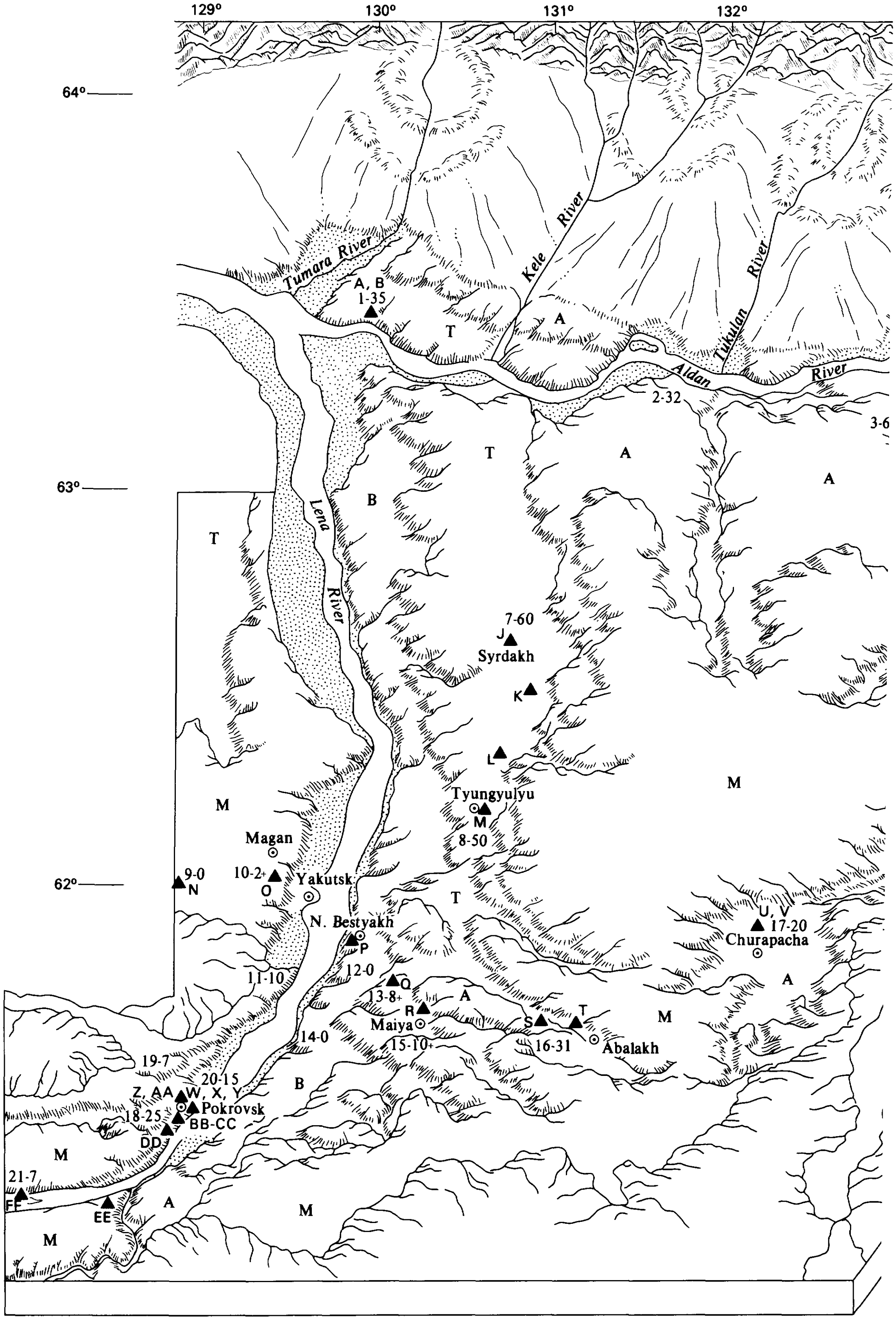
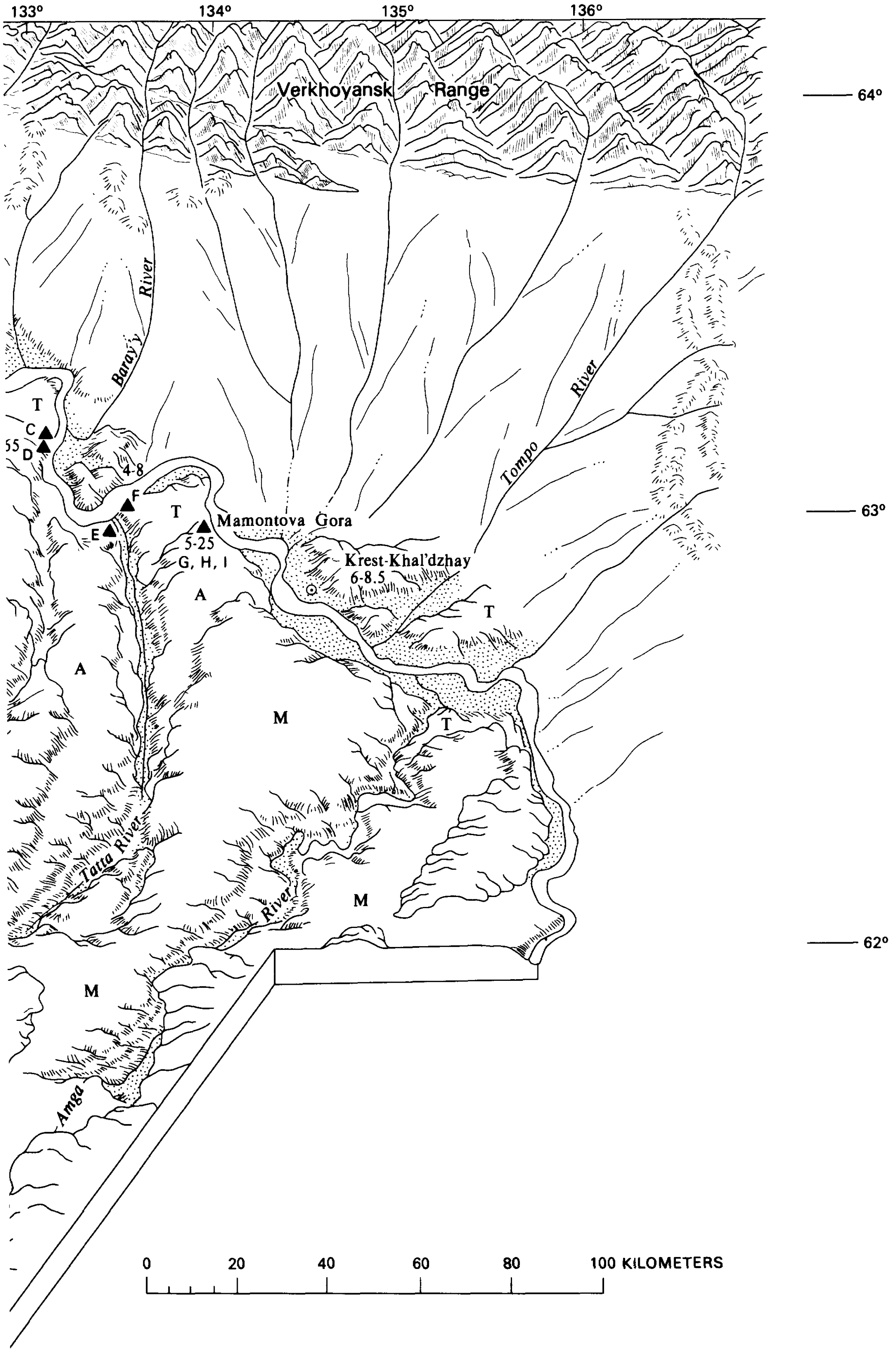


FIGURE 3.—Physiographic diagram of the region of the Lena, lower Aldan, and lower Amga Rivers, central
T., Tyungyulyu; A, Abalakh; M, Magan. Lettered triangles mark sediment sample locations (see table 1).
table 2). Basic physiographic data south of Aldan River are from Solov'ev (1959, fig. 9); north of river from



Yakutia. Fine-dotted area, major flood plain and low flood-plain terraces. Major high terraces: B, Bestayakh; First number (1–35) indicates site of thickness measurement, second number, thickness of silt in meters (see satellite photography. Drawn by Susan M. Selkirk.

The study area is bounded by the Lena, Aldan, and Amga Rivers (fig. 3). The greatest part of the area consists of four silt-covered terraces 50–300 m above the major rivers: the Bestyakh, Tyungyulyu, Abalakh, and Magan Terraces, from lowest to highest. The Emilsk Terrace, separately mapped in other reports, is here combined with the Magan Terrace, The type localities of all four terraces lie within 50 km of Yakutsk and are described in detail by Solov'ev (1959). They are underlain by Cenozoic rocks to the north, Mesozoic rocks in the south-central part of the study area, and by Paleozoic rocks at the southernmost edge. Besides these high-level terraces, four low flood-plain terraces bound the Lena and Aldan Rivers.

The Bestyakh Terrace, the lowest of the upper terraces, is the most restricted in area and extent. In the study area, it occurs on the east side (right limit) of the Lena River extending northward from the vicinity of Pokrovsk to the mouth of the Aldan River (fig. 3). It is 1–10 km wide and 55–75 m above the river and has a maximum relief of 30 m. The terrace is underlain by 60–115 m of cross-bedded homogeneous clean well-sorted sand (table 1, sample P). The surface exhibits windblown ridges 2–10 m high and small merged parabolic sand dunes. The silt cover, widespread on the higher terraces (fig. 3), is not present on this terrace nor on the modern flood-plain terraces. The scarp is cut by precipitous active gullies 20–30 m deep, some eroded by spring sapping.

The Tyungyulyu Terrace is widespread in the area but occurs mainly adjacent to the Bestyakh Terrace east of the Lena River. It is as much as 40 km wide and 65–100 m above the river; it has a maximum relief of 70 m. It is blanketed by a well-sorted silt as much as 60 m thick, and characterized by a vast complex of ice wedges and well-developed thermokarst topography This topography is characterized by a multitude of alases and steep-walled valleys. Lowering of as much as 30–50 percent of the terrace surface by melting of the ground-ice leaves interalas areas as ridges and connected smooth areas 5–10 m high.

The Abalakh Terrace occupies a large area in the central Yakutia lowland and is 115–135 m above river level. It is blanketed with a thick silt layer, in places 65 m thick. The thermokarst relief is the same as on the Tyungyulyu Terrace, but it is more dissected and has a higher density of alases.

The Magan Terrace, a gently undulating plain, covers many hundreds of square kilometers, but in some areas consists of relatively narrow remnants between drainageways (fig. 3). The terrace is 155–175 m above major rivers. Valleys 80–100 m deep penetrate the Magan Terrace. In some valleys cut into the Magan Terrace there have been formed small strips of Tyungyulyu and Abalakh Terraces with alas relief. The silt cover on the Magan Terrace is 6—15 m thick, and alas development is very poor.

The study area is underlain by the lower Aldan depression (Alekseev, 1961), an asymmetrical basin trending east with its axis along the lower Aldan River. The south flank dips gently northward, and the north flank, which crops out in the Verkhoyansk Range, is near vertical (Solov'ev, 1959; Alekseev, 1961, fig. 20; Katasonov and Solov'ev, 1969). Dolomitized Cambrian limestone crops out along the Lena River in the southern part of the area (fig. 3), where it is overlain by sandy shale and conglomerate of Late Jurassic age; and the limestone in turn is overlain by sandstones and shales of Early Cretaceous age. The axis of the downwarp contains Oligocene, Miocene, and Pliocene deposits, and early Pleistocene fossiliferous sediments (Vangengeim, 1961) exposed under the silt-covered terrace surfaces along the rivers. The stratigraphy is particularly well exposed at Mamontova Gora (Vangengeim, 1961; Giterman, 1963; Boyarskaya and Malayeva, 1967; Rosanov, 1968; Sudakova, 1969; Markov, 1973; Baranova and others, 1975; Péwé and others, 1977) on the Aldan River, 310 km upstream from its junction with the Lena River (fig. 3).

Much of central Yakutia has not been glaciated (fig. 4) (Giterman, 1963; Baranova, and others, 1968; Kind, 1972, 1975) but it was almost entirely rimmed by glacial ice in middle Pleistocene time. Glacier-clad mountains stood to the north, east, and south, and the front of the continental ice sheet was in northwest Yakutia. Glaciers probably approached to within 140 km of Yakutsk. During glacial advances, all the major rivers drained glaciated terrain and were heavily laden with sediment, filling the wide valleys with glacial outwash. Except in the Verkhoyansk Range, the extent of glaciation in Yakutia is highly controversial. Figure 4 shows one of the larger estimates of the extent of middle Pleistocene glaciation. Late Pleistocene glaciation was much less extensive, but its extent is also controversial.

CLIMATE

The central Yakutia area has an extreme continental climate characterized by a great range between summer and winter temperatures (fig. 5). The absolute minimum temperature recorded at Yakutsk is −60°C, the absolute maximum is 38°C. Oymyakon, on the northeast edge of the area, is noted as, with the exception of Antarctica, the coldest spot on Earth; −67.7°C was reliably recorded there in February 1933 (Filippovich, 1974). The mean annual number of days of freezing temperatures at Yakutsk is 205, and freezing temperatures have been reported for every month of the year (Gavrilova, 1973).

The mean annual precipitation is 246 mm (fig. 5). Thunderstorms occur during the summer, but most precipitation falls in light showers. Sixty-five percent of the annual precipitation falls between May and September.

Wind patterns in central Yakutia include a long, relatively calm winter period from September to May and a short, slightly windy summer period from June to August. A 75-year record at Yakutsk (Gavrilova, 1973) indicates that the average wind velocity in winter is about 2.2 m/s and in summer about 3.0 m/s. The mean annual wind velocity at Yakutsk is 2.4 m/s. High winds are uncommon. During the winter 49 percent of all days are calm, and during the summer, 16 percent. Cyclones move across Yakutia from west to east, and are the most common circulation process except in winter when the Siberian anticyclone spreads in a northeastern direction. Little is known about the general wind pattern between the Aldan River and the Verkhoyansk Range, but local winds may spread south from the mountains.

PERMAFROST

Central Yakutia lies in an area of widespread permafrost. Permafrost, or perennially frozen ground, is naturally occurring material that has been at a temperature of 0°C or colder continuously for 2 or more years. Permafrost is defined on the basis of temperature alone

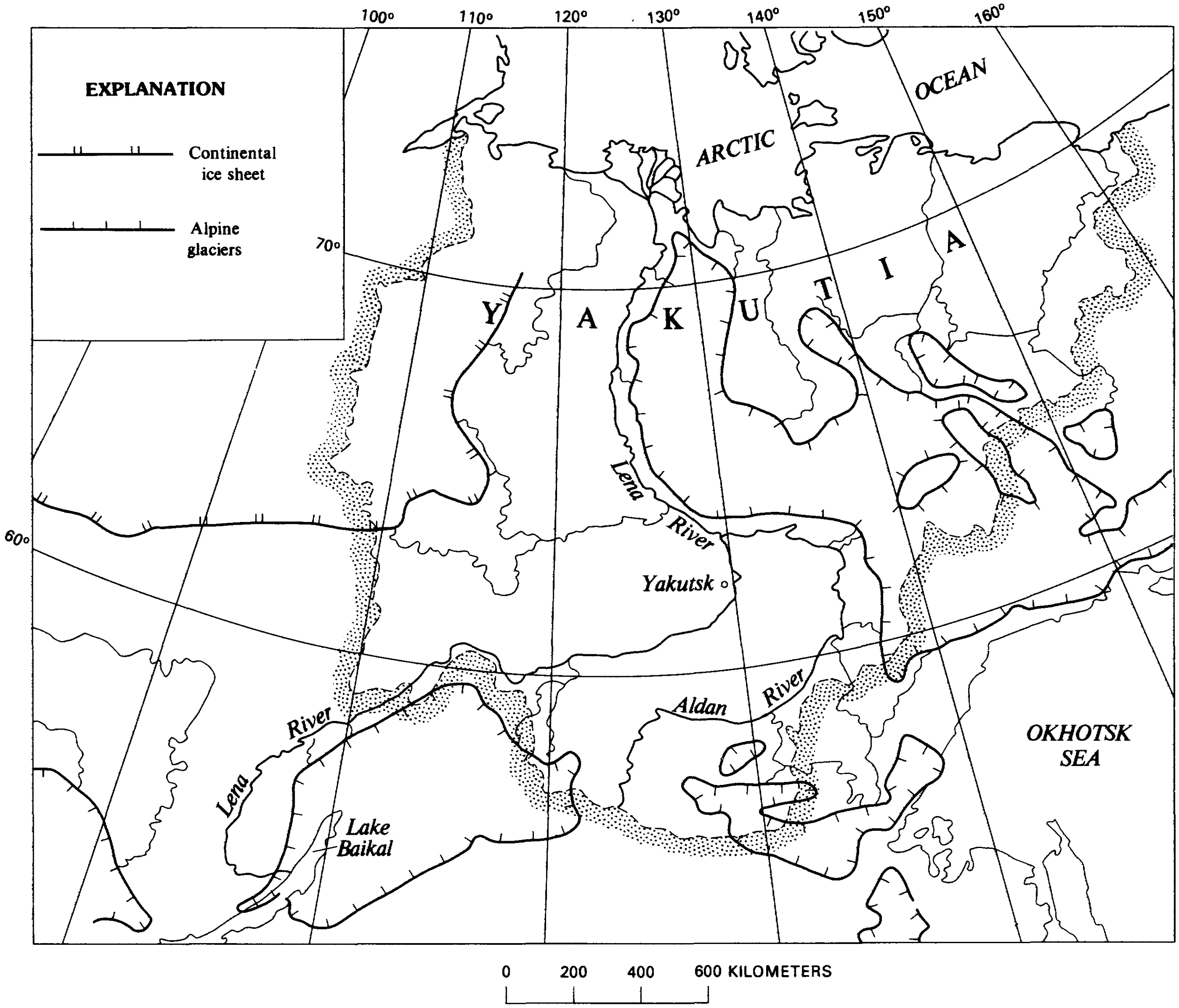


FIGURE 4.—Generalized extent of glaciers in Yakutia during middle Pleistocene time (Samarov Glaciation). Boundary of Yakutia indicated by dotted pattern. Extent of mountain glaciers from Baranova and others (1968, fig. 24); extent of continental ice sheet from Soviet Ministrov SSSR (1969, p. 72).

TABLE 1.—*Data on Quaternary sediment samples collected in central Yakutia, Siberia, U.S.S.R.*

[All samples collected by Troy L. Péwé, except where indicated]

Sediment sample (fig. 3)	Thickness site no. (fig. 3)	Lab No.	Material	Date collected	Location	Stratigraphy	Age	Analysis performed: Granulometric	Heavy mineral	Chemical	$CaCO_3$	X-ray
A	2	1315-2	Loess	7/21/73	Right limit of Aldan River, 30 km upstream from mouth of Tumara River.	1 m from top of cliff, Tyungyulyu Terrace.		X	X	X	X	----
B	3	1315-3	Sandy loess	7/21/73	Right limit of Aldan River, 30 km upstream from mouth of Tumara River.	2 m from top of cliff, Tyungyulyu Terrace.		X	----	----	X	----
C	31	841-1	Loess	7/22/69	Left limit, 244 km from mouth of Aldan River.	Silt cliff of Abalakh Terrace.	Late Quaternary.	X	X	----	----	X
D	8	1315-8	Loess	7/23/73	Left limit, 244 km from mouth of Aldan River.	Silt cliff of Abalakh Terrace.		X	X	----	X	----
E	7	1315-7	Sandy-silty river alluvium	7/23/73	Ust'Tatta Village	Flood plain alluvium 3 m above river level.	Holocene	X	X	----	X	----
F	32	841-2	Loess	7/23/69	Left limit of Aldan River 284 km from mouth.	Silt cliff of Abalakh Terrace.	Late Quaternary.	X	X	----	----	X
G	4	1315-4	Loess	7/22/73	Mamontova Gora	1 m from top of cliff	Holocene	X	X	X	X	X
H	5	1315-5	Loess	7/22/73	Mamontova Gora	7 m from top of cliff	Wisconsinan.	X	X	X	X	X
I	6	1315-6	Loess	7/22/73	Mamontova Gora	23 m from top of cliff	pre-Wisconsinan	X	X	X	X	X
J	12	1316-2	Loess	7/25/73	East side of Lake Syrdak.	1 m below surface of Tyungyulyu Terrace.		X	X	X	X	X
K	11	1316-1	Loess	7/25/73	10 km south of Syrdak Village.	Edge of alas cliff, Tyungyulyu Terrace.		X	----	----	X	----
L	10	1315-10	Clayey loess	7/25/73	10 km north of Matte Village	25 cm below surface in roadcut.		X	----	----	X	----
M	9	1315-9	Loess	7/25/73	Edge of Tyungyulyu alas at Tyungyulyu Village.	1 m below surface in thermokarst pit.		X	X	----	X	----
N	29	1317-9	Sand	8/3/73	53 km west of Yakutsk	Top of Magan Terrace, sand under turf.	Tertiary	X	X	----	X	----
O	1	1315-1	Sandy loess	7/19/73	3 km west of Yakutsk	3 km from bluff of Magan Terrace.		X	X	X	X	X
P	34	841-4	Eolian sand	8/3/69	2 km east of Bestayakh Village.	Low sand dune on Bestayakh Terrace.	Holocene(?)	X	X	----	----	X
Q	13	1316-3	Sandy loess	7/27/73	9 km east of Bestayakh Village.	Edge of alas on edge of Tyungyulyu Terrace.		X				
R	33	841-3	Loess	8/3/69	0.6 km south of Maiya Village.	Edge of alas	Late Quaternary.	X	X	----	----	X
S	14	1316-4	Loess	7/27/73	1 km west of Abalakh Lake	Abalakh Terrace, 16 cm from surface.		X	X	X	X	X

T	15	1316-5	Loess	7/27/73	Edge of Abalakh Lake, Tyungyulyu Terrace.	1-m depth from west side of lake.		X	X	----	X	----
U	T2-1	1399-4	Loess	1973[1]	Churapacha			X	----	----	----	----
V	T2-3	1399-5	Loess	1973[1]	Churapacha			X	----	----	----	----
W	16	1316-6	Loess	7/29/73	Pokrovsk, 70 km up Lena from Yakutsk.	10 m above Lena River at river bank.		X	X	----	X	----
X	17	1316-7	Loess	7/30/73	Pokrovsk, 70 km up Lena from Yakutsk.	1 km west of river, 45 cm deep, Tyungyulyu Terrace.		X	X	X	X	----
Y	18	1316-8	Loess	7/30/73	Pokrovsk, 70 km up Lena from Yakutsk	5 km west of river, 30 cm deep, Tyungyulyu Terrace.		X	X	----	X	----
Z	19	1316-9	Loess	7/30/73	Pokrovsk, 70 km up Lena from Yakutsk.	Abalakh Terrace, 30 cm deep, 6 km west of river.		X	X	----	X	----
AA	20	1316-10	Alluvial (2) sand	7/30/73	7 km west of Pokrovsk.	1.5-m depth, lens of sand.		X	X	----	X	----
BB	22	1317-2	Sandy loess	7/31/73	Left limit of Lena River 12 km upstream from Pokrovsk.	Overlying fractured limestone at base of loess section 3.		X	X	X	X	X
CC	23	1317-3	Loess	7/31/73	Left limit of Lena River 12 km upstream from Pokrovsk.	1 m above BB		X	X	X	X	X
DD	27	1317-7	Sandy loess	8/2/73	Left limit of Lena River 12 km upstream from Pokrovsk.	1.7 m below surface at contact with underlying limestone.		X	X	X	X	X
EE	24	1317-4	Eolian sand	7/31/73	Right limit of Lena River 40 km upstream from Pokrovsk.	Top of cliff-head dune derived from Bestyakh Terrace.		X	X	----	X	----
FF	26	1317-6	Loess	8/1/73	Ilanskjo Village, 70 km upstream from Pokrovsk.	5 m below top of cliff in tributary.	Late Quaternary	X	X	X	X	X
GG	25	1317-5	Silt from limestone	8/1/73	250 km on right limit of Lena River south of Yakutsk.	147 m above river on limestone cliff.		X	X	X	X	X

[1]Collected by E. M. Katasonov.

