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Selenium in Glacial and Associated Deposits

Walter V. Searight

Alvin L. Moxon

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SELENIUM
In Glacial and Associated Deposits

Department of
Experiment Station Chemistry

AGRICULTURAL EXPERIMENT STATION
South Dakota State College of Agriculture and Mechanic Arts
Brookings, S. D.

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WALTER V. SEARIGHT AND ALVIN L. MOXON*

Introduction

The element selenium has been found to be the cause of poisoning of livestock and poultry in several Great Plains states, including South Dakota. Selenium poisoning is known locally under a number of descriptive names, such as "alkali disease," "frozen feet," "hoof rot," and "blind staggers." An animal suffering from chronic poisoning is commonly said to be "alkalied." Previous studies have been made in South Dakota of the stratigraphic and geographic distribution of selenium in Cretaceous and other rocks (1, 2). Certain horizons in the Cretaceous, particularly the Niobrara formation and the upper part of the Virgin Creek member of the Pierre and the Mobridge (Interior) member of the Pierre formation, have been found to be the chief contributors of selenium in soils and plants of toxic areas (2).

The occurrence of the element has been recently noted in wheat grown on soils derived from glacial materials in Saskatchewan (3). Analyses of plants from glaciated areas in Montana, North Dakota, and Canada indicate the occurrence of selenium in noteworthy amounts in glacial deposits and in soils derived from them (4, 5, 6). The selenium "indicator" plant, *Astragalus racemosus* Pursh, was collected by one of the authors on soils derived from glacial and other Pleistocene deposits in the summer of 1941 in Kingsbury and Beadle Counties, South Dakota. Analyses showed the presence of considerable amounts of selenium in some of these plants. Field studies of Pleistocene materials, soil, and "indicator" plants were made in July and August of 1942 in the localities of discovery and in the surrounding area. These studies were further expanded in July and August, 1944. Laboratory studies of glacial and associated materials, soils derived from them, and "indicator" plants were made to determine the amounts of selenium present.

In order to determine the geographic distribution of selenium and its signficance, the character and relations of Pleistocene deposits were investigated and their origin determined as far as possible. Bedrock was also studied where it was thought to be related to the occurrence of selenium in the drifts and associated deposits.

The area studied (Figure 1) extends from the Minnesota boundary westward somewhat beyond Brown, Spink, and Beadle Counties, South Dakota. The area extends from the latitude of Aberdeen, Brown County, southward to the southern boundaries of Beadle, Kingsbury, and Brookings Counties. The most detailed work was done in Brookings, Kingsbury, Hamlin, and Beadle Counties but observations were also made outside the mapped area in connection with this and related studies.

Geologic History of the Area

Eastern and northeastern South Dakota were last covered by Cretaceous seas which on retreating left a thick succession of sands and shales over a surface previously eroded down into pre-Cambrian granite and quartzite. Exposures of these ancient pre-Cambrian rocks can be seen in outcrops between Sioux Falls and Mitchell, in South Dakota, where the hard Sioux quartzite outcrops and east of Milbank, in Grant County, South Dakota, where the Milbank

*Geological consultant, Experiment Station, and Experiment Station Chemist, South Dakota State College respectively.