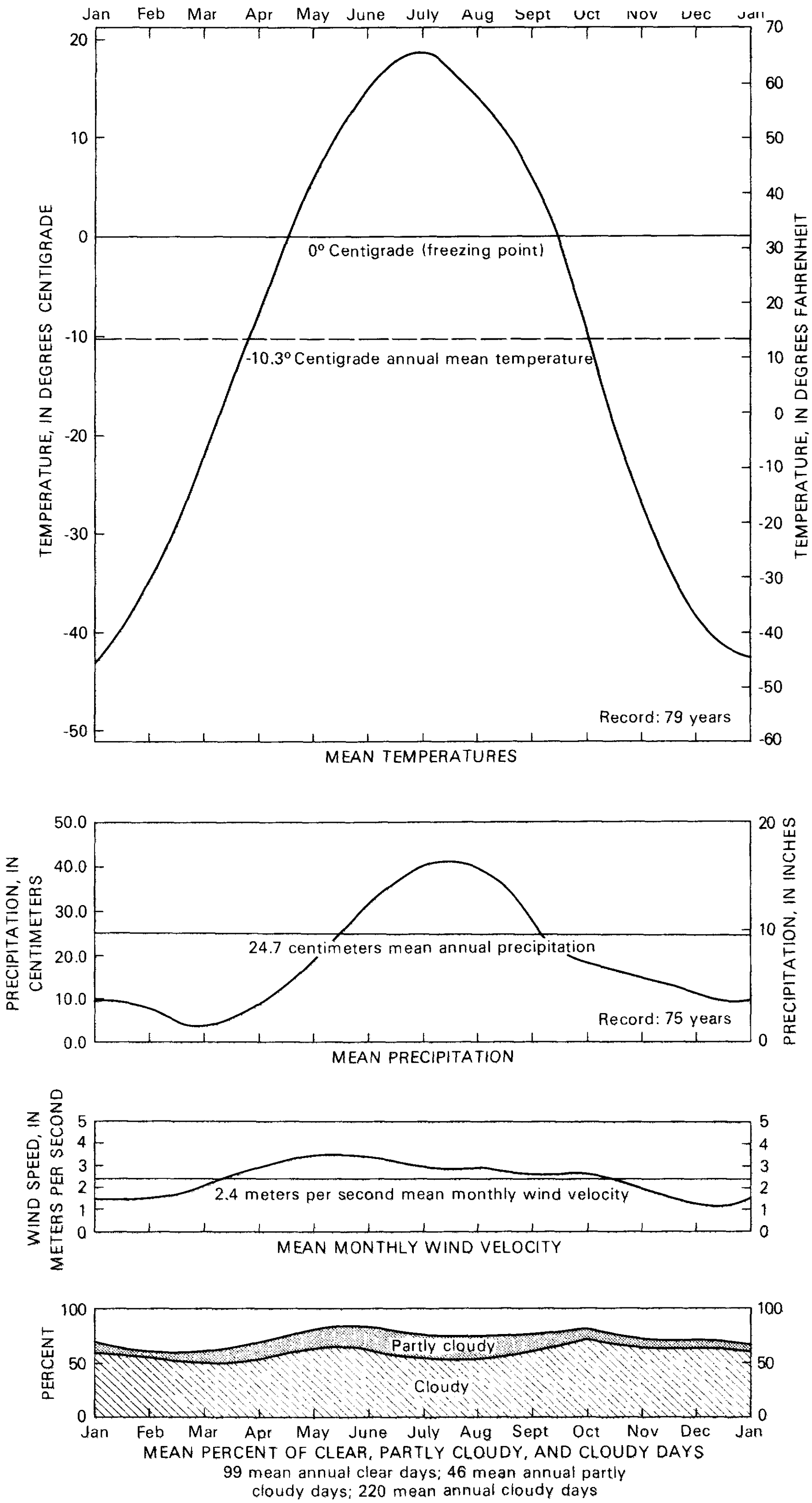


Figure 5.—Climatic data for Yakutsk, Yakutia. From Gavrilova (1973).

notwithstanding the type of sediment, rock, or the ice content. Most permafrost is consolidated by ice. Permafrost occurs in about 50 percent of the U.S.S.R. and is reported to be 1,600 m thick in northern Siberia. The frozen ground thins progressively to the south and can be differentiated into two broad zones: the continuous and the discontinuous. In the continuous zone permafrost is present almost everywhere except under lakes and rivers that do not freeze to the bottom. The discontinous zone includes permafrost-free areas that increase progressively in size and number from the north to the south.

The temperature of permafrost is measured at the level of zero annual amplitude, that is, at a depth of about 10 or 15 m, where the seasonal temperature change in the ground is hardly detectable. The temperature of permafrost at the depth of minimum annual seasonal change varies from about 0°C at the south limit of permafrost to −10°C in northern Alaska and −13°C in northeastern Siberia. Its thickness also increases northward.

Melnikov (1966) has shown that the thickness of permafrost in Yakutia ranges from near 100 m in the southern part to more than 900 m in the north. The temperature of the frozen ground at the depth of zero annual temperature change ranges from about −1°C in the south to −12°C in the north. The general thickness of permafrost in central Yakutia is about 300–350 m.

The ice content is probably the most important feature of permafrost affecting human activity in the north. Almost as important is the evidence it provides concerning past climates. Ice content ranges from ice in the pores between the grains to small ice segregations to large massive bodies. Various classifications have been proposed to describe the different sizes, shapes, and distributions of ground ice (Shumskii and others, 1955; Péwé, 1966; Mackay, 1972).

The most conspicuous and controversial type of ice in the permafrost is the large ice wedge or mass, characterized by parallel or subparallel foliated structures. Most foliated ice masses occur as wedge-shaped vertical, or inclined sheets or dikes 1-cm to 3-m wide and 1- to 10-m high when seen in transverse cross sections (fig. 6). Some masses seen on the face of frozen cliffs may appear as horizontal bodies in a few centimeters to 3-m thick and 0.5–15 m long. Their true shape can be seen only in three dimensions. Ice wedges are part of a polygonal network of ice enclosing polygons or cells of frozen ground 3–30 m or more in diameter. They grow in almost any kind of frozen sediment, including fractured bedrock, but seem to grow to their largest size, both vertically and horizontally, and most commonly in areas of widespread thick loess deposits.

They are common in the ice-rich silt, referred to as "Edoma" by Tomirdiaro (1975), that covers much of the Arctic, from northeast Siberia to central Alaska and the Yukon. They are abundant and well developed in central Yakutia; gigantic wedges are exposed along the Aldan, Lena, and Yana Rivers (Toll, 1895; Popov, 1955, 1969; Rusanov, 1968; Washburn, 1973, 1980; Péwé and others, 1977).

GEOMORPHOLOGY

Although the silt-covered terraces are generally flat or gently rolling, the permafrost and the nature of the silt result in a number of distinctive surface features.

Wherever large ground-ice masses are present in permafrost, thawing caused by a disturbance of insulating vegetation, for example, or by general climatic change, can produce thermokarst topography. Thermokarst is an uneven topography of mounds, sink holes, tunnels, caverns, and short ravines. A thermokarst feature that is especially typical of central Yakutia is the alas (spelling after Fyodorov, 1974) (Solov'ev, 1959, 1973; Czudek and Demek, 1970; Katasonov, 1963, 1979). Alases are broad, steep-sided depressions that form as small depressions coalesce and sediment is washed into the bottom. The depression thus has fairly steep walls and a grass-covered flat bottom. They are 3–40 m deep and as much as 0.1–15 km in diameter. They tend to be round or oval and many contain small lakes (figs. 7, 8). These areas, where ground ice has almost completely disappeared, are important to the agriculture of the area (Solev'ev, 1959, 1973; Shilo, 1978). Where the thawed sediments refreeze, closed-system pingos are common; conical ice-cored hills as high as 30 m formed by the pressure of freezing water (fig. 9). On the Tyungyulyu and Abalakh Terraces, as much as 50 percent of the Pleistocene surface has been modified by alases, many of which formed during the past 7,000 years, some as a result of human activity (Are, 1973).

Many spectacular steep-walled gullies cut the lip of silt terraces on the left limit of the lower Aldan River. Here the abundant water created by the melting of ice wedges cuts the easily erodable silt into gullies, leaving interfluve areas as pyramid-shaped remnants. Such remnants, where mainly the result of the thawing of ice wedges, are called baydjarakhs (fig. 10). The competency that allows such features to stand also permits the silt to form steep cliffs and gullies elsewhere where eroded by water. Gullies form where runoff is concentrated, as below culverts, in ditches, or where vegetation has been disturbed, for example, as by cultivation on a slope. The steep walls of many alases are gullied, and many of the gullies on the left limit of the Aldan River are spectacular. Like the cliffs in loess in China, the Mississippi valley, central Alaska, France, and elsewhere, the silt cliffs in central Yakutia apparently

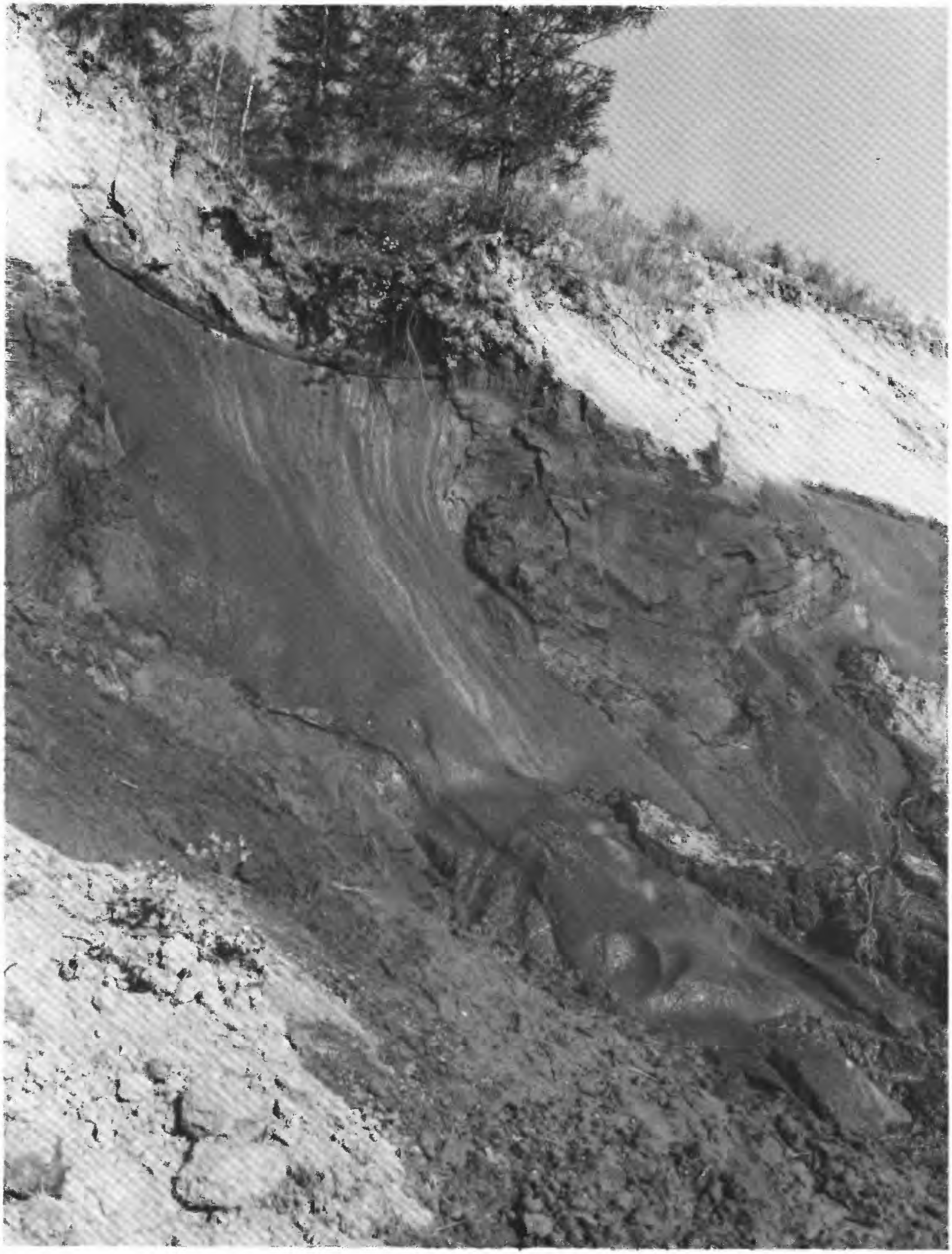


FIGURE 6.—Ice wedge in silt of Tyungyulyu Terrace at Syrdakh Lake, 70 km northeast of Yakutsk. Photograph 3452 by T. L. Péwé, July 25, 1973.

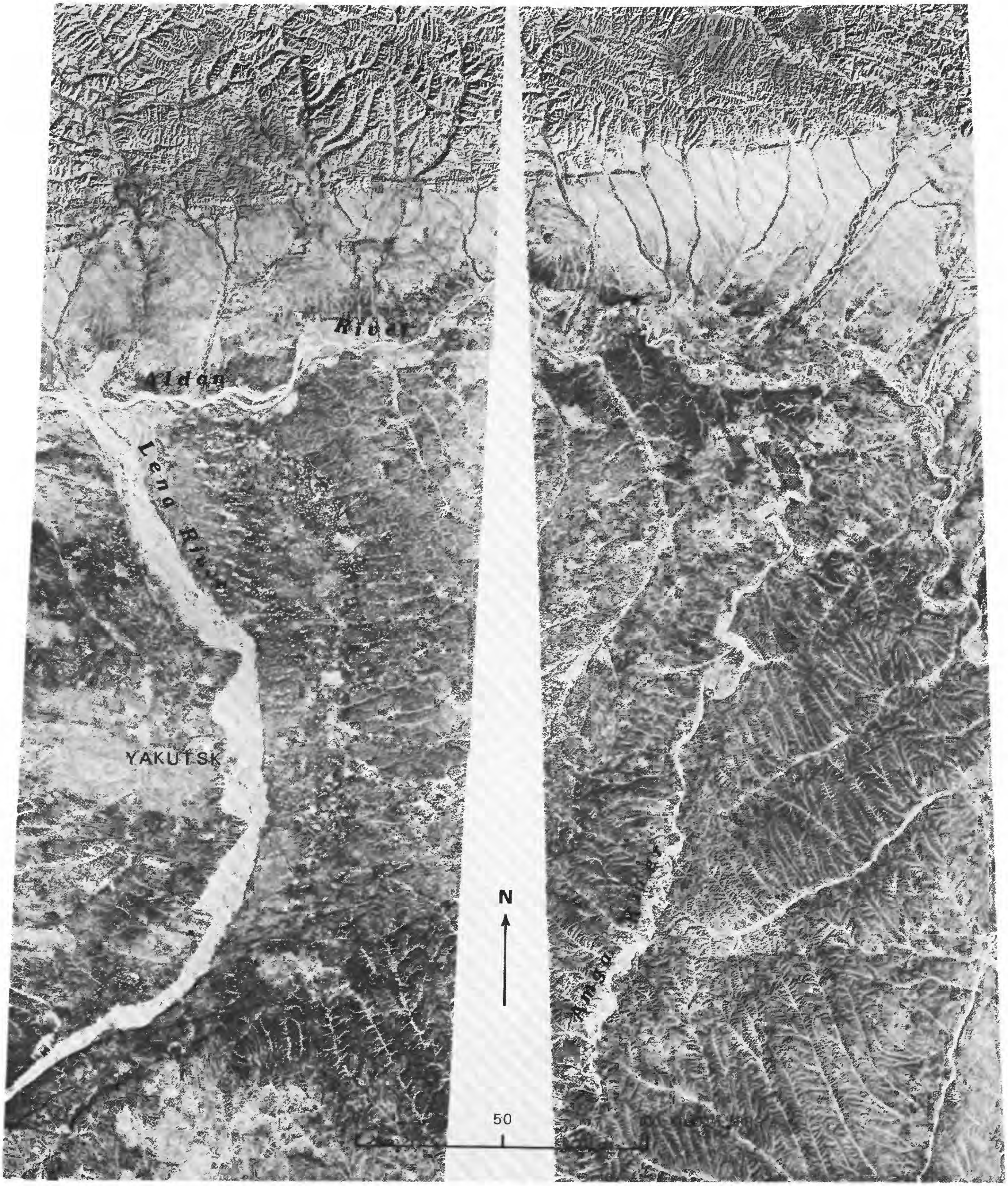


FIGURE 7.—Adjacent satellite images of the Lena-Amga area, south-central Yakutia. See figure 3. Courtesy D. M. Anderson and Lawrence Gato, U.S. Army, Cold Regions Research Engineering Laboratory. Prepared from ERTS-1 imagery, courtesy NASA.

FIGURE 8.—Alas (or thaw basin) of Tyungyulyu in loess on Tyungyulyu Terrace, 50 km northeast of Yakutsk. Photograph 3448 by T. L. Péwé, July 25, 1973.

FIGURE 9.—Eastern half of Olong-Erien alas with large closed-system pingo in loess, 75 km east of Yakutsk on Abalakh Terrace. Photograph 3455 by T. L. Péwé, July 27, 1973.

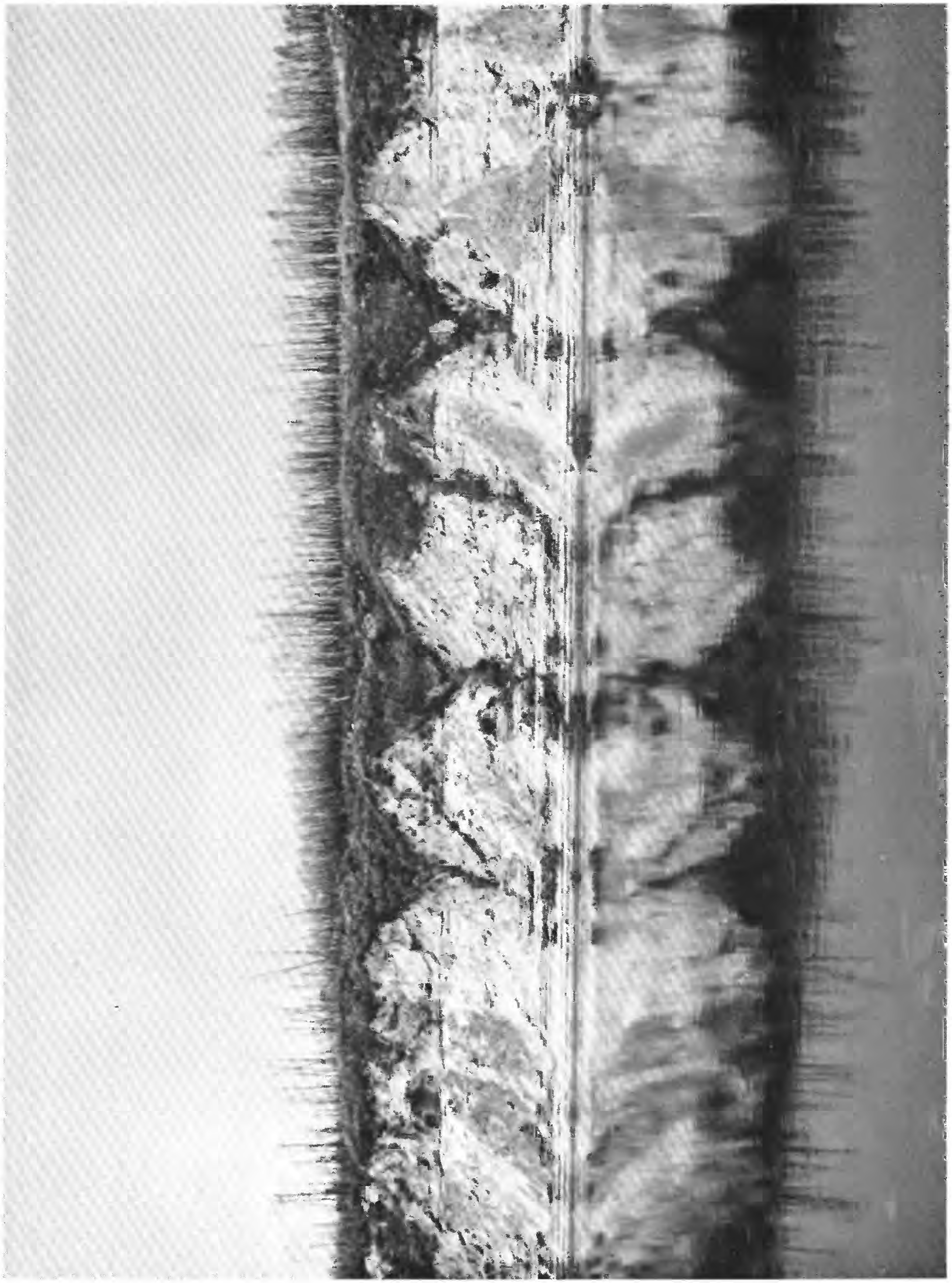


FIGURE 10.—Baydjarakhs, pyramid-shaped remnants resulting from thawing of ice wedges, left bank Aldan River, 224 km above junction with Lena River. From Washburn (1973, fig. 10.2, p. 234.

stand for many years. Along the lower Aldan River the cliffs are as much as 25 m high. The stability of these cliffs may be due to the angularity of the grains and the strengthening effects of concretionary rods and tubes.

DISTRIBUTION AND THICKNESS OF UPLAND SILT

The silt is thickest near the major rivers draining glaciated areas, but absent on the flood plains and low flood plain terraces. It is especially thick along the south side of the Aldan River where it blankets all the high terraces and the tops of ridges and hills. The blanketing distribution is also recorded in the central and eastern part of the Vilyuy River basin (Alekseev, 1970) (fig. 2). Rusanov (1968, fig. 5) and Sudakova (1969, fig. 11) describe the thick cap of silt on the terraces on the left limit of the lower Aldan (fig. 11). Along the Lena River, silt is 10–25 m thick on the edge of the west side of the valley but thins rapidly to a featheredge west of Yakutsk (fig. 3). On the Tyungyulyu Terrace it reaches a maximum thickness of 60 m near Syrdakh in the general region between the junction of the Aldan and Lena Rivers (table 2). On the edge of the Tyungyulyu Terrace adjacent to the the Bestyakh Terrace the silt is very thin, but it rapidly thickens eastward (Solov'ev, 1973, p. 34) and northward toward Syrdakh (Are, 1973). All thicknesses of loess reported from the river bluffs and inland toward Tyungyulyu and Maiya are at elevations no higher than 200 m above the level of the rivers. The silt is thin and locally absent on the Magan Terrace.

The silt is only a few meters thick on glacial and glaciofluvial deposits (fig. 3) on the north (right) side of the Aldan River (Vangengeim, 1961; Katasonov and Solov'ev, 1969). Just southwest of the study area (fig. 3), on the steep limestone cliffs of the "Pillars of the Lena" (fig. 12), the loess is thin to absent 200 m or more above the Lena River, but on the north side (left limit) of the river it is 7–25 m thick on the terraces (fig. 13), which are only 30–40 m above the river. In general, silt is thickest in the bottoms of small valleys and on lower slopes and thinner on the highlands, especially on the Magan Terrace. Are (1973, p. 16–20) describes 60 m of silt at Syrdakh (fig. 3), but he does not state if this thickness is in a small valley or on the general terrace level.

Hilltops, where the original silt thickness has not been supplemented by slopewash, are probably the only place where total original thickness can be approximated, modified only by the amount removed by erosion. Some scarps of the terraces along the Lena River and almost all scarps along the south side of the Aldan River are capped with 10–35 m of silt. This does not represent the original thickness of the silt as the upper part has been washed away (Sudakova, 1969).

In general, it appears from exposures west of Pokrovsk (figs. 3, 14) that the silt is thicker on the Abalakh Terrace than on the Tyungyulyu Terrace. Solov'ev (1959, p. 43) states that the Abalakh Terrace is covered with "limnitic-alluvial clay," 60 m thick, the top part pierced with ice veins. Alases, which form best in thick silt, are well developed on both the Tyungyulyu and Abalakh Terraces.

Detailed measurements of loess thickness over a large area, similar to those made in Illinois by Smith (1942), in Iowa by Davidson and Handy (1952) and Ruhe (1969), and in parts of Alaska by Péwé (1955; Péwé and Holmes, 1964) have not yet been made in central Yakutia. As seen from the air, however, the loess forms a widespread cover, evident in the well-developed dendritic drainage patterns on the terraces (fig. 7).

The thickness reported here (table 2) include measurements from exposures and bore holes. Although silt has plainly washed into depressions in some localities measured, no coarse sediment was observed, so the measurements may give a reliable estimate of the total amount present.

The thick deposits on the south side (left limit) of the Aldan River face the enormous apron of glaciofluvial

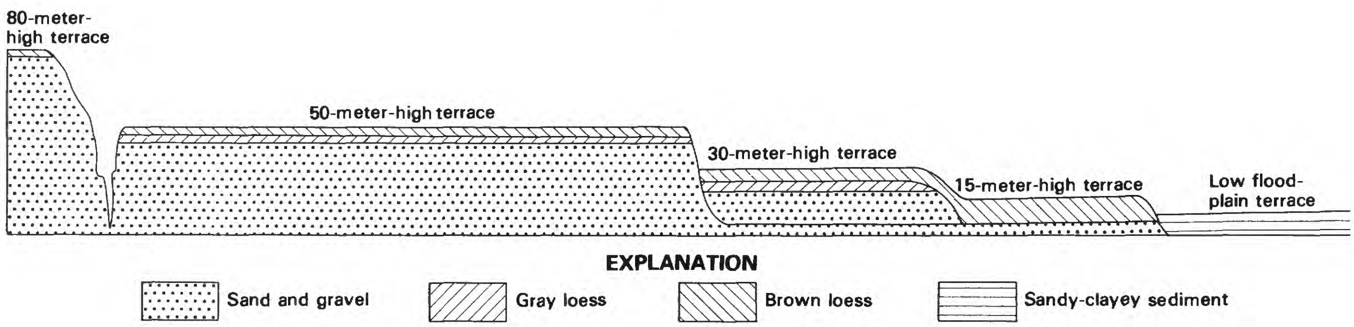


FIGURE 11.—Loess-capped sand terraces near Mamontova Gora along the Aldan River, Yakutia. Slightly modified from Rusanov (1968, fig. 5).

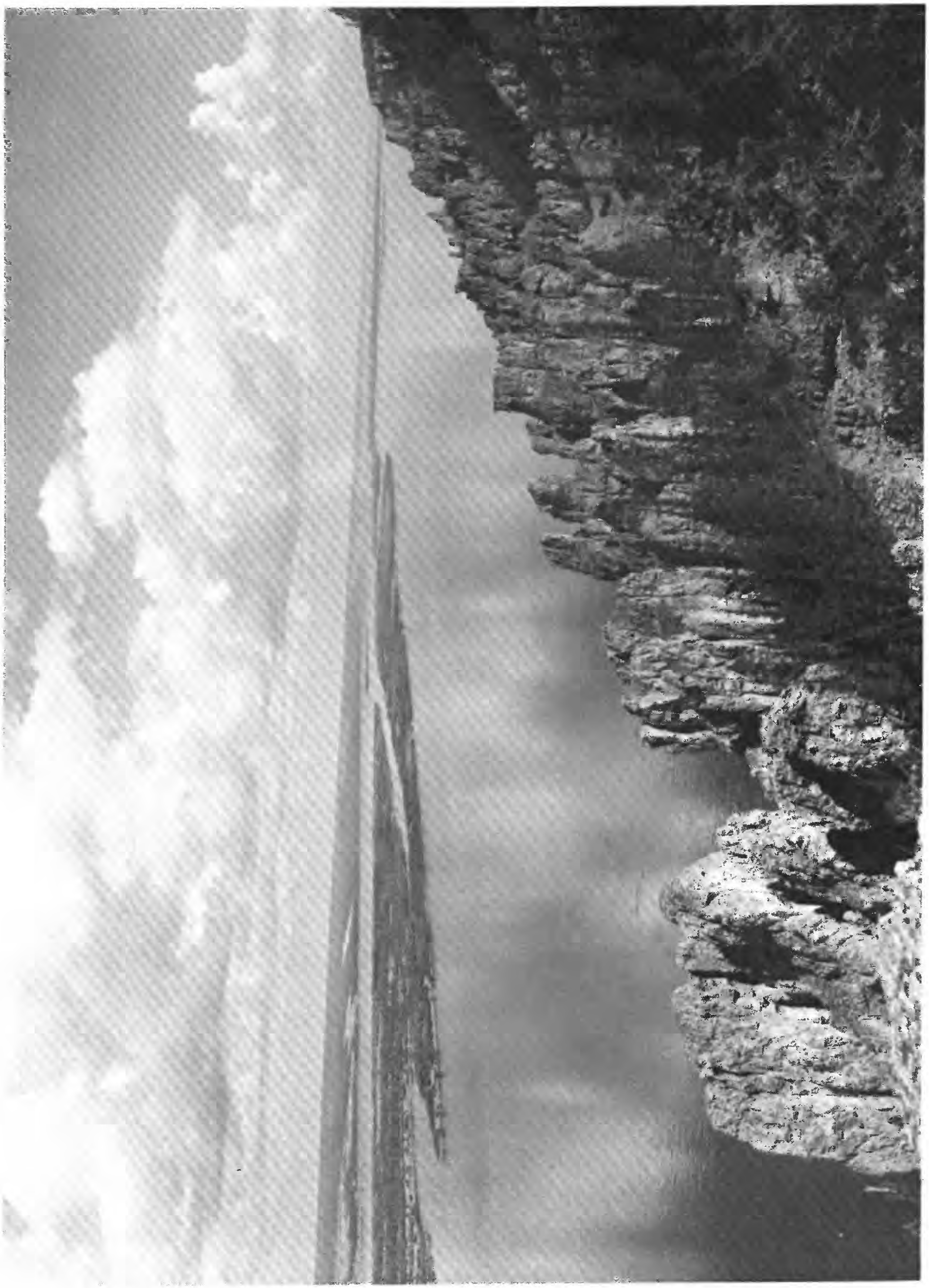


FIGURE 12.—Lena River valley from atop "Pillars of the Lena," Cambrian dolomitized limestone, 255 km upstream from Yakutsk. Loess-covered terrace on left limit in distance. Photograph 3465 by T. L. Péwé, August 1, 1973. (Reproduced by the courtesy of *Zeitschrift für Gletscherkunde und Glazial-geologie*.)

TABLE 2.—*Thickness of silt in central Yakutia, Siberia, U.S.S.R.*

Thickness site no. (fig. 3)	Thickness (m)	Location	Source	Sediment sample (fig.3)
1 --	30–35	Chuysakaya Mountain, right limit of the Aldan River, 30 km upstream from mouth of Tumara River.	Katsanov and Solov'ev (1969, p. 21) Katasonov and Ivanov (1973, p. 18).	A,B
2 --	25–32	Tettigi, left limit of the Aldan River, 130 km from mouth.	Katasonov and Solov'ev (1969, p. 22).	
3 --	25–30 40–65	Rossypnoy Perekat, left limit of the Aldan River, 244 km from mouth.	Katasonov and Solov'ev (1969, p. 22) Katasonov and Ivanov (1973, p. 24).	C
4 --	5–8	285 km from the mouth on the right limit of the Aldan River, overlies glaciofluvial material.	Katasonov and Solov'ev (1969, p. 23).	
5 --	25	310 km from the mouth on the left limit of the Aldan River at Mamontova Gora.	Péwé and others (1977).	G,H,I
6 --	7–8.5	Krest Khal'dzhay, right limit of the Aldan River, 360 km from mouth.	Katasonov and Solov'ev (1969, p. 27) Vangengiem (1961, fig. 20).	
7 --	60	Syrdakh.	Are (1973, p. 16, 20).	J
8 --	50	Tyungyulyu.	Are (1973, p. 12).	M
9 --	.0	53 km west of Yakutsk.	Péwé, 1973 field data.	N
10 --	2+	Bluff west of Yakutsk, 0.5 km from the edge.	Péwé, 1973 field data.	O
11 --	5–101	Tabaga Cape, left limit of Lena River, 30 km south of Yakutsk.	Katasonov and Solov'ev (1969, p. 12).	
12 --	.0	On Bestyakh terrace 2 km south of N. Bestyakh Village.	Péwé, 1969 field data.	P
13 --	8+	At alas, Bestyakh-Maiya Road, edge of Tyungyulu Terrace.	Péwé, 1973 field data.	D
14 --	.0	On Bestyakh Terrace 25 km south of N. Bestyakh Village.	Péwé, 1969 field data.	
15 --	10+	7 km southeast of Maiya Village.	Katasonov and Solov'ev (1969, p. 41).	
16 --	31	Abalakh Terrace near Abalakh.	Katasonov and Solov'ev (1969, p. 43).	
17 --	20	Churapacha.	Solov'ev (1973, p. 30).	
18 --	25	On the Abalakh Terrace, 6 km west of Pokrovsk Village.	E. M. Katasonov (oral commun, 1973).	Z
19 --	7	12 km upstream from Pokrovsk on the left limit of the Lena River.	Péwé, 1973 field data.	BB, CC
20 --	10–15	On the Tyungyulyu Terrace, 1–5 km west of Pokrovsk.	E. M. Katasonov (oral commun, 1973).	X, Y
21 --	7	Ilankjo Village, left limit of the Lena River, 70 km upstream from Pokrovsk.	Péwé, 1973 field data.	FF

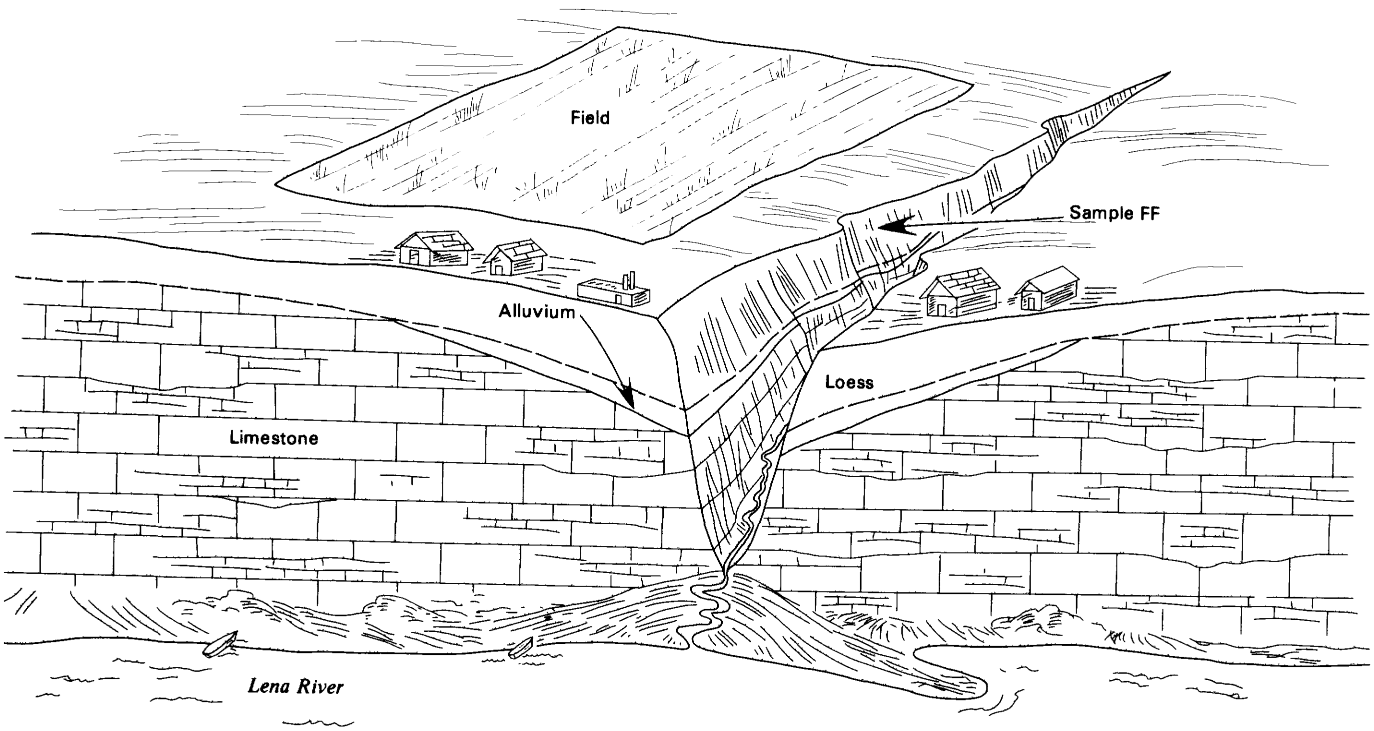


FIGURE 13.—Loess-covered terrace of Ilanskjo Village on Cambrian dolomitic limestone, 70 km upstream from Pokrovsk on left limit of Lena River. See figure 3. Loess is 7 m thick at gulley.

terrain and glacial moraines emanating from the Verkhoyansk Range to the north (fig. 3). Such a distribution is very similar to distribution in central Alaska where thin loess is present on the apron of glaciofluvial debris emanating from the towering Alaskan Range and terminating at the Yukon-Tanana Upland to the north mantled by loess of great thickness (Péwé, 1955, 1968).

Although loess thicknesses of 10–35 m are reported from northern Yakutia (Tomirdiaro and others, 1974), the thickest deposits in the Republic appear to be along the Lena and Aldan Rivers in central Yakutia. This relation, too, is similar to the distribution of loess in central Alaska where loess as much as 60–100 m thick occurs on the north side of the Tanana River near Fairbanks (Péwé, 1955, 1968; 1982), the thickest known loess deposits in the State.

COLOR AND TEXTURE

The unfrozen upland silt is commonly tan, although grayish-tan silt is not rare; when wet or frozen, it is brown to black. In many localities, the frozen silt is gray to black and has thin dark carbonaceous layers and iron-stained bands and mottling.

As an aid to understanding the mechanical composition of the upland silt, analyses were completed on 27 samples; analyses were also done on several samples of river silt and eolian and fluvial sand (table 1). The mechanical analyses (granulometric analyses) were made at the Centre de Geomorphologie in Caen, France, by sedimentation in water. Grains smaller than 20 μm were separated by sieving. For comparison, silt samples from other countries were analyzed in the same laboratory by the same method: windblown dust from Tempe, Arizona, and loess collected by Péwé from Alaska, New Zealand, and Czechoslovakia, and from China (near Peking) collected by R. J. E. Brown (table 3).

The silt examined is well sorted, especially on highlands away from river flood plains and sand terraces and from low areas where silt has been retransported short distances. On the high edges of major alases, as, for example, near Maiya or Syrdakh (fig. 3) (samples R, J and K; table 1), mechanical analyses (fig. 15) reveal that the sediments are 70–80 percent silt, 1–15 percent sand, and about 15 percent clay[2]. Because the clay content is low, the material has little plasticity.

In general, the mechanical analyses of upland silt throughout the area show that the mechanical composition and texture of the tan silt is remarkably uniform (figs. 16, 17, 18) (table 3). The range of texture of the 27 samples is shown by the shaded envelope in figure 16, the average texture is sand 17 percent, silt 70 percent, and clay 13 percent. Solov'ev (1959) states that on the Abalakh Terrace near Churapacha, the upper clayey loam is 70–90 percent silt and is unbedded. Tomirdiaro (1975b) states that this uniform texture exists from the Aldan River to the north coast and even to the Novosibirsk Archipelago. Some samples near the sandy Magan or Bestyakh Terraces may be as much as 40 percent very fine sand (fig. 19, samples Q and O) and some of the silt adjacent to the Aldan and Lena River flood plains may be 20–25 percent fine sand (fig. 19, BB,

[2]In this report the U.S. Department of Agriculture classification is used: very fine sand, 0.10–0.05 mm; silt, 0.05–0.005 mm; clay, 0.005–0.002 mm.

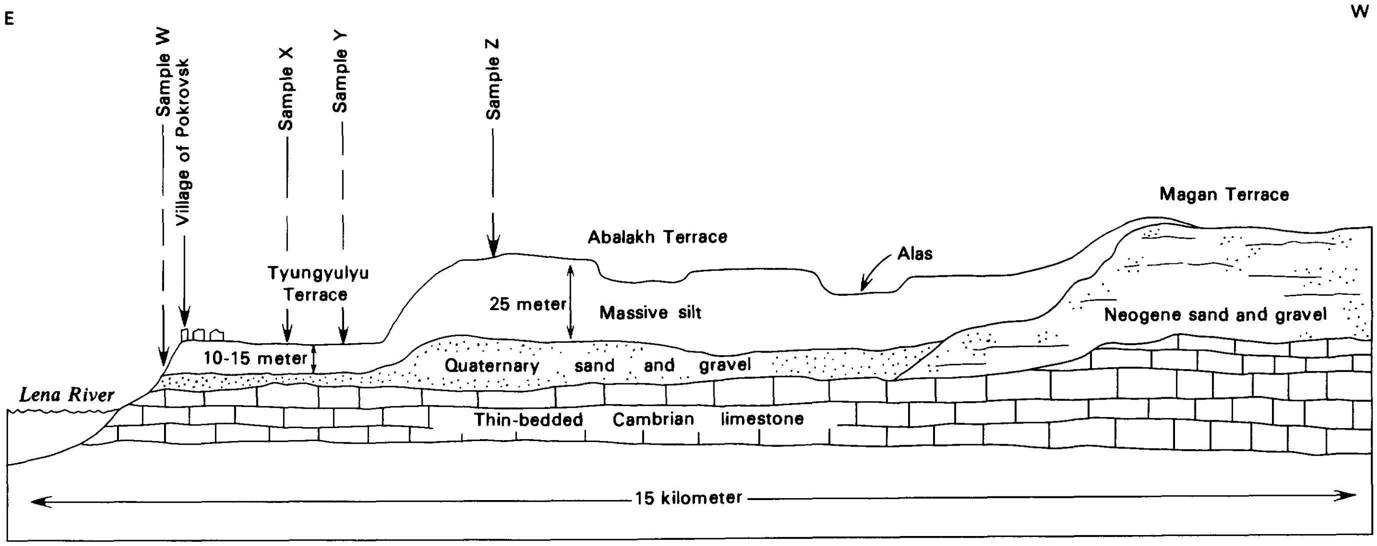


FIGURE 14.—Upland silt mantling terraces west of Pokrovsk, showing location of silt samples. Vertical exaggeration 150×. Stratigraphic relations and silt thicknesses from E. M. Katasonov (oral commun., July 30, 1973).