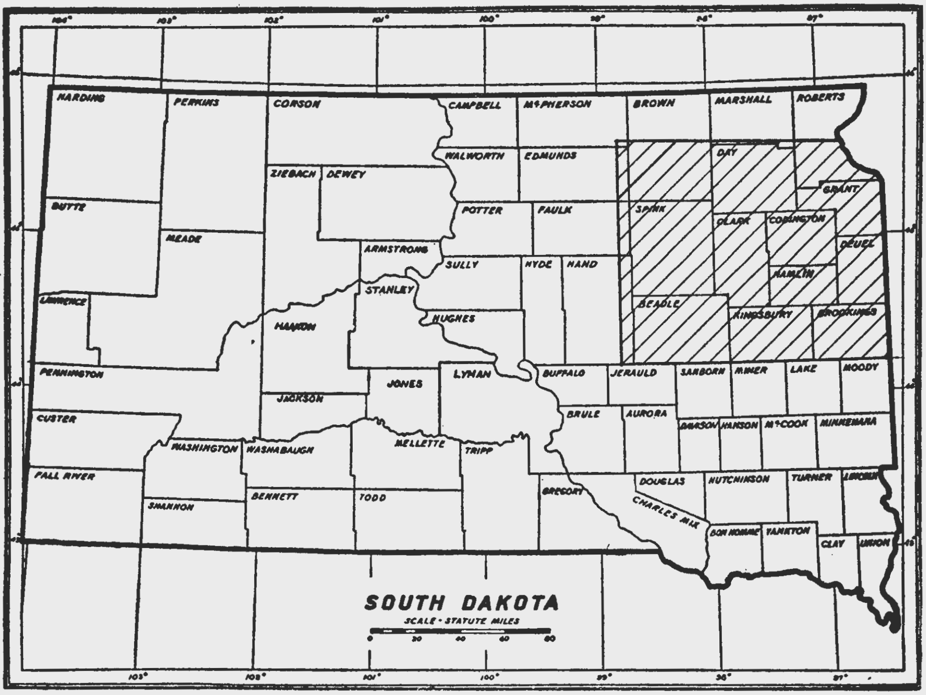

Figure 1. Map of South Dakota showing area studied.

granite is at the surface. During a long interval of erosion which followed the retreat of the Cretaceous seas, the Cretaceous rocks were cut down into the Pierre shale over most of the mapped area. In Roberts and Grant Counties, South Dakota, from Sisseton to Lake Traverse and Bigstone Lake, the Pierre was completely removed and the chalky beds of Niobrara and the Carlile shale beneath it were probably uncovered.

During the Pleistocene, or glacial period, glaciers, originating to the north, west of Hudson Bay, advanced over this surface. Although the Mississippi valley was invaded by glaciers during four Pleistocene epochs, glaciers covered parts of South Dakota, so far as is now known, in but three epochs; the Grandian, Ottumwan, and Eldoran (Figure 2). The history of the earliest ice invasion of South Dakota is obscure, but old glacial deposits along the Big Sioux river in Moody County, South Dakota, probably were left by the Nebraskan glacier. Deposits left by this glacier are well known in neighboring states, Iowa and Nebraska. Whatever may have been the extent and duration of Nebraskan ice in South Dakota, a long period of weathering and erosion known as the Aftonian age followed the retreat as is distinctly shown by the record in neighboring states. Following this long age of deglaciation the Kansan glacier advanced from its Canadian source over eastern South Dakota. At the southern boundary of the state the western edge of the ice sheet was near the mouth of the Niobrara river and the Kansan ice in South Dakota may well have spread westward beyond the present Missouri river. The deposits are well known in the Big Sioux valley and were uncovered by erosion in many places in Grant and Roberts Coun-

Figure 2. Pleistocene Classification

MISSISSIPPI VALLEY*				NORTHEASTERN SOUTH DAKOTA
PERIOD *(System)*	EPOCH *(Series)*	AGE *(Stage)*	SUBAGE *(Substage)*	FORMATIONS AND MATERIALS
PLEISTOCENE	Eldoran	Recent		Alluvium, soil, loess.
		Wisconsin	Mankato	Mankato till, gravels, sands, silts.
			Gary	†De Smet till, sands, gravels, silts.
			Tazewell	Arlington till, sands, gravels, Arlington loess and loess-like silts.
			Iowan	Iowan till, gravels and sands, Peorian loess.
	Centralian	Sangamon Illinoian		Loveland loess and sands, volcanic ash, and soil.
	Ottumwan	Yarmouth		Kansan gumbotil and weathered zone on Kansan drift
		Kansan		Kansan drift.
	Grandian	Aftonian		Weathered zone on Nebraska drift, loess or silt.
		Nebraskan		Nebraskan drift.
Pre-Cambrian through Cretaceous				Cretaceous; Carlile, Niobrara, Pierre formatoins, pre-Cambrian granite in northeastern Grant County.