TABLE 3. —*Mechanical properties of sand and loesslike silt from central Yakutia and loess and ash from other parts of the world*

[Sedimentological terms from Folk (1974). Compiled by J. Bales. See Table 1 and cumulative-frequency curves (figs. 15–21, 23, 26–29)]

Sediment sample (fig. 3)	Material	Graphic mean (Mz) ϕ	Median (Md) ϕ	Inclusive graphic standard deviation (sorting) (σI) ϕ	Inclusive graphic skewness (S_{KI})	Graphic kurtosis (K_G)
A	Loess	6.20	5.44	2.33	0.58	1.43
B	Sandy loess.	4.78	4.57	1.60	.50	2.49
C	Loess	6.58	5.57	2.58	.65	1.42
D	Loess	6.14	5.89	1.97	.36	1.47
E	Sand-silty river alluvium	4.39	3.78	1.75	.48	1.05
F	Loess	6.71	5.80	2.44	.61	1.12
G	Loess	7.47	6.70	2.67	.42	1.08
H	Loess	7.43	6.75	2.77	.39	1.07
I	Loess	7.14	6.88	2.14	.27	1.06
J	Loess	5.80	5.27	2.15	.49	1.41
K	Loess	5.58	5.27	1.87	.43	1.86
L	Clayey loess	6.90	5.80	3.02	.53	.97
M	Loess	6.27	5.72	2.54	.40	1.19
N	Sand	1.93	1.84	.69	.29	1.05
O	Sandy loess	4.94	4.64	3.24	.23	1.02
P	Eolian sand	2.98	2.84	.55	.43	.89
Q	Sandy loess	5.03	4.18	2.99	.51	1.90
R	Loess	6.27	5.11	2.45	.84	1.96
S	Loess	6.90	5.80	2.97	.48	1.05
T	Loess	6.64	5.72	2.47	.58	1.15
U	Loess	7.53	6.27	3.20	.59	1.08
V	Loess	7.33	6.38	2.74	.52	1.01
W	Loess	6.27	5.44	2.69	.52	1.44
X	Loess	7.21	5.64	3.28	.70	1.11
Y	Loess	7.05	5.8	2.99	.54	.93
Z	Loess	7.19	6.06	6.33	.63	3.24
AA	Alluvial sand	2.16	2.15	.59	−.11	1.51
BB	Sandy loess	7.59	5.51	4.68	.58	1.15
CC	Loess	8.43	6.27	4.25	.63	.84
DD	Sandy loess	5.94	5.01	3.10	.43	1.34
EE	Eolian sand	.83	.71	.57	.36	1.17
FF	Loess	7.41	5.89	3.36	.64	1.01
GG	Silt from limestone	5.63	5.21	1.40	.45	1.33
Tomi	Loess	5.45	5.44	1.70	.23	3.83
Dust, German		5.42	5.50	.95	.17	1.02
Volcanic Ash, Fairbanks		6.24	6.15	1.28	.026	1.23
Dust, Kansas		6.84	5.90	2.41	.44	1.26
Dust, Arizona		7.80	6.65	2.87	.46	1.47
Loess, New Zealand		8.10	7.80	2.83	.10	.92
Loess, Czechoslovakia.		7.37	5.95	2.96	.56	.98
Loess, Alaska		5.84	5.50	1.36	.26	1.12
Loess, China		7.94	7.65	2.84	−.10	.83
Loess, Illinois		6.07	5.95	1.23	.075	1.64

CC, and DD) similar to the sandy loess adjacent to braided glacial streams in Alaska (Péwé and Holmes, 1964; Trainer, 1961).

The clay content is 10–20 percent where the silt is little transported. Where the silt is reworked, as in valley bottoms, alases, or thermokarst lakes, it contains more clay (20–40 percent) and minute organic fragments (figs. 20, 21, samples G, H, FF). Samples taken close to the surface (probably from the B soil horizons) are also slightly higher in clay (fig. 20, samples L, 25 cm below surface and S, 16 cm below the surface). Detailed sampling of silt for clay content in relation to soil age and depth, location, and rate of silt accumulation (see Ruhe, 1969; Smith, 1942) remains to be done on these deposits.

Samples taken at various depths from several sections (for locations see fig. 3) demonstrate the vertical uniformity of the silt. Three samples (G, H, and I, taken at depths of 1, 7, and 23 m, respectively) from a 25-m-high cliff at Mamontova Gora (Péwé and others, 1977), two samples (U and V, from 2 and 3 m deep, respectively) from Churapacha, and two samples (BB and CC, from the bedrock surface and 1 m above, respectively; fig 22) from the silt overlying dolomitic limestone at a quarry 12 km south of Pokrovsk (fig. 3) and very similar in texture (table 3 and figs. 19 and 21) and other sedimentologic parameters (table 3). Similar vertical uniformity is apparent in a 29.5-m-thick section of loess on the north coast of Yakutia (Tomirdiaro and others, 1974, table 1). The samples from the limestone quarry emphasize the independence of the silt from the underlying bedrock.

In an attempt to gage lateral uniformity, samples (W, X, Y, Z) of silt were taken at various distances (fig. 14)

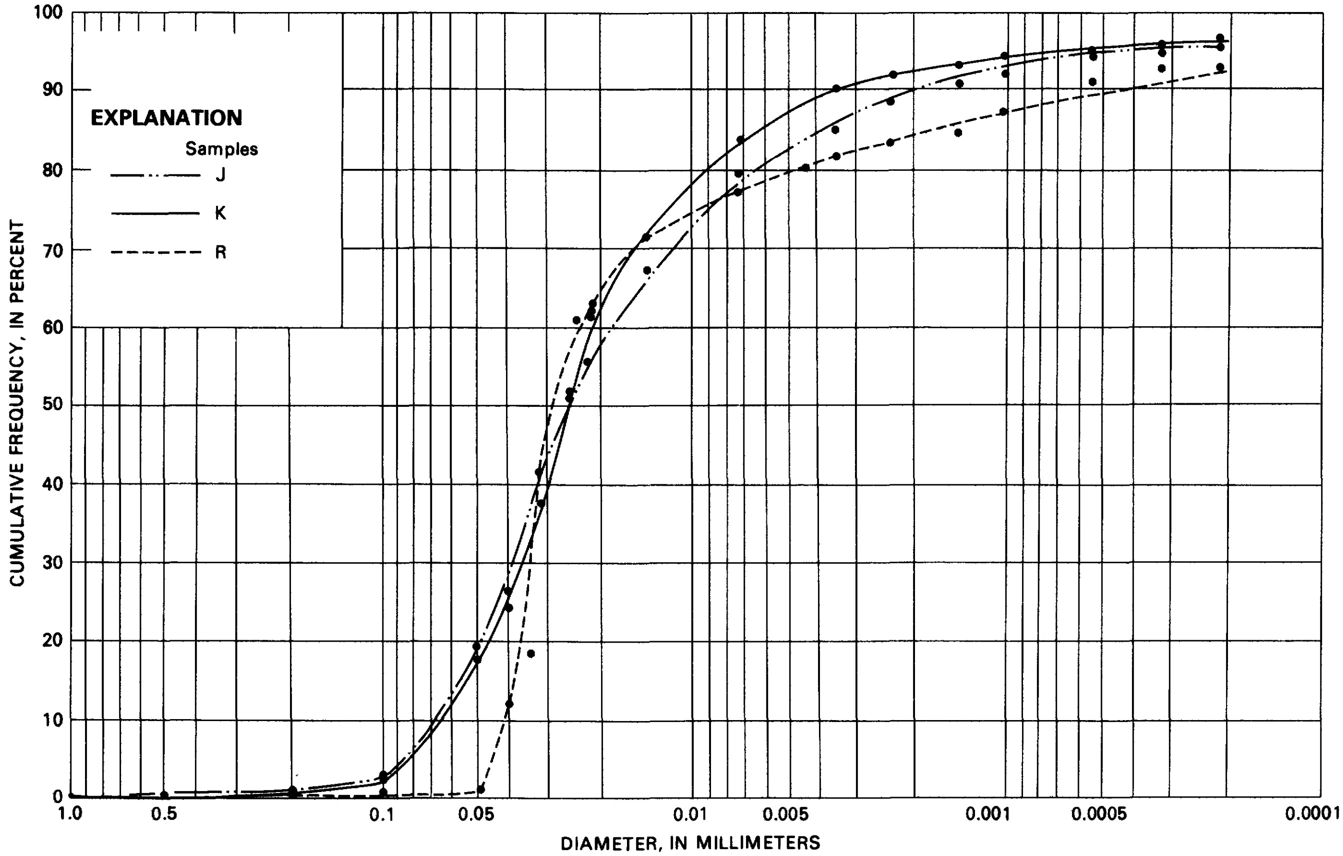


FIGURE 15.—Cumulative-frequency grain-size curves for loess from edge of alases on Tyungyulyu Terrace, 40 km west of Yakutsk. See figure 3 for locations.

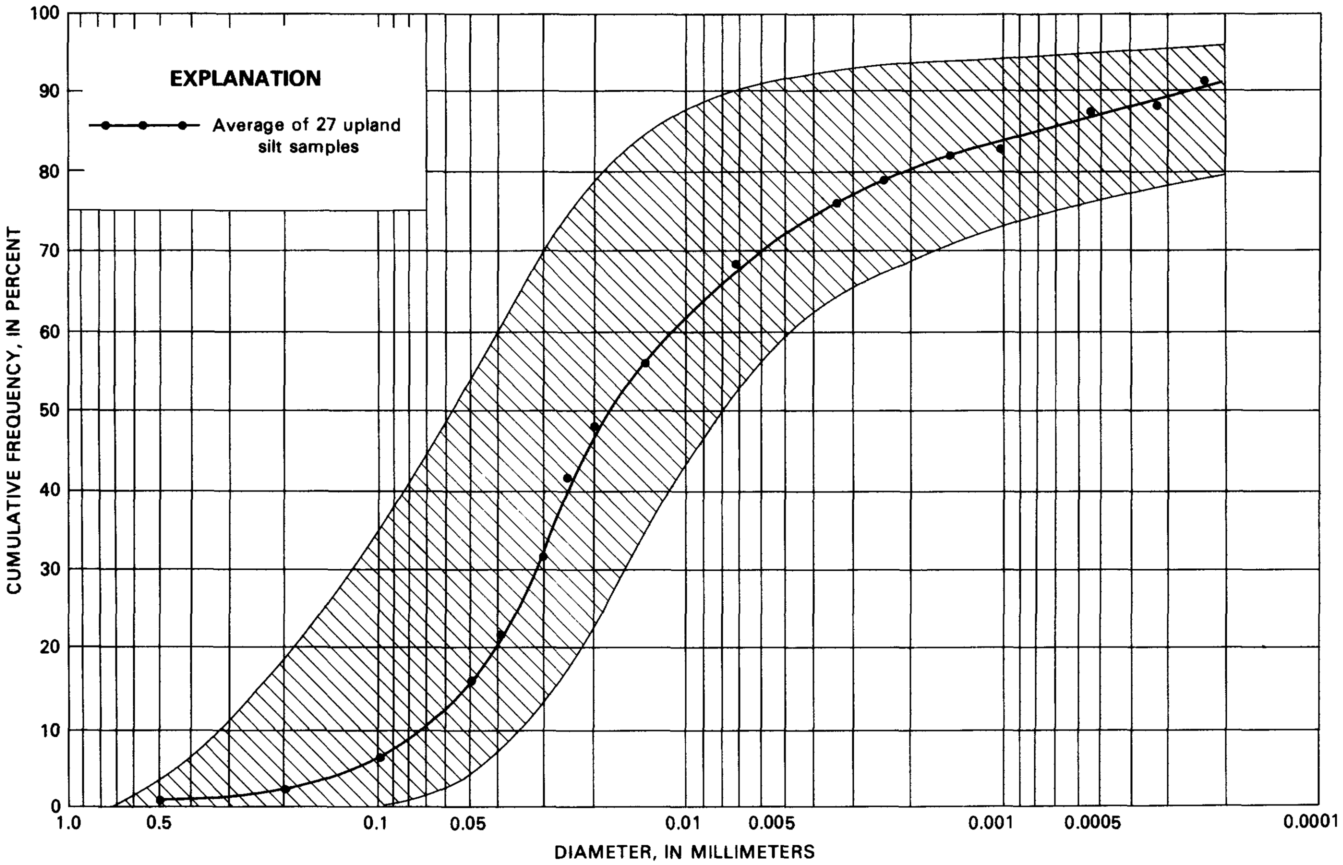


FIGURE 16.—Average cumulative-frequency grain-size curve for 27 samples of upland silt on high terraces in central Yakutia. Range of texture of samples shown by cross-hatched area.

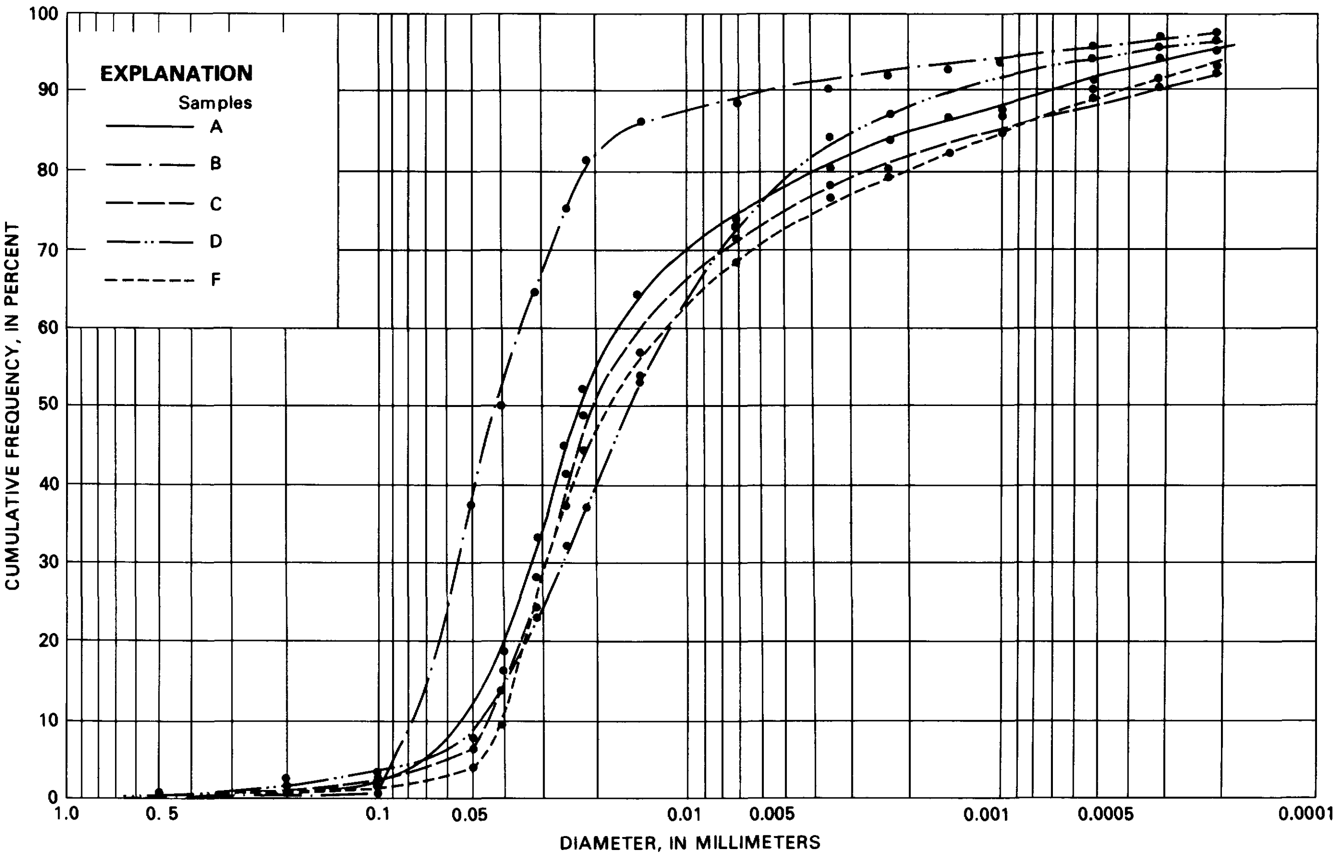


FIGURE 17.—Cumulative-frequency grain-size curves for loess blanketing terraces along lower Aldan River. Distance of sample locations up Aldan River from mouth: A and B, 30 km; C and D, 244 km; F, 284 km. See figure 3 for locations.

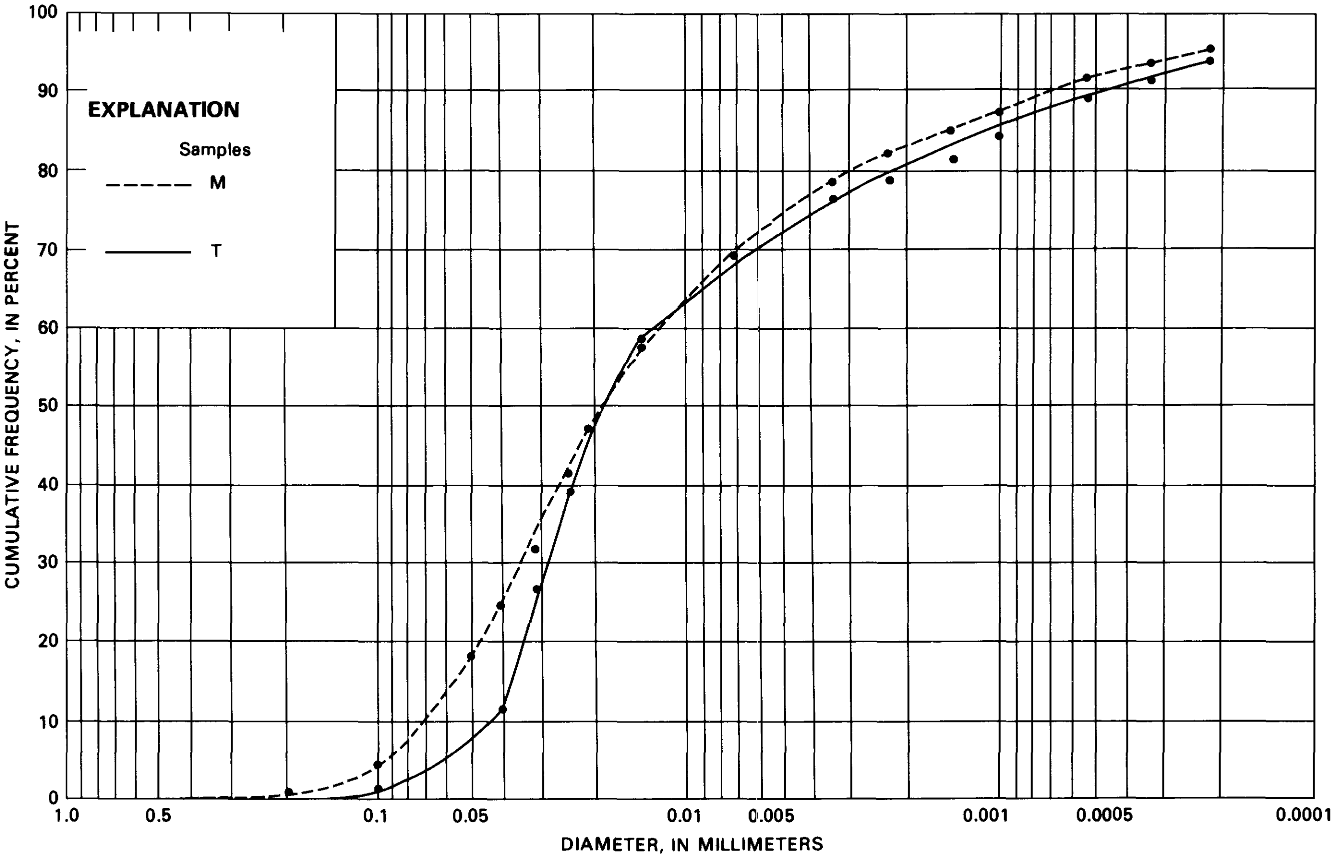


FIGURE 18.—Cumulative-frequency grain-size curves for loess mantling Tyungyulyu Terrace west of Lena River. See figure 3 for locations.

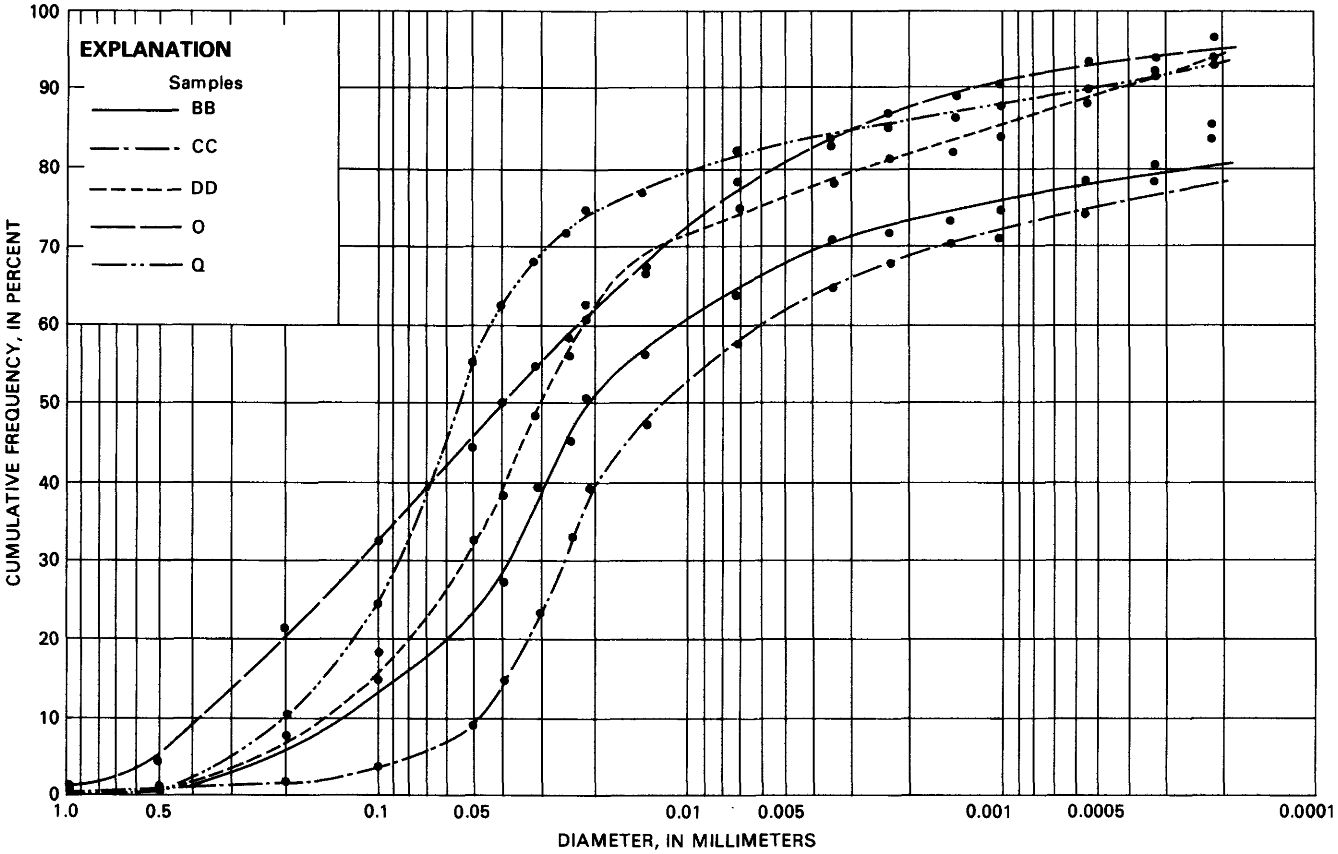


FIGURE 19.—Cumulative-frequency grain-size curves for upland loess near sandy terraces (Q and O) and near sandy flood plains (BB, CC, and DD) along Lena River. Samples BB and CC are in same section, respectively 1 cm and 70 cm above bedrock. See figures 3 and 22.

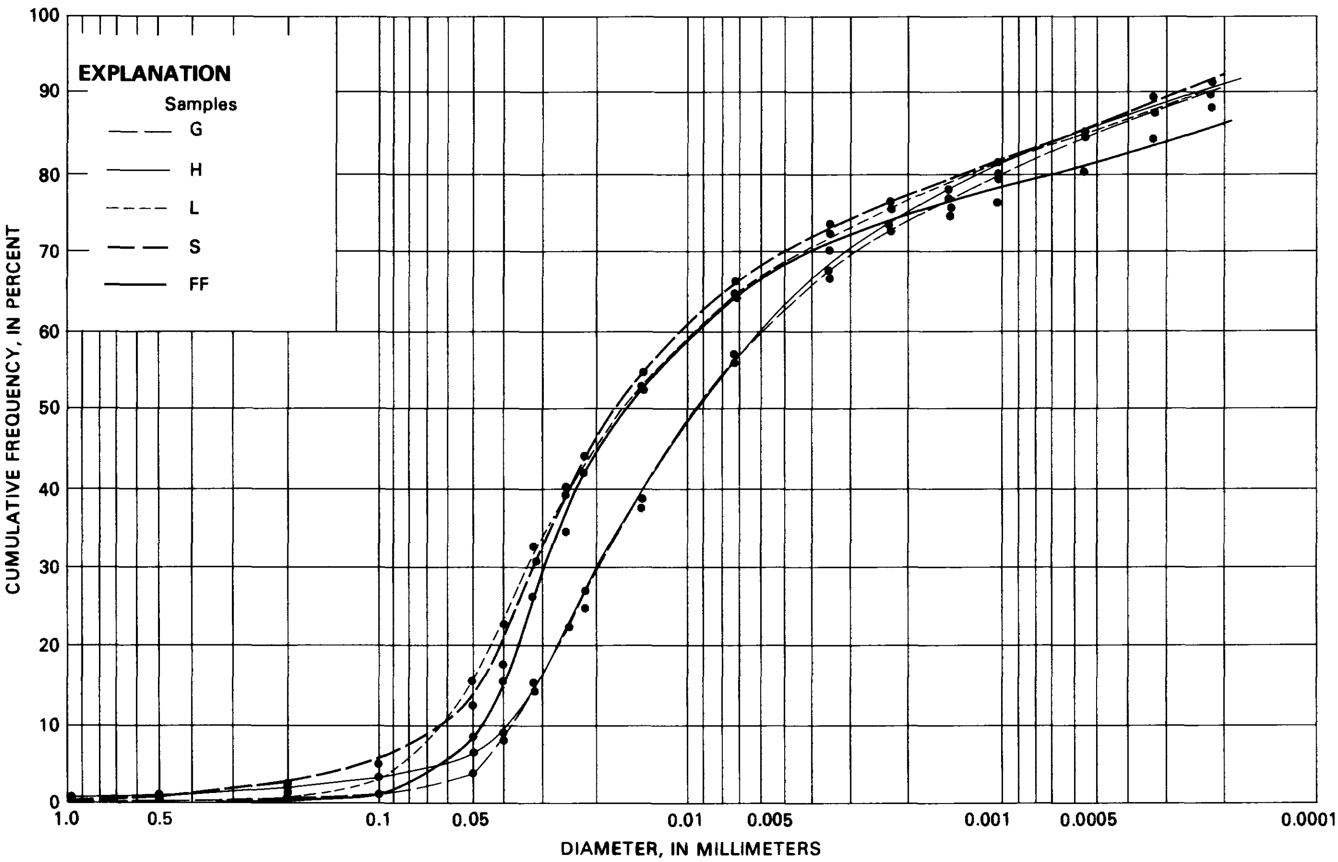


FIGURE 20.—Cumulative-frequency grain-size curves for reworked upland loess and B soil horizon illustrating relatively high clay content. See figures 3, 12.

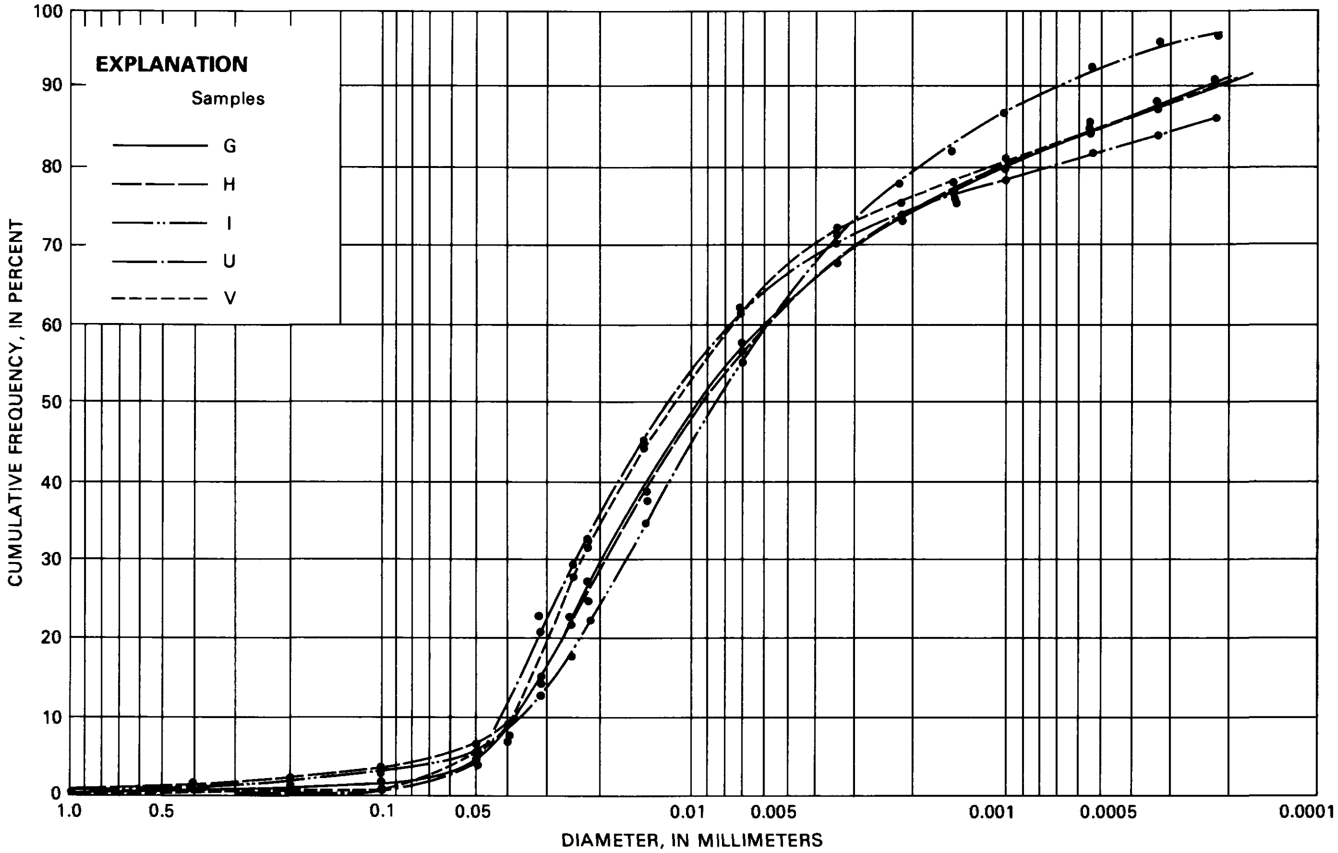


FIGURE 21.—Cumulative-frequency grain-size curves for retransported upland loess at various depths in section, illustrating vertical uniformity of texture. Samples G, H, I, Mamontova Gora; U, V, Churapacha. See figures 3, 30, and table 1.

away from the Lena River in the Pokvorsk area to determine whether the percentages of sand, silt, and clay changed (see Ruhe, 1969, p. 71). Within distance covered, only 6 km, no significant changes were seen in the the size distribution (fig. 23).

MINERAL AND CHEMICAL COMPOSITION

A number of chemical and mineral analyses of representative samples were made at the Centre de Geomorphologie, Caen, France. Heavy mineral analyses were made of 27 samples of the upland silt and of 3 samples of local fluviatile and eolian sand for comparison. The minerals were separated by bromoform (2.87 sp gr) after washing with HCl (20 percent) and sieving in three granulometric fractions. Fourteen samples were analyzed for 11 oxides. Thirty samples were analyzed for calcium carbonate content alone, and 16 by X-ray for types of clay minerals present. Petrographic examination reveals that the silt grains, although slightly iron-stained, are angular and fresh.

The mineralogy of the loesslike silt is nearly uniform (table 4); typical samples contain abundant quartz, mica, and feldspar, with a lesser amount of heavy minerals. These include 30 to more than 70 percent hornblende; 12–30 percent epidote, and lesser amounts of hypersthene and garnet, and very small amounts of zircon, anatase, tourmaline, rutile, disthene, monazite,

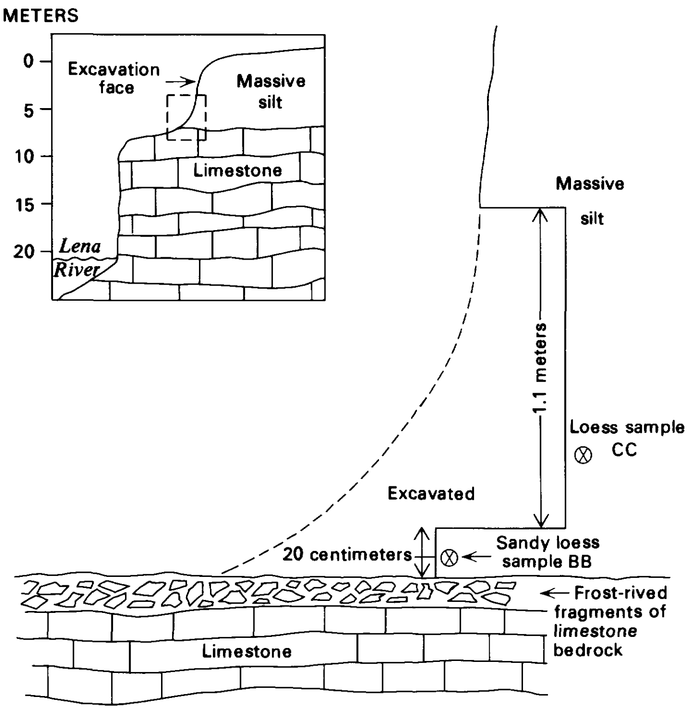


FIGURE 22.—Location of samples of upland silt mantling dolomitic limestone on right limit of Lena River, 12 km upstream from Pokrovsk.

and other heavy minerals. The analyses show that, in addition to mineral uniformity in the loesslike silt geographically, there is vertical uniformity. Samples from various levels in the cliff at Mamontova Gora (table 1, samples G, H, I) and two samples (BB–CC) from a section over limestone 12 km upstream from Potrovsk (fig. 22) are practically the same mineralogically and chemically with respect to each other.

The absence of heavy minerals in the limestone that underlies the silt upstream from Yakutsk along the Lena River (sample GG, table 4) confirms the independence of the silt and bedrock.

On a local scale, the mineralogy of floodplain sandy-silty alluvium from near the mouth of the Tatta River (sample E) is very similar to nearby upland silt (sample S, table 4). Sands of the Magan and Bestyakh terraces (samples N and P, table 4) are also similar to adjacent silts.

On a larger scale, differences in heavy-mineral content between samples from the Lena River and the lower Aldan River may indicate general regional differences despite the small number of samples. In both, hornblende, epidote, hypersthene, and garnet constitute 80-90 percent of the heavy minerals present. The samples from the Lena River area, however, are considerably higher in hornblende and epidote and lower in hypersthene and garnet than those from the lower Aldan River. Percentages are: hornblende, 61.0 for the Lena River samples, 46.8 for the Aldan River samples; epidote, 24.1 and 20.0; hypersthene, 1.4 and 8.5; garnet, 5.6 and 12.7. A "mineralogy index" defined as

$$M = \frac{(\text{epidote} + \text{hornblende})}{\text{garnet}} - \text{hypersthene gives}$$

M = 14.9 for the Lena area and M = 4.6 for the Aldan (fig. 24).

To determine the statistical confidence level for the mineralogical differences described here (fig. 24), we calculated a probability value (P), using the "t" test. This value was less than 0.005 and indicates a high degree of confidence. Further, to determine whether the mineralogic differences merely reflected differences in grain-size distribution, we compared textural parameters (defined by Folk, 1974) for the samples from the two areas. Despite the mineralogic differences, the average values of these parameters are essentially the same for the two groups (table 5). Thus, the mineralogic differences seem to reflect a real division between the upland silt of the Lena River area and that of the lower Aldan River.

Chemical analyses (table 6) shows that the upland silt is nearly constant in chemical composition over large areas. The chemical analyses of the upland silt on the

TABLE 4.—*Percentage distribution of heavy minerals in sediments from Yakutia, Siberia, U.S.S.R.*

[Sample No. 30, loess from Peking, China, collected by R. J. E. Brown, National Research Council of Canada, Ottawa, 1973. Analyses made at Centre de Geomorphologie, Caen, France]

Sediment sample (fig. 3)	A	C	D	E	F	G	H	I	J
Mineral	Loess	Loess	Loess	Allu-vium	Loess	Loess	Loess	Loess	Loess
Hornblende	61.6	42.4	56.5	44.7	31.4	58.8	45.4	46.3	63.0
Epidote	20.2	28.0	15.6	17.4	17.2	19.8	12.1	27.1	27.3
Hypersthene	5.8	1.7	14.4	16.3	11.2	7.7	12.1	3.9	.6
Garnet	8.2	5.9	10.6	13.9	19.4	11.4	16.8	11.9	3.6
Sphene	.7	.8	.7	----	1.5	.4	1.5	.6	1.8
Zircon	.7	.8	.3	1.4	8.9	.4	1.1	5.6	----
Staurolite	.3	5.9	----	----	6.7	----	----	----	.6
Pyroxenes	----	----	----	----	----	----	----	----	----
(monoclinic)	----	----	.5	4.1	----	----	5.5	.6	.6
Anatase	.3	.8	.5	1.1	----	1.1	.7	.6	1.8
Tourmaline	.3	1.7	----	.3	----	----	.4	1.1	----
Rutile	.7	----	.3	.5	----	.4	1.1	.6	----
Disthene	.3	.8	----	----	----	----	.4	.6	----
Sillimanite	----	----	----	----	----	----	----	----	----
Andalusite	.3	8.4	----	----	3.7	----	----	----	----
Chloritoid	----	----	.2	.3	----	----	.7	----	----
Topaz	----	----	----	----	----	----	----	.6	----
Monazite	----	----	.3	----	----	----	----	.6	.6
Total	99.7	97.2	99.9	100.0	100.0	100.0	97.8	100.1	99.9

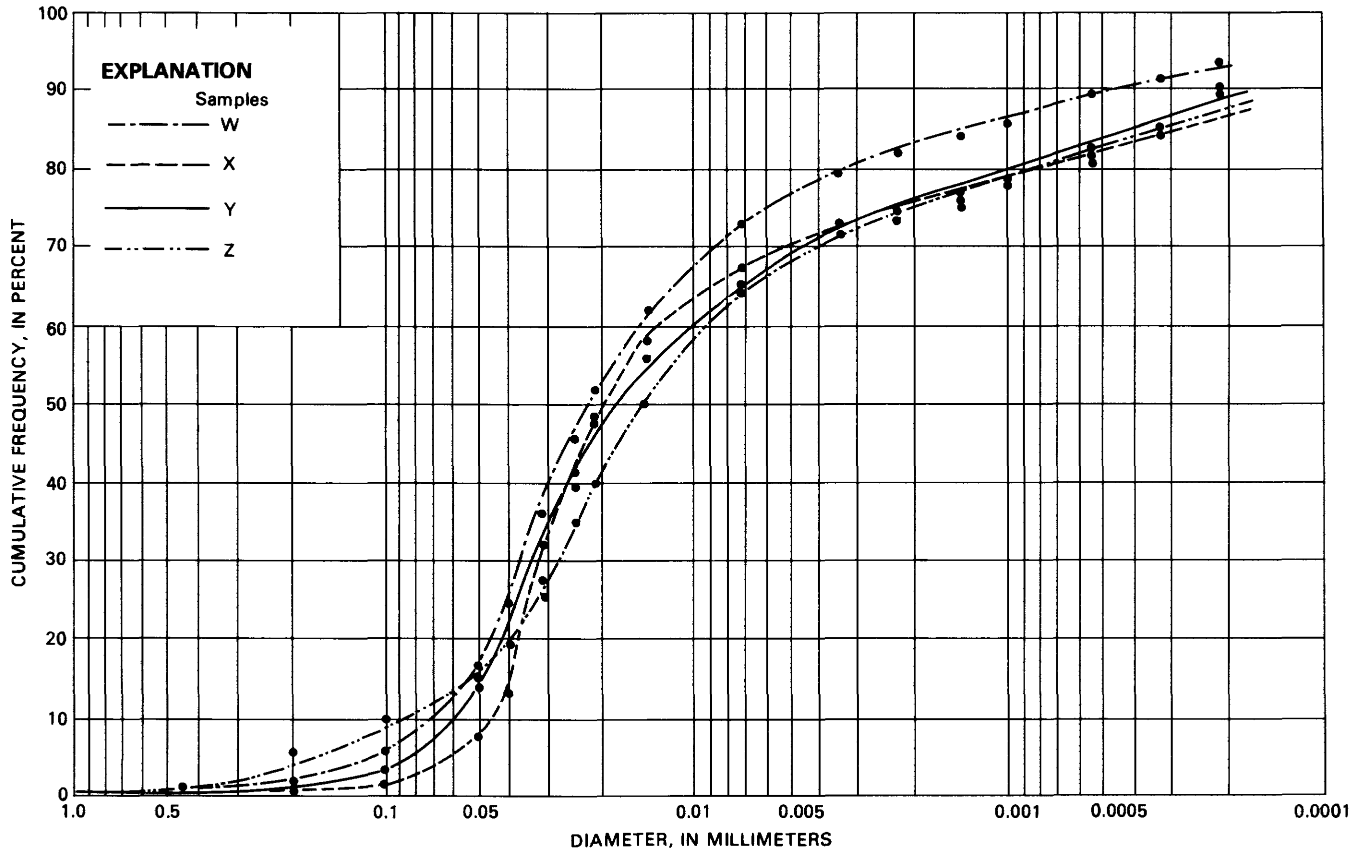


FIGURE 23.—Cumulative-frequency grain-size curves for upland loess. Distances from Lena River: W, 10 m; X, 1 km; Y, 5 km; Z, 6 km. See figures 3, 13.