*Kay, G. F., and J. B. Graham, The Illinoian and post-Illinoian Pleistocene geology of Iowa. Iowa Geol. Surv. Bul. 38:13 (1943).

†The De Smet drift may be Mankato in age.

ties, South Dakota, within the area of the map (Plate I). When the Kansan glacier had rereated, weathering and erosion again began and continued throughout the Yarmouth, Illinoian, and Sangamon ages. During the long Yarmouth interglacial interval, the Kansan drift was deeply weathered so that the material known as gumbotil believed to be the weathered residue of glacial drift, was formed on it and the upper part of the Kansan drift was deeply oxidized and leached of its soluble ingredients (7). The Illinoian glacier did not, so far as is known, invade South Dakota. During this interval erosion continued, perhaps at an accelerated rate. During Sangamon time at least a part of the Loveland formation including volcanic ash outcropping in Walworth and Gregory Counties, South Dakota, and lying beneath younger deposits in Moody and Minnehaha Counties, South Dakota, reddish brown loess, and certain sands and gravels were accumulated on the eroded surface of the Kansan. A part of these sands and gravels, however, may well have been deposited previously, during the Illinoian and Yarmouth intervals. Old soil profiles with the characteristics of a podzol or forest soil occur in Grant County (8) and in many other places in eastern South Dakota. These appear to have been formed during the latter part of the long Sangamon age.

Evidence presented in this report indicates that three or possibly four glacial advances and retreats occurred in South Dakota during Wisconsin time, instead of the two, Iowan and Mankato, previously recognized. The Iowan glacier, advancing into Iowa during early Wisconsin time spread westward over northeastern South Dakota into the Big Sioux valley across eastern Brookings, Deuel, Hamlin, Codington, western Grant, Day and southwestern Roberts Counties in South Dakota, left a thin veneer of pebbly till over the eroded surface of the Kansan. Extensive windwork followed the retreat of this glacier and boulders shaped by wind and deeply pitted by sandblasting are profuse, both at the surface of the Iowan and the older Kansan. The Peorian loess, a wind deposit so well known to the south and southeast is poorly developed in the mapped area but it is normally exposed in eastern Moody, Minnehaha, Lincoln, and Union Counties, South Dakota.

Later in Wisconsin time a second glacier, advanced down the James River valley. The deposits made during this advance and retreat have been presumed to have been made at the time of the Mankato advance but new evidence indicates that they are considerably older and that this glacier advanced and retreated before the advance of Mankato ice. The second, the Arlington, occupied the James River valley and spread south, west, and east. In the mapped area (Plate I) this ice extended nearly to the Big Sioux river, well into Brookings County, two-thirds of the distance across Hamlin County, western Codington, to the eastern boundary of Day County, South Dakota, and into an area of unknown extent to the northward. The deposits of the Arlington glacier, where they have not been removed or covered by later ice invasions produced a surface essentially as it is today, characterized by knobs and kettles and on the flatter areas by swells and swales. Sands and gravels, washed out by melt waters during the stand of the ice at its greatest development and during its retreat, are found here and there, chiefly along the eastern border of South Dakota. Large depressions, possibly large pre-existing stream valleys incompletely filled by Arlington drift, were also left as prominent features of the topography. The larger lakes of the region occupy these basins today.

The Arlington glacier in due time retreated, probably northward from South Dakota. The newly exposed surface was subjected to the usual processes which go on in a temperate climate. Wind deposition was a prominent feature of this time and silty, fine, highly calcareous material was removed from exposed surficial area both on and outside the drift. This deposit formed a thin veneer over the new surface and probably beyond it both to the east and the west. This deposit is the Arlington loess which is particularly important in eastern South Dakota as the parent material of some of the better soils of the area. In addition to wind deposition, some of these silts were reworked by water, especially in lower places. Once they were covered by vegetation they were retained in the area, particularly over the Arlington drift since streams were not then and are not now sufficiently developed to remove them. It should be emphasized that the wind deposition