TABLE 4.—*Percentage distribution of heavy minerals in sediments from Yakutia, Siberia, U.S.S.R.-Continued*

Sediment sample (fig. 3)	M	N	O	P	R	S	T	W	X
Mineral	Loess	Sand	Loess	Sand	Loess	Loess	Loess	Loess	Loess
Hornblende	68.6	55.1	51.7	60.8	54.5	69.9	63.1	60.3	73.6
Epidote	25.5	33.9	29.7	19.3	13.0	21.3	25.4	26.2	19.9
Hypersthene	.7		.5	1.7			.3	.4	
Garnet	2.6	5.1	9.9	4.1	7.1	3.9	3.1	4.4	2.1
Sphene	1.8	1.9	3.3	2.3	1.7	.9	3.5	1.9	1.1
Zircon	.4	3.5	1.6	9.3	15.3	1.4	1.7	2.4	1.6
Staurolite	----	----	----	.6	5.6	----	----	1.2	----
Pyroxenes	----	----	----	----	----	----	----	----	----
(monoclinic)	----	----	1.0	----	----	----	1.0	.8	.5
Anatase	.4	----	.7	----	----	1.9	.3	.8	.5
Tourmaline	----	----	.3	----	----	----	.3	----	----
Rutile	----	.5	1.0	----	----	----	----	1.6	.5
Disthene	----	----	----	1.2	.5	----	.7	----	----
Sillimanite	----	----	.2	----	----	----	----	----	----
Andalusite	----	----	----	.6	1.1	.5	.3	----	----
Chloritoid	----	----	----	----	----	----	----	----	.5
Topaz	----	----	----	----	----	----	----	----	----
Monazite	----	----	----	----	----	----	----	----	----
Total	100.0	100.0	99.9	99.9	98.8	99.8	99.3	100.0	99.8

Sediment sample (fig. 3)	Y	Z	AA	BB	CC	DD	EE	FF	GG	30
Minerals	Loess	Loess	Sand	Sandy loess	Loess	Loess	Sand	Loess	Silt from limestone	Loess
Hornblende	67.8	61.8	37.3	60.6	58.8	43.7	46.5	56.4	No measurable heavy minerals	57.8
Epidote	22.3	24.1	45.6	24.1	23.6	30.9	30.0	28.7		34.5
Hypersthene	.9				1.2	1.1	2.9	2.9		.2
Garnet	4.3	7.3	10.4	5.6	8.4	9.1	10.3	4.9		3.6
Sphene	.9	2.1		4.4	2.4	4.6	4.1	3.4		2.2
Zircon	.9	2.1	4.1	2.8	2.4	5.8	2.5	1.5		.2
Staurolite	----	----	.5	----	----	.1	.8	----		----
Pyroxenes	----	----	----	----	----	----	----	----		----
(monoclinic)	.9	----	----	----	----	.6	----	----		----
Anatase	.9	.5	1.0		1.6	1.4	.8	.5		.2
Tourmaline	----	----	----	----	----	----	----	----		.4
Rutile	----	.5	.5	.4	.8	.8	1.6	----		.8
Disthene	.5	1.0	----	.4	.4	.3	----	.5		----
Sillimanite	----	----	----	----	----	.1	----	----		----
Andalusite	----	----	----	----	----	.1	----	.9		----
Chloritoid	----	----	----	----	----	----	----	----		----
Topaz	----	----	----	----	----	----	----	.5		----
Monazite	.5	.5	.5	1.6	.4	1.1	.4	----		----
Total	99.9	99.9	99.9	99.9	100.0	99.7	99.9	100.2		99.9

50-m terrace along the Aldan River presented by Rusanov (1968, table 8) are almost the same as those listed for the same area in this paper. The chemical analyses are also similar to those analyses of loess along the Main River in northeast Siberia (Tomirdiaro, 1972, table 2). No chemical or mineralogical analyses are readily available for the bedrock in the Verkhoyansk Range or upstream on the Aldan or Lena Rivers. The calcium carbonate composition of the silt ranges from less than 2 percent to about 7 percent and is fairly consistent over the area under consideration (table 7). All loesslike silt samples analyzed by X-ray contain montmorillonite, chlorite, and illite, and most samples contain kaolinite.

FIELD RELATIONS

The massive silt overlies various substrates with a sharp contact: limestone along the Lena River, alluvial

TABLE 5.—*Average grain-size values of samples of upland silt along the Lena and Aldan Rivers in south-central Yakutia, U.S.S.R., analyzed for heavy-mineral content*

[Parameters and word descriptions from Folk, 1974, and Folk and Ward, 1957. See figs. 2, 24]

Mechanical property	Aldan River Group (6 samples)	Remarks	Lena River Group (15 samples)	Remarks
Graphic mean M_z	6.91	----	6.60	----
Median M_d	6.27	----	5.33	----
Inclusive graphic standard deviation (sorting), $\sigma I\phi$	2.43	Very poorly sorted	3.26	Very poorly sorted
Inclusive graphic skewness, Sk_I	.44	Strongly coarse-skewed	.66	Strongly coarse-skewed
Graphic kurtosis, K_G	1.20	Leptokurtic	1.35	Leptokurtic

sand on the left limit of the Aldan River, and glaciofluvial deposits at places on the right limit of the Aldan River.

The upland silt is massive, showing little or no stratification or jointing except in the retransported facies; however, near valley bottoms where some silt has been retransported, crude stratification is apparent. The faint stratification consists of iron oxide-stained horizons, organic films, vague colored bandings of short lateral extent and thin seams of ice, "Taber ice," which have grown parallel to the very indistinct bedding of the retransported silt. Differences of moisture content at certain horizons outline faint stratification. In no instance does the faintly developed stratification resemble fluvial or lacustrine bedding. It is only in the frozen

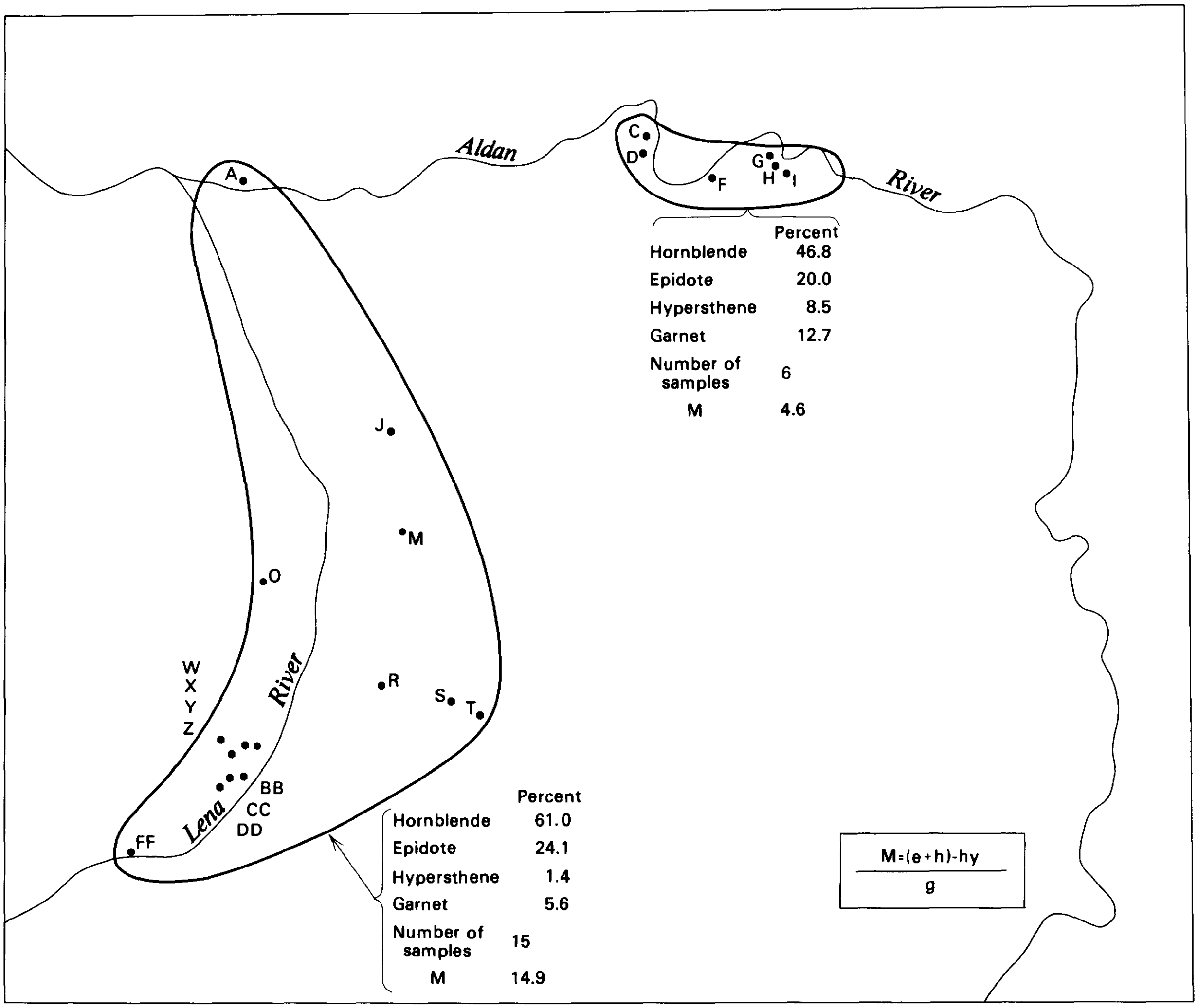


FIGURE 24.—Location of loess samples along Lena River and lower Aldan River analyzed for heavy-mineral content. Heavy lines encircle two different mineral suites based on average percentage of composition and differences of "mineralogy index," M. See text for explanation of equation. Only 10 samples of Lena River silt analyzed for hypersthene.

TABLE 6.—*Chemical analysis of Quaternary loess from central Yakutia, Siberia, U.S.S.R.*

[All calculations in weight percent. Analyses made at Centre de Geomorphologie, Caen, France. Samples collected by Troy L. Péwé]

Sediment sample (fig.3)	Sediment	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MaO	CaO	MgO	K_2O	Na_2O	P_2O_5	H_2O	Loss on ignition
A	Loess	59.01	11.84	4.60	0.715	0.163	7.19	1.43	2.56	2.18	0.81	2.25	7.79
G	Loess	59.94	12.32	5.36	.724	.145	4.83	.974	2.82	2.04	.53	3.14	7.15
H	Loess	58.49	1.10	5.21	.736	.152	4.82	.958	2.74	2.08	.497	3.01	8.48
I	Loess	59.12	12.81	6.70	.715	.217	4.21	.855	2.73	1.73	.55	3.60	6.59
J	Loess	64.31	11.92	4.42	.669	.149	4.91	1.055	3.12	2.61	.421	1.32	4.26
O	Loess	69.19	11.29	2.92	.72	.151	4.48	.826	3.14	2.58	.370	1.45	3.87
S	Loess	61.77	12.32	4.76	.723	.173	5.09	1.01	2.89	2.20	.629	3.05	5.42
X	Loess	61.20	11.29	3.48	.622	.146	7.25	1.02	2.90	2.50	.331	2.51	6.24
BB	Sandy loess	64.91	12.38	3.97	.725	.173	3.82	.813	2.91	2.27	.551	3.26	3.97
CC	Loess	63.04	12.66	3.98	.786	.138	4.02	.820	2.89	2.22	.510	3.82	4.81
DD	Loess	65.37	10.79	3.60	.628	.174	4.73	.975	2.97	2.45	.435	1.62	4.84
FF	Loess	57.91	11.40	4.59	.715	.165	7.04	1.16	2.71	2.26	.566	1.00	8.88
GG	Silt from limestone	2.49	.76	.86	.07	.142	32.44	17.05	.32	0	.350	.25	45.39

TABLE 7.—*$CaCO_3$ in Quaternary sediments from central Yakutia, Siberia, U.S.S.R.*

[Analyses made at Centre de Geomorphologie, Caen, France. Samples collected by Troy L. Péwé]

Sediment sample (fig. 3)	Sediment	Weight percent $CaCO_3$
A	Loess	6.8
B	Loess	≈2
D	Loess	≈3
E	Alluvium	<2
G	Loess	<2
H	Loess	≈3
I	Loess	4.5
J	Loess	<2
K	Loess	<2
L	Loess	<2
M	Loess	≈3
N	Sand	<2
O	Loess	<2
Q	Loess	<2
S	Loess	≈2
T	Loess	≈3
W	Loess	4.5
X	Loess	7.6
Y	Loess	4.7
Z	Loess	<2
AA	Sand	<2
BB	Sandy loess	<2
CC	Loess	<2
DD	Loess	<2
EE	Sand	<2
FF	Loess	7.6
GG	Silt from limestone	Dolomite
30[1]	Loess	6.3

[1]Collected in China by R.J.E. Brown, 1973.

or freshly thawed sediments that the bedding can be seen; after the silt has been thawed for years, it is tan instead of gray to black, and most of the indistinct bedding can no longer be seen. This retransported silt has the same texture and composition as the tan loesslike silt away from the depressions (figs. 15, 20, and 21; tables 3, 4, and 6) but is distinguished by a higher ice content and a fetid odor, as well as by faint stratification.

Because of the uniform texture, composition, and color of the silt, structural disturbance is rarely evident. Where stratification is visible, however, minor folds and faults are common and, near the boundaries of ice wedges, the strata are commonly bent upward.

FOSSILS

The upland silt represents the greatest repository of late Quaternary flora and fauna in central Yakutia. Fossils in glacial and flood-plain deposits of equivalent age are less abundant and less well preserved, especially the Pleistocene mammal fossils. Fossil remains are uncommon in the silt on ridges or low hills but common in lowlands and slight depressions where retransported silt has accumulated.

This report does not consider in detail the flora and fauna of the silt, already reported by Alekseev (1961), Vangengeim (1961), Rusanov (1969), Motuzko and others (1969), Markov (1973), Péwé and others (1977), and other investigators. In summary, the silt deposits are characterized by numerous remains of *Mammuthus primigenius* of a late type, *Equus caballus, subsp. B* (small form), *Bison priscus* aff. *deminutus* W. Grom, muskox, moose, caribou, and other large mammals and rodents such as *Lemmus* and *Dicrostonyx*. These fossils are especially common on the terraces of the Aldan River valley. Some, such as the large horse and the long-horn bison, are older fossils. These older remains may be from the lower levels of the silt or reworked from the underlying sand terraces (Vangengeim, 1961, p. 34). Although a considerable number of specimens in central Yakutia have been identified, it remains to relate individual fossils to specific stratigraphic units within the silt as suggested by Péwé and others (1977).

It is not uncommon for many of the skeletons to be found with several of the bones joined together, and Vangengeim (1961, p. 38–39) reports recovery of an entire skeleton. Some of the widely reported carcasses, or partial carcasses, of ice-age mammals, including the Berezovka mammoth, have come from this silt (Shilo, 1978). Partial carcasses of Pleistocene mammals have also been recovered from the perennially frozen retransported silt in Alaska (Péwé, 1975a).

Aquatic fossils in the silt include two mollusk species collected by Péwé on the south side of the Aldan Valley: *Valvata piscinalis* Mull. and *Valvata cristata* (O. F. Muller) (identified by J. Vasatko, Czechoslovakia Academy of Science, Brno, CSSR, written commun., 1974). Solov'ev (1959) reports aquatic mollusks at various depths in the upper of two major clayey loam layers near Churapacha.

The retransported frozen silt contains a varied megaflora in the form of peat, sticks, twigs, pods of plant remains, and isolated tree limbs and stumps. Study of such specimens and pollen analysis indicate the predominance of herbaceous tundra and forest-tundra vegetation at the time of silt accumulation (Vangengeim, 1961; Giterman and Golubeva, 1967).

ORIGIN

Although the origin of loess has been a controversial subject worldwide for about 100 years, most of the discussions have centered on the loess in China, central United States, and later, Alaska. Less is known about the probable origin of the widespread loesslike silt in the lowlands of unglaciated eastern Siberia. Marine, estuarine, lacustrine, fluvial, weathering, and eolian processes have been invoked to explain the loesslike silt. The marine and estuarine hypotheses have had little support; but the lacustrine, fluvial, and residual hypotheses, either separately or in combination, have had widespread support and are currently strongly held by Soviet workers, especially by researchers working with frozen ground. In recent years, however, the eolian hypothesis has been advocated by some workers (Tomirdiaro and others, 1974; Tomirdiaro, 1975b; Péwé and others, 1977).

MARINE AND ESTUARINE HYPOTHESES

Many of the river valleys in central Yakutia, especially in the north, are less than 100 m above sea level. It has been suggested that much of the loesslike silt could result from inundation by an advancing sea (Wright, 1902). To deposit such uniform silt at both high and low elevations, however, flooding the valleys many hundreds of meters deep would have been required (fig. 2).

Moreover, deltas, shorelines, and beaches would be present if the water level had been constant for a long period of time. The silt would stratify and would contain large amounts of clay, mud cracks or ripple marks, and marine fossils, but none of these features are present.

WEATHERING HYPOTHESIS

Berg (1960) proposed that loess forms in place as the underlying rock breaks down. His hypothesis exerted a profound influence over many Soviet scientists, but now it seems to have little support in the western part of the Soviet Union. In Yakutia, however, many workers have argued more recently that the loesslike silt there is a product of breakdown by seasonal freezing and thawing (Sudokova, 1959; Popov, 1965, 1967, 1972, 1976; Agadzhanyan and others, 1973; Danilova, 1973), a combination of frost action and chemical weathering (Chigir, 1972; Konishchev, 1972; Konishchev and Rogov, 1972), or chemical weathering alone, a "loessification" process in place (Morozova, 1971). According to this theory, the upland silt of central Yakutia is in the initial stages of loess formation and not yet as well formed as the loess of the Russian plains.

If the upland silts were formed in place by disintegration of local country rock, the following features would be expected:

1. The mineralogy of the silt and the underlying rock would be similar, allowing for differential resistance to weathering. In central Yakutia, the silt overlies many substrates, including dolomitic limestone, alluvium, poorly consolidated sands, glacial outwash, and till of diverse provenance. In all areas, the mineralogy and chemistry of the silt is similar despite the great diversity of underlying material.

   In the southern part of the area, the upland silt lies directly on dolomitic limestone, but samples (W, X, Y, Z, BB, CC, DD, and FF; fig. 3) overlie the limestone and could not have been derived from the weathering, either chemical or mechanical, of the underlying rock. These samples contain a suite of heavy minerals similar to other samples, minerals not present in the underlying bedrock (tables 1, 2, and 4). The percentage of calcium carbonate in these samples is actually about the same as in the rest of the mapped area, or slightly less; yet, one would expect a tremendously high concentration of calcium carbonate in loess if it had originated from the underlying limestone. On top of dolomitic limestone cliffs 147 m above the Lena River at the Pillars of the Lena, a sample (tables 1 and 4) of weathered limestone was taken from a crevice deep in the rock in a dry environment. Although the sample is a well-sorted silt, it contains no heavy minerals and is pure calcium carbonate (fig. 27). The silt occurs high on the bluffs and could not have originated from some other local bedrock at higher altitudes and been transported to the area (figs. 13, 14, and 22). It is evident, therefore, that the silt in these localities did not come from the underlying or nearby bedrock.

2. Sediments produced by rock disintegration would undoubtedly contain some large particles, especially of the more resistant minerals, but such resistant particles are scarce, At some localities, angular pieces of resistant limestone as much as 5 cm in diameter occur at the base of the loesslike silt, probably broken from the underlying limestone by frost action. The massive loesslike silt overlies these frost derived fragments on a sharp contact that marks (fig. 22) a great change in textural, chemical, and mineralogical composition.
3. If silt accumulated on top of a hill or a flat-lying area through the disintegration of underlying bedrock, the material should be finer and more weathered at the surface than that closer to bedrock. The vertical uniformity of size distribution evidenced at Mamontova Gora (fig. 21), at consecutive depths of 2 m (U) and 3 m (V) (fig. 3) at Churapacha on the Abalakh Terrace, and by samples BB and CC in loesslike silt overlying dolomitic limestone (figs. 19 and 22) contradicts this expectation.
4. Mechanical disintegration, probably the dominant process of bedrock weathering in subarctic climates, depends largely on the action of alternate freezing and thawing (cryolithic processes). Where a thick layer of breakdown residuum develops, it might be expected to shield the underlying rock from further disintegration. On hillsides, the silt might be removed as fast as it forms, but it would accumulate on flat hilltops and ridges. The depth of seasonal freeze and thaw of the ground in central Yakutia ranges from 1 to 3 m with deepest penetration in gravel and least penetration in silt. Under present climatic conditions seasonal freeze and thaw of bedrock probably does not occur under a protective mantle of silt thicker than 1–2 m. In past colder periods, seasonal penetration of frost may have been slightly deeper in the nonperennially frozen ground. It is true that, in the past, well-drained silt may have been perennially frozen, but if no frequent alternation of freeze and thaw occurred, little disintegration would take place. Because much more than 3–4 m of upland silt is present on the relatively flat terraces and uplands, including the highest terrace, it is clear that the material could not have originated in place from seasonal frost action.
5. Residual silt on hilltops, ridges, plateaus, or terraces would contain no carbonaceous layers or soil horizons if the material were formed by a progressive downward disintegration of the underlying bedrock. Sections of the silt do, however, reveal carbonaceous layers and soil horizons.

In summary, a number of characteristics that would be expected in the loesslike silt if it were formed by disintegration in place are not observed. Together the lack of these characteristics argue convincingly against the disintegration hypothesis.

LACUSTRINE AND FLUVIATILE HYPOTHESES

The most popular explanation of the origin of the upland silt in central Yakutia is that the loesslike silt is a combination of lacustrine and alluvial deposits formed on great flood plains and marshy plains (Popov, 1953; Solov'ev, 1959; Boyarskaya and Malayeva, 1967; Katasonov and Solov'ev, 1969; Motuzko and others, 1969; Agadzhanyan and others, 1973; Ivanov and Katasonov, 1973; Katasonov and Ivanov, 1973; Konishchev, 1973; Popov, 1973). Periglacial researchers concerned with various forms of ground ice favor this hypothesis because of the faint stratification where the silt has flowed into shallow depressions when large amounts of segregated ice melts. The quantity of ground ice present indicated, they thought, that the silt had been deposited on vast partly flooded plains.

It has long been known (Bunge, 1884; Toll, 1895) that ground ice of various types and quantity (fig. 6) is widespread in the loesslike silt cover of the high and low terraces of central Yakutia, as well as on the coastal plain of the north. The lacustrine-alluvial hypothesis evolved over the years in an attempt to explain the different types and distribution of ground ice. According to Tomirdiaro and others (1974), until the early 1950's of the 20th century, it was believed that most of the ice in the ground was remnant ice and snow from Pleistocene glaciers buried by clayey alluvium; this idea is the so-called glacial firn theory. It is now known that the glaciers were not that extensive (fig. 4) and that the foliated ground-ice wedges (figs. 6, 25) formed in thermal contraction cracks in the perennially frozen ground. Many scientists thought that the ice wedges must have grown syngenetically in the saturated sediments of a gigantic flood plain and invoked great floods and colossal lacustrine-alluvial plains to account for the great vertical extent of the ice, from modern flood plains to high terraces (Popov, 1953, 1965).

A number of factors combine to make the fluvial and lacustrine hypotheses unlikely. Fluviatile silt is well stratified and crossbedded, individual beds are lens shaped, and, though individual beds are fairly well sorted, samples collected over a broad area or from a thick section are poorly sorted. The upland silt, however, is unstratified and uniform in texture. Moreover, though fluviatile silt is abundant on the flood plains of the Lena and Aldan Rivers, it is typically of larger grain size than the upland silt (fig. 26 and table 3, sample E). It is also difficult to explain, in the context of the fluvial hypothesis, the presence of as much as 25 m of silt on bedrock bluffs as much as 50–100 m above the river level and the character of the silt as a nearly continuous blanket over a surface with 100–200 m of relief.

The lacustrine hypothesis is also improbable for several reasons:

1. No known barriers capable of damming water 200 m deep, 150 km up the Lena River from Yakutsk and 300 km up the Aldan River from its mouth existed in the area where the silt was deposited.
2. No features such as preserved shorelines, wave-cut benches, and deltas, which would be expected to form in a lacustrine environment, are evident in the silt.
3. Lacustrine deposits have a limited vertical extent, but the loesslike silt occurs at various elevations and even on the moraines at the foot of the Verkhoyansk Range, hundreds of meters above the Aldan River.
4. Lacustrine silt would be stratified and might even contain varves. The only stratification in the upland silt is produced by isolated carbonaceous layers and iron-stained horizons, and, in most places, stratification is absent. Crude stratification is outlined by concentrations of ground ice and by slight differences in grain size. In the retransported materials that were carried by slopewash to shallow depressions, however, this crude stratification disappears upon thawing and complete drying of the silt in cliffs.
5. An appreciable amount of clay could be expected in the deposits of any large lake. The average cumulative-frequency curve of 27 samples from the upland silt has a very low content of clay, only about 5–15 percent.
6. As would be expected of lacustrine deposits, the upland silt bears little lithologic relation to the underlying rock. This characteristic, however, is typical of any transported sediment.
7. Some forms of life would have existed in these lakes. So far as we are aware, no lacustrine fossils have been found in the high upland silt, although gastropods and pelecypods have been found in the reworked material of the valley bottoms. The fossils in the valley bottoms probably were derived from thermokarst lakes (alases) that existed at the time of silt accumulation.
8. Land fossils would be absent or scarce in lacustrine deposits, as they are in the nonretransported upland silt. But land fossils are preserved in the upland silt although they are fragmentary and show evidence of transport. These features, however, are to be expected in

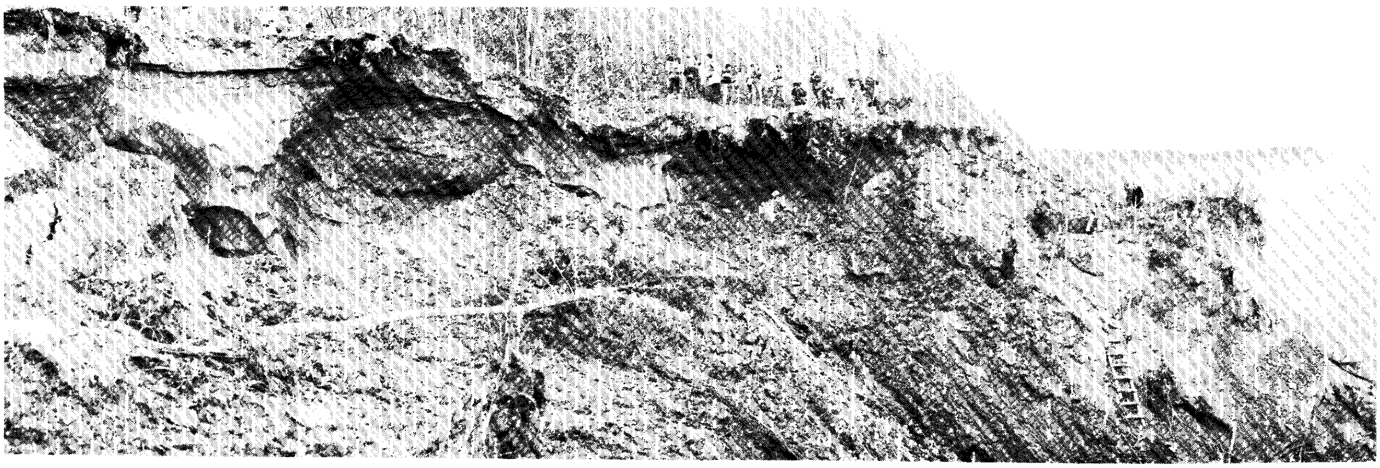


FIGURE 25.—Panorama of late Quaternary silt containing ice wedges exposed at Mamontova Gora, left limit of Aldan River, 310 km upstream from junction with Lena River. View downstream. Photographs 3427, 3428, 3429, and 3430 by T. L. Péwé, July 22, 1974. (Reproduced by the courtesy of *Quaternary Research.*)

transported sediments regardless of the transport mechanism.

9. Mud cracks and ripple marks would be expected in lacustrine silt, but none have been observed.

All but two of these features of lacustrine deposits are contrary to the observed nature of the upland silt. The two features that are consistent are typical of deposits transported by any mechanism. The observed characteristics of the silt in central Yakutia cannot be explained by the lacustrine and fluviatile hypotheses alone. Moreover, radiometric and paleontologic dating show that the silt accumulated in middle and late Pleistocene glacial times (Vangengeim, 1961; Sher, 1971; Péwé and others, 1977), not during a warm period when melting would inundate the region. The remains of steppe animals such as *Siaga* (Sher, 1967, 1969, 1971) and steppe tundra (Yurtsev, 1972; Hopkins, 1976; Mathews, 1976) confirm the general dryness of the climate.

EOLIAN HYPOTHESIS

Although the idea that the silt in central Yakutia is eolian in origin is not new, it has not been described and evaluated in detail. Obruchev (1945), a longtime Soviet leader in loess studies, mentioned that loess existed in central Yakutia. Volkov and others (1969) have demonstrated that the widespread silt in southwest Siberia is eolian in origin. Recently, Tomirdiaro (1972) and Tomirdiaro and others (1974) recognized that the silt in northern Yakutia is loess. Vangengeim (1961, p. 37) referred to the silt as dusty loam, "the formation of

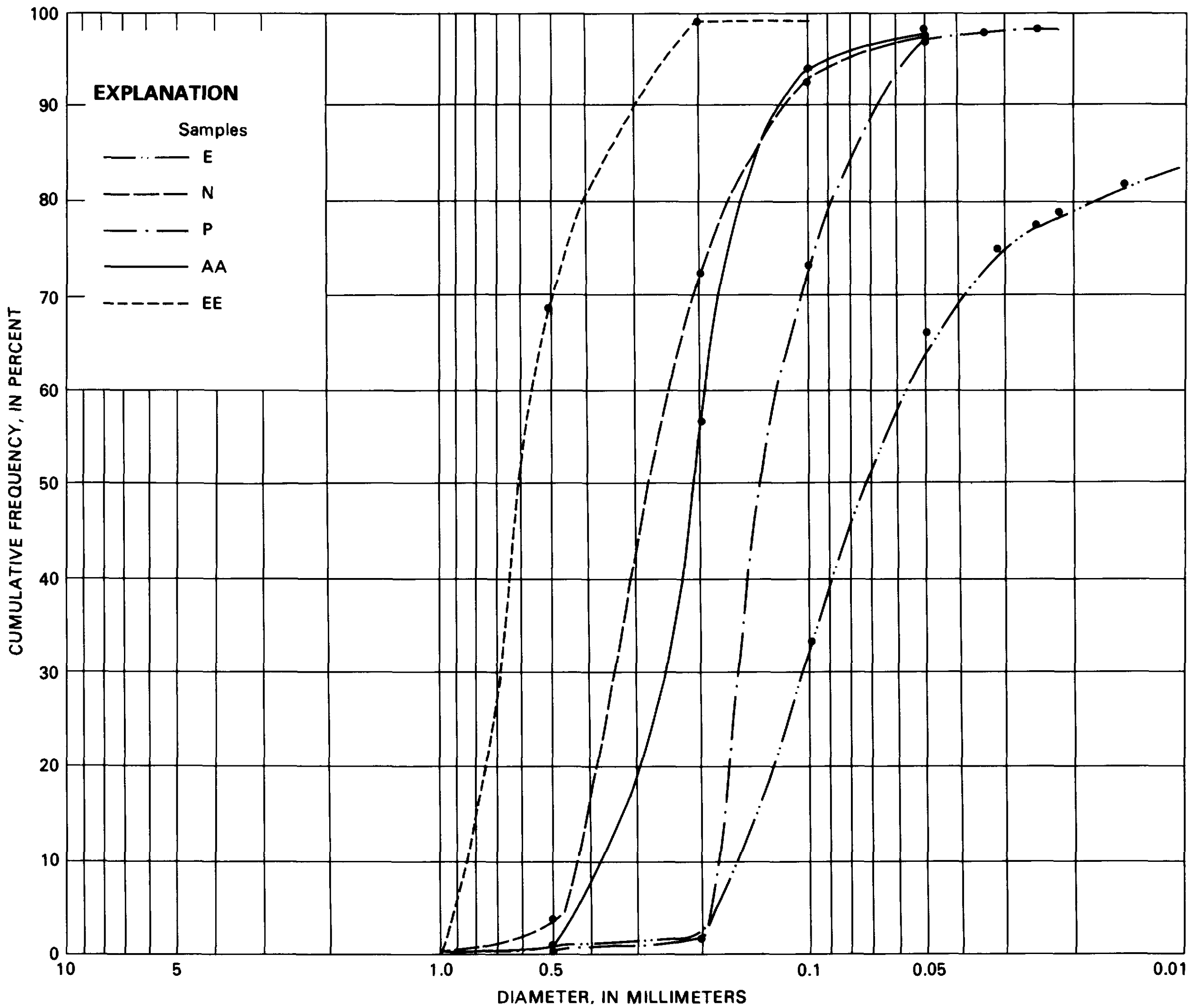


FIGURE 26.—Cumulative-frequency grain-size curves for sand from Lena-Aldan Rivers area. E, flood-plain alluvium, Ust'Tatta Village; N, sand, top of Magan Terrace, 53 km west of Yakutsk; P, sand dune on Bestyakh Terrace; AA, alluvial sand, 7 km west of Pokrovsk; EE, eolian sand from cliff-head dune, 40 km upstream from Pokrovsk on Lena River. See table 1, figure 3.

which the majority of geologists have correlated with unusual physical-geographical conditions in glaciated regions." Rusanov (1968) mapped all the silt on the high terraces of the lower Aldan River valley as loess. Giterman and Golubeva (1967) referred to the sediments on the high terraces as loess but did not provide supporting data. Fedorovich (1972) recently mentioned that the study of the silt in Yakutia should be undertaken to provide new contributions to loess science. Our studies of the silt in southcentral Yakutia, and comparisons with similar deposits in other parts of the world, support the identification of the deposits as loess.

Features and characteristics of eolian-deposited silt fall into three groups: field relations, mechanical composition, and petrographic character (Smith and Frazer, 1935).

FIELD RELATIONS

Topographic distribution.—Loess characteristically mantles preexisting topography, "filling up the gulleys, covering minor depressions, lying deepest in the depressions and thinning-out up the flanking slopes of the higher ridges" (Barbour, 1930, p. 468). The silt in central Yakutia conforms closely to this pattern.

It is draped over river terraces of varous levels and thinly over the glacial outwash and moraines emanating from the Verkhoyansk Range. It is absent on the flood plain, low floodplain terraces, and the sandy Bestyakh Terrace. It is not known why the silt is absent from the Bestyakh Terrace, possibly because the terrace surface, part of a late Pleistocene sandy flood plain of the Lena River, was a source of windblown silt, not an area of accumulation. In general, the high Magan Terrace has little or no loess because: (1) the terrace, in most areas, is distant from the major rivers (fig. 3); (2) the Lena River is narrow and has a small flood plain where it is near this terrace and; (3) the terrace was upwind from a major glacial flood plain, the source of silt.

Independent lithologic character of the deposits.—Wind-deposited material may differ mineralogically and texturally from the underlying material. In southcentral Yakutia, uniform silt covers glacial till, dolomitic limestone, poorly consolidated sandstone, and alluvium. At these several localities, the fine texture of the silt contrasts strongly with the texture of the underlying material, but is very similar to that of the typical tan upland silt in south-central Yakutia (fig. 4) and northern Yakutia (fig. 27).

Decrease in thickness away from source of supply.—The greatest thickness of the silt blanket is near its source, the flood plains and low terraces of the Lena and Aldan Rivers. The silt is 2–5 m thick on the bluff of the Magan Terrace west of Yakutsk and thins westward to a featheredge within a few kilometers (fig. 3). Such marked thinning is consistent with present-day westerly prevailing winds and may indicate similar wind patterns during the Pleistocene from the west.

Absence of distinct stratification.—Absence of distinct stratification, a characteristic of loess, is a conspicuous feature of the upland untransported silt. The only suggestion of stratification is imparted by thin carbonaceous horizons and iron-stained horizons.

Color and texture.—Wind-deposited silt, like that described here, is generally light colored except where stained by solutions or carbonaceous inclusions; the texture is generally uniform and the clay component makes up no more than 10–15 percent of the sediment.

Association with other evidences of wind action.—Smith and Fraser (1935, p. 19) state that sand dunes and ventifacts may be expected near the source of material. Well-developed, vegetated sand dunes cover the entire narrow Bestyakh Terrace adjacent to the wide Lena River from Pokrovsk to the mouth of the Aldan River (fig. 3). The eolian forms exist as ridges 2–10 m high and as small merged parabolic dunes. An active cliff-head dune 20 m high occupies the edge of the Bestyakh Terrace on the right limit of the Lena River about 40 km upstream from Pokrovsk. This dune and other dunes are evidence of eolian action still going on where sediment source areas are nearby. Small dust clouds raised today from the almost completely vegetated braided-stream deposits of the major rivers in central Yakutia suggest that enormous clouds of dust may have come from the unvegetated braided streams present during the Pleistocene. It has been demonstrated by many workers that no more wind is necessary to blow this dust than is present today, as winds up to 20 m/s are more than strong enough to bear quantities of dust in both periglacial areas and hot desert areas (Bryan, 1927, p. 39–40; Péwé, 1951; Warn, 1953, p. 70–71; Péwé and others, 1976; Péwé and others, 1981). Chigir (1972), however, believes that much higher wind velocities are necessary and that such winds were produced by the nearness of glaciers. Instead, only larger source areas than now available are necessary, in our opinion, and they were provided by the wide unvegetated, braided Lena and Aldan Rivers in Pleistocene time.

Fossils of air-breathing animals.—Fossils of air-breathing animals should logically be expected to be present in the silt if the material is eolian. Middle and late Pleistocene vertebrate fossils are distributed widely in the silt blanketing the terraces on the Lena, Aldan, and Vilyuy Rivers (for example, Alekseev, 1961; Vangengeim, 1961; Rusanov, 1968; and others). Fossils present include remains of mammoth, horse, bison, and other mammals. The preservation of many of the specimens shows evidence of very little transportation.

No land gastropods have been reported in the upland silt in Yakutia. Russell (1944, p. 34) regarded land gastropods as being characteristically present in loess. Some other loess deposits, however, in the upper Mississippi Valley and most of the loess in Alaska, do not contain land gastropods (Péwé, 1955, p. 720–721). Also, Dr. T. C. Yen (oral commun., June 27, 1950), former paleontologist at the United States National Museum, Washington, D.C., reported that much of the loess of China and the Rhine Valley contained no terrestrial gastropods so this evidence is not conclusive.

MECHANICAL COMPOSITION

If the upland silt is loess, the grain size and degree of sorting would be similar to that of windblown dust or volcanic ash that has been transported a considerable distance (Udden, 1898, p. 31–60; Swineford and Frye, 1945, p. 252; Warn and Cox, 1951, p. 559; Péwé, 1955, fig. 11; and Péwé and others, 1976), or similar to silt known to be loess. Cumulative-frequency curves of mechanical analyses of windblown dust from Kansas (Swineford and Frye, 1945, p. 252) and Germany (Zeuner, 1949, p. 27) and Arizona (Péwé and others, 1981) are similar to the average cumulative-frequency curve of the upland silt from central Yakutia (fig. 28).

It was thought that a great similarity of grain size and degree of sorting between the upland silt of Yakutia and deposits of silt of known eolian origin elsewhere in the world, would constitute a strong argument for the eolian hypothesis. For comparison, samples of silt long known to be loess were collected from Czechoslovakia, Alaska, Illinois, China, New Zealand, France, and Uzbekistan. All but one of the samples were analyzed by the same method in the same laboratory as the Yakutian samples. The cumulative-frequency curve of a typical sample from Yakutia is strikingly similar to curves of loess from other parts of the world (fig. 29).

PETROGRAPHIC CHARACTER

Angular grains have long been considered typical of loess (Twenhofel, 1932; Charlesworth, 1957), and scanning-electron-microscope analysis supports that assumption (Cegla and others, 1971). The silt grains from Yakutia are clearly angular, especially the light minerals such as quartz. It has been suggested that loess grains should also be largely unweathered and clay minerals almost absent (Smith and Fraser, 1935;

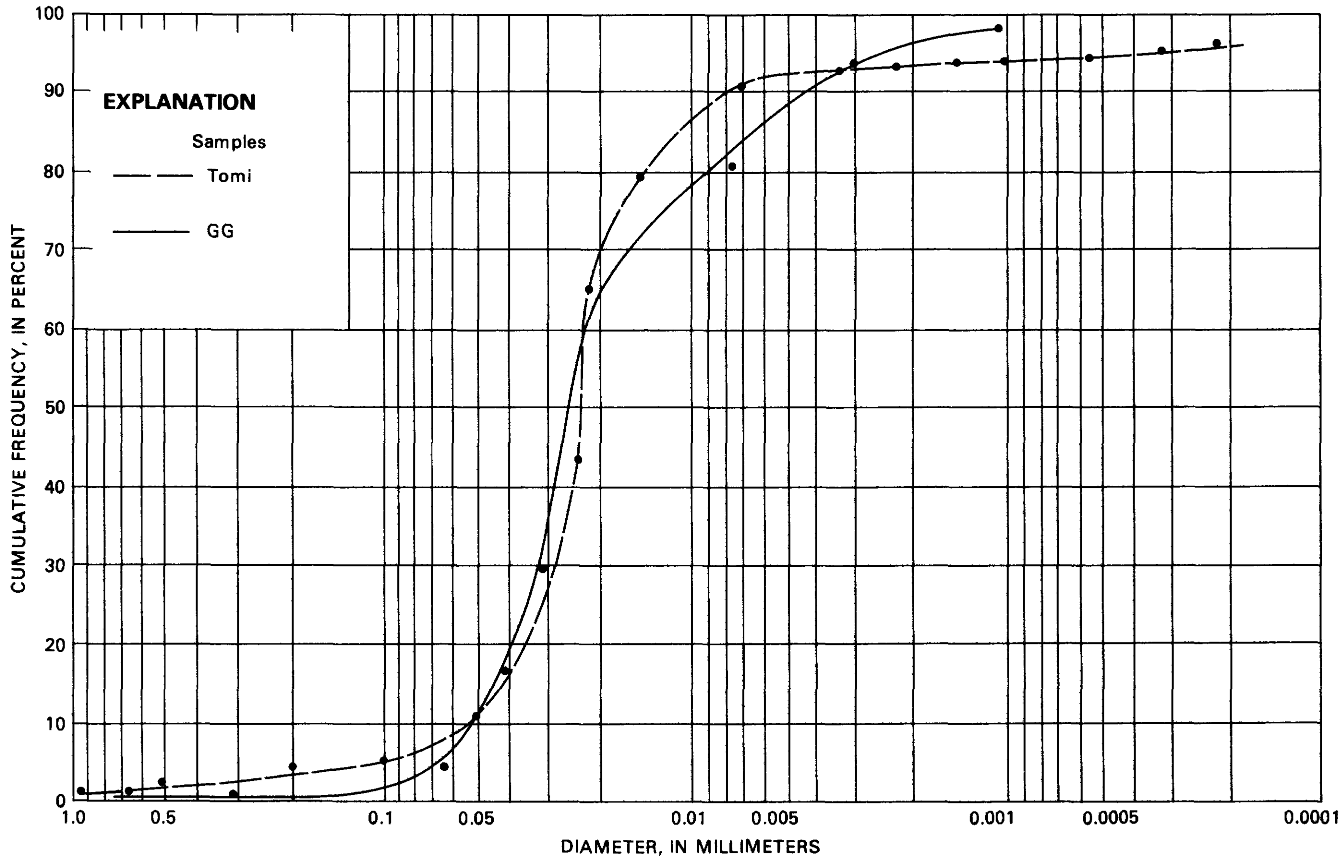


FIGURE 27.—Cumulative-frequency grain-size curves of silt from Yakutia. Sample GG is silt from weathered dolomitic limestone in crevice 147 m above Lena River, 250 km south of Yakutsk. Sample Tomi is loess from northern Yakutia (Tomirdiaro and others, 1974, table 2).

Charlesworth, 1957), though the degree of weathering would depend on the age and rate of deposition of the deposit and the effects of diagenetic processes. The silt from Yakutia, like middle and late Pleistocene loess from other parts of the world, is relatively fresh but shows some weathering under the scanning electron microscope.

The heavy-mineral content of the silt in the Lena and Aldan Rivers area (table 4) confirms the independence of the silt from the underlying deposits, in contrast to Sudakova's (1969, p. 55) claim that the microscopic component is inherited from the underlying rocks. It also indicates the general uniformity of the silt, though it can be used to distinguish the Lena River and Aldan River flood plains (fig. 24). Heavy-mineral content in loess has been used to distinguish source areas in many parts of the world (Kay and Graham, 1943; Péwé, 1955; Frye and others, 1962; Goldthwait, 1968; Journaux and others, 1969; Codarcea and others, 1972).

Summary.—Many points of similarity between the characteristics of loess and the loesslike silt in central Yakutia support the eolian hypothesis. In light of this evidence we conclude that the silt on the terraces and plateaus of the major river valleys such as the Lena, Aldan, and Vilyuy Rivers in south-central Yakutia is loess.

AGE AND CORRELATION

Glaciers pushed southward and westward from the Verkhoyansk Range in pre-Wisconsinan and Wisconsinan time, advancing almost as far as the Aldan River (fig. 4). During advances of glaciers from this range and ranges farther southeast and of continental glaciers to the west (fig. 4), braided silt-laden melt-water streams such as the Lena, Aldan, and Vilyuy Rivers flowed over wide vegetation-free flood plains and spread glacial flour over the outwash plains. Winds picked up some of the silt on the flood plains and outwash plains and redeposited it as loess on the lowlands, mainly the high terraces and low plateaus.

At least two major periods of loess deposition are recorded in the upland silt in central Yakutia, according

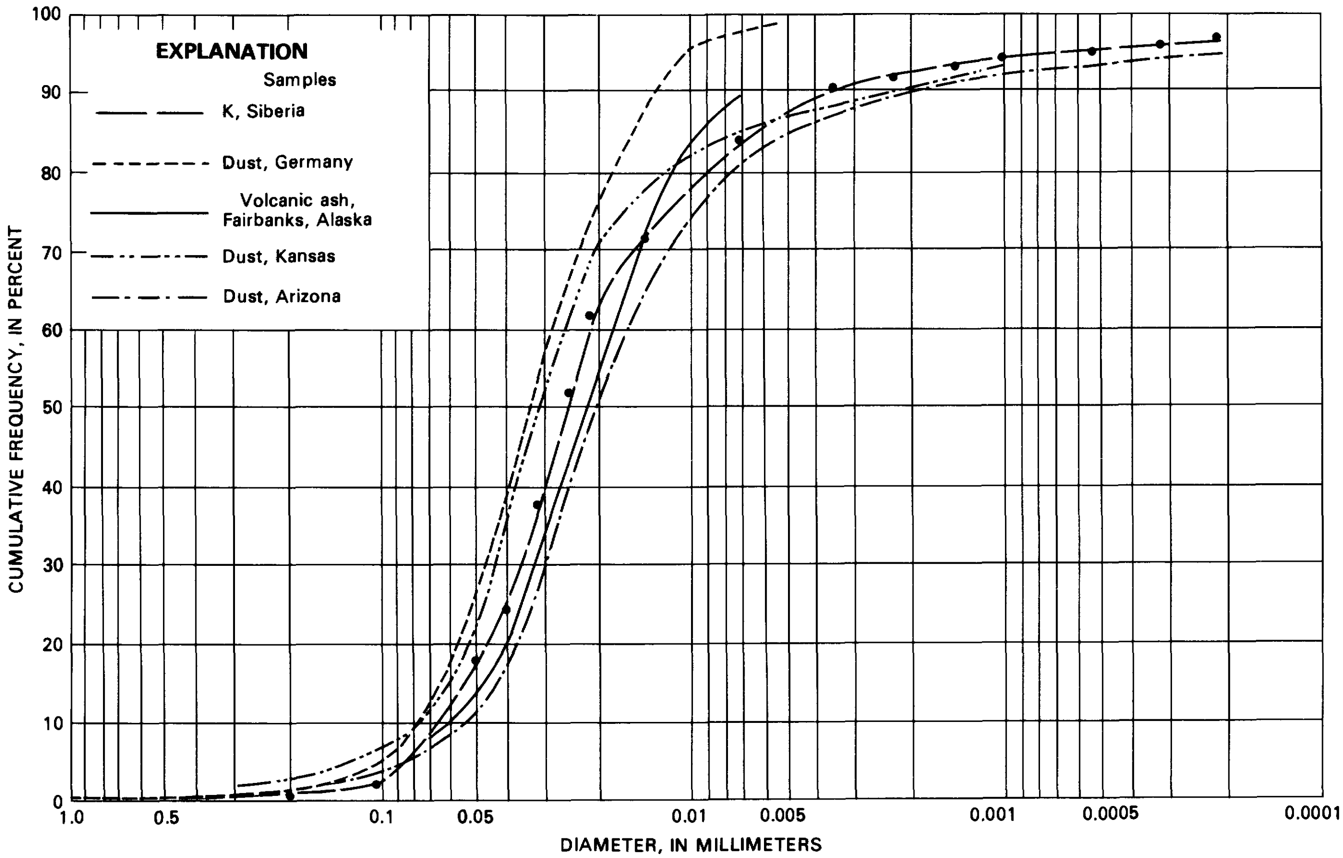


FIGURE 28.—Cumulative-frequency grain-size curves for upland silt (sample K) from near Yakutsk, volcanic ash from Fairbanks, Alaska, and modern wind-deposited dust from Germany (Zeuner, 1949, p. 27), Kansas (Swineford and Frye, 1945, p. 252), and Tempe, Ariz. Samples from Alaska, Arizona, and Siberia collected by T. L. Péwé. Siberian and Arizona samples analyzed at Centre de Geomorphologie du Centre National de la Recherche Scientifique, Caen, France; Alaskan sample analyzed by U.S. Army Corps of Engineers, Rock Island, Ill.

to Péwé and others (1977). On the basis of biostratigraphic studies and radiometric dating, we believe that the loess here is middle and late Pleistocene in age, correlative to Maximum Glaciation and later glaciations equivalent to pre-Wisconsinan and Wisconsinan glaciations in North America.

On the basis of biostratigraphic studies, Vangengeim (1961) believes that the loess first began to accumulate during the time of the Maximum Glaciation (Samarov) in the Verkhoyansk Range. Further, the silt deposits on the terraces, at least the upper part, are characterized by a late Pleistocene fauna consisting largely of numerous remains of *Mammuthus primigenius* of late type, *Equus caballus*, subsp. B. (small form), *Bison priscus* aff. *deminutus* W. Grom, and other species. The fossils are found not only at Mamontova Gora, but also elsewhere on the terraces of the Aldan River valley (Vangengeim, 1961, p. 38–39). This fauna has been described at Mamontova Gora by Motuzko and others (1969, p. 63). Giterman and Golubeva (1967, p. 237) believe that the loess on the high terraces is correlative with the Samarov (Maximum) and Zyryan Glaciations.

Much of the stratigraphic information is from the well-known section at Mamontova Gora, where perennially frozen ice-rich silt and associated flora and vertebrate fauna of late Quaternary age are well exposed. It is true that on some of the higher terraces along the Aldan, mammalian remains of older types are also present, as reported by Motuzko and others (1969) and Vangengeim (1961). This is to be expected, because the older silt could be present on the older, higher terraces. In fact, Motuzko and others (1969, p. 65) report remains of a long-horned bison and large horse in the lower silt of the 50-m-high terrace. At Mamontova Gora, Vangengeim (1961, p. 33) reports remains of an early-type mammoth and large horses in an exposure in the northern part of the area but late-type mammoths and small horses elsewhere in the area. She (1961, p. 34) believes that the older fauna was derived from the base of the silt section or from the top of the underlying sand.

Alekseev (1961, table 3) reports some early radiocarbon dates of wood from central Yakutia and one from an exposure of "clay loam/sandy loam" at a depth of 17 m on the right bank of the Aldan River, 50 km from its

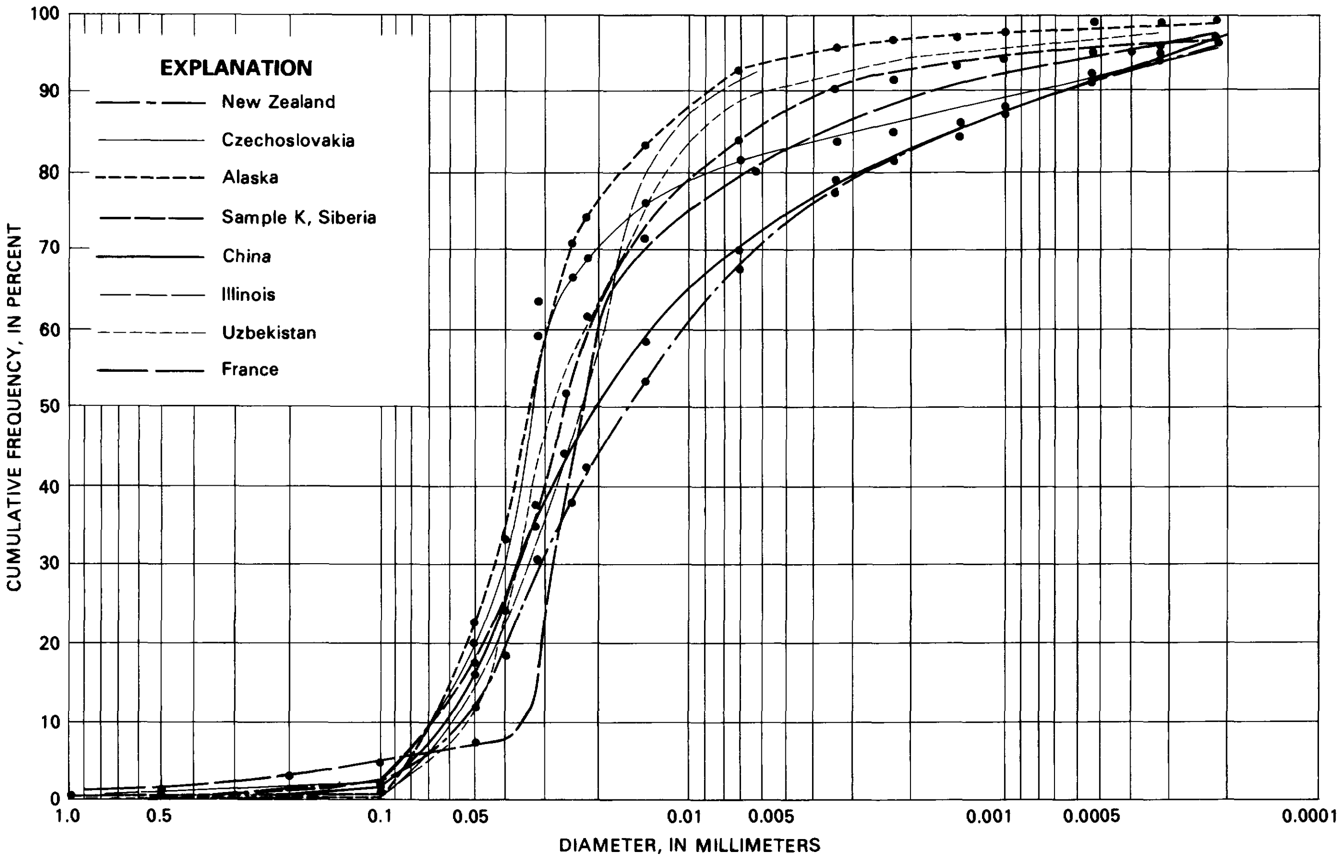


FIGURE 29.—Cumulative-frequency grain-size curves for upland silt from central Yakutia (sample K) and loess from Czechoslovakia, Alaska, Illinois, China, New Zealand, France, and Uzbekistan. Samples from all areas except Illinois analyzed at Centre de Geomorphologie du Centre National de la Recherche Scientifique, Caen, France; Illinois sample analyzed by U.S. Army Corps of Engineers, Rock Island, Ill. All samples except those from France collected by T. L. Péwé; sample from France collected by André Journaux.

mouth. The wood fragment was dated by the solid carbon method as being more than 20,000 years old.

Radiocarbon dates for what appears to be the upper loess unit where exposed in the 50-m-high terrace at Mamontova Gora have been presented in Markov (1973, p. 4–5, 163). These dates are on samples from depths of 1–8 m but not from one continuous section or from one locality; therefore, the depth below the surface does not define stratigraphy. The dates and sample depth reported are: 26,800±600 years B.P., 5.5 m; 40,600±500 years, 3 m; and 44,000±1,900 years, 8 m. We believe that the nature of erosion and deposition of these sediments is such that at a depth of 3 m in one area, the sediments may be 20,000 years old, whereas at this depth at another locality, the age may be 40,000 years. At Mamontova Gora, truncation of the top of the upper loess unit is indicated by an unconformity.

In an attempt to better understand the stratigraphy of the loesslike silt, Péwé in 1973 collected carefully located organic specimens in a vertical section at Mamontova Gora (Péwé and others, 1977). This section comprises two thick silt units and an overlying thin (1-2 m thick) silt layer of loess and retransported loess of Holocene age (fig. 30). The radiocarbon dates on the 1973 samples ranged from about 42,000 to 46,000 years B.P. for the thick upper loess and greater than 46,000 years B.P. for the thick lower loess. Samples collected by M. S. Ivanov and V. V. Kastukevich in 1974 indicate a range from about 34,000 to greater than 56,000 years B.P. for the upper loess and greater than 56,000 years B.P. for the lower loess (fig. 30). Location and dates of the radiocarbon samples, dating organizations, and location of silt samples for mineralogical and chemical examinations area shown in figure 30.

On the basis of the biostratigraphy, radiocarbon dates, and relation to the glacial record of nearby areas, we believe that the age of the upper thick loess in south-central Yakutia and the middle silt unit of Mamontova Gora, dated at 26,000 to greater than 56,000 years B.P., is Wisconsinan. This age correlates to the Sartan and Zyryan Glaciations and included interstadials and interglaciations of Siberia. Although the youngest date now available from the upper loess on the 50-m-high terrace at Mamontova Gora (26,000 years) does not provide evidence that the age of the loess corresponds to the time of the Sartan Glaciation, supposed to have begun about 25,000 years ago (Kind, 1972, p. 56–7; 1975, fig. 1), the unconformity at the top of this unit indicates truncation of the section. Kind (1972, p. 57) cites a date of 20,900±300 years B.P. from loesslike material on a terrace on the Yenisei River. Until younger dates are determined from the upper part of the upper thick loess and dates are obtained from the lower part of the Holocene silt, the relation of the upper loess

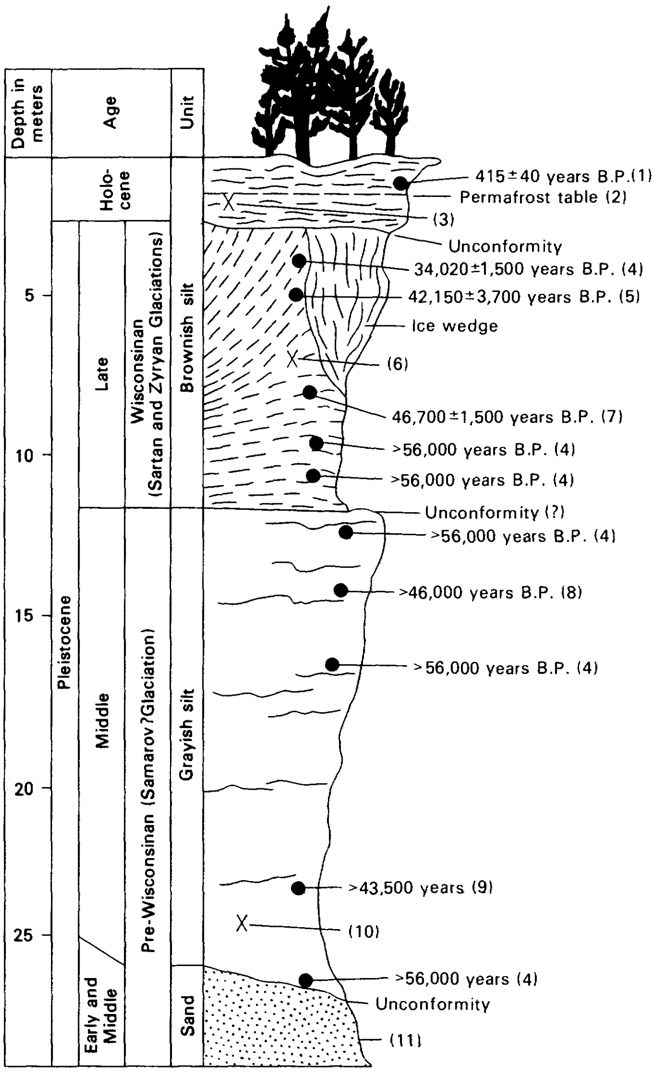


FIGURE 30.—Diagrammatic stratigraphic section of perennially frozen late Quaternary silt in the exposure of the 50-m-high (Abalakh) terrace at Mamontova Gora, left limit of the Aldan River 310 km from its mouth, central Yakutia. Radiocarbon material dated in U. S. and loesslike silt samples collected by T. L. Péwé, 1973. Radiocarbon material dated in U.S.S.R. collected by M. S. Ivanov and V. V. Kastukevick, 1974 (P. I. Melnikov, written commun., June 6, 1975). From Péwé and others, 1977 (fig. 3). (Reproduced by the courtesy of *Quaternary Research.*) (1) Radiocarbon date on a root 1 m below the surface, SI 1968 (SI numbers indicate laboratory number of Smithsonian Institution, United States). (2) Depth to permafrost is about 1-2 m under the forest. Flat-topped ice wedges indicate a lower permafrost table with thawing down to the top of ice wedges sometime in the past. (3) Loess sample G. See figure 21 for mechanical analyses; tables 3, 4, and 6 for chemical and mineralogical analyses of samples G-I. (4) Radiocarbon date from Permafrost Institute, Yakutsk. (5) Radiocarbon date on tree fragments, SI 1965. (6) Loess sample H. (7) Radiocarbon date from two small fragments of unidentified late Quaternary mammal ribs, SI 1972. (8) Radiocarbon date on wood fragments, SI 1967. (9) Radiocarbon date on wood fragments, SI 1966. (10) Loess sample I. (11) Crossbedded brown sand of early and middle Pleistocene age.

to the Sartan Glaciation is speculative. The base of the upper loess is more than 56,000 years old, and possibly as old as 100,000 years. The top may be as young as 10,000 years. No definitive dates are yet available to mark the boundaries, but we believe the boundaries will prove to be of the order of those ages.

The lower loess is definitely beyond the range of conventional radiocarbon dating. It may be Wisconsinan in age, but a Samarov age is a strong possibility, correlative with the Maximum Glaciation of Siberia and older than the last interglacial period. Mammalian remains support the hypothesis that the loess first began to accumulate in Maximum time (Vangengein, 1961; Giterman and Golubeva, 1967); if it did, interglacial beds may be found separating it from the Wisconsinan beds.

Alekseev (1970) believes that the silt beds along the lower Vilyuy River with large ice wedges and mammalian remains were deposited in the second half of the Pleistocene. He suggests that they represent a large interval of time, from the Riss Glaciation to the end of the Würm Glaciation.

It is hoped that additional dating of loess samples from the units exposed on the high terraces along the Aldan River and elsewhere will soon be undertaken.

SUMMARY

Loesslike silt mantles the upland terraces and low plateaus throughout south-central Yakutia, reaching maximum thickness along the south side of the Aldan River valley and the east side of the Lena River valley. It is well exposed in the river cuts in these areas, the greatest thickness recorded being more than 60 m on the Tyungyulyu Terrace. The texture and mineral composition are uniform throughout central Yakutia, whether the silt overlies limestone, poorly consolidated sandstone, alluvium, or glacial outwash. All loesslike silt samples examined contain a high percentage of quartz and feldspar and lesser amounts of hornblende, epidote, hypersthene, and garnet. Most samples contain a small amount of sphene, zircon, and rutile.

The loesslike silt is massive except where retransported and has developed crude stratification. Vertebrate fossils, not common in the untransported silt, are very common in the retransported silt in shallow depressions. No land snails, typical in loess deposits in some areas, have been found in these deposits.

Hypotheses advanced to explain the origin of the upland silt proposes marine, estuarine, lacustrine, fluvial, residual, or eolian sources, or a combination of these. A marine or estuarine source is unlikely because of the absence of evidence of deltas, shorelines, beaches, clay, mud cracks, ripple marks, and marine or brackish-water fossils. Moreover, such an origin would require a rise of sea level or a subsidence of the land of many meters in late Pleistocene time, an inundation not borne out by geologic evidence.

The upland silt is not of fluviatile origin because (1) it is unstratified and contains no individual beds or lenses of other sediments, (2) it occurs as a nearly continuous blanket over a surface of irregular topography with relief of 200 or 300 m and is more than 200 m above the major rivers; and (3) no fresh-water fossils are present.

The lacustrine hypothesis is strongly supported by workers studying the ice wedges in the perennially frozen ground. They believe that the loesslike silt is a combination of lacustrine and alluvial deposits formed on great flood plains and marshy plains. But there are several reasons for believing this origin unlikely. No evidence of shorelines, wave-cut beaches, or deltas are present; nor are mud cracks, ripple marks, or fresh-water fossils found. Neither stratification nor an appreciable amount of clay exists in the silt. No definite upper limit, to be expected under a lacustrine hypothesis, is present.

The hypothesis that loesslike silt is a product of the breakdown in place of the underlying rocks, mainly by frost action, has also received strong support from many workers. Evidence against this hypothesis includes: (1) the minerals in the silt are not everywhere similar to the underlying bedrock, (2) no large particles of more resistant minerals are present, (3) the silt does not become progressively coarser toward bedrock, (4) mechanical disintegration by alternate freezing and thawing could not produce untransported silt 60 m thick on flat terraces, and (5) the silt contains undisturbed carbonaceous layers.

Evidence for the eolian origin of the upland silt is abundant: (1) the silt mantles older topography, (2) it is lithologically independent of the underlying material, (3) stratification is indistinct or absent, (4) it is associated with sand dunes, (5) it contains fossils of air-breathing land animals, (6) its sorting and texture are similar to those of loess and windblown dust from many places elsewhere in the world, and (7) the grains are angular and relatively fresh.

Central Yakutia has not been glaciated. However, glaciers from the Verkhoyansk Range on the north and west as well as glaciers in the ranges south and east and the continental glacier on the west almost surrounded the interior of Yakutia during times of glacial maxima (fig. 4). We believe the upland silt to be loess deposited mainly during periods of glacial expansion by winds blowing across the unvegetated outwash plains and flood plains of glacial streams.

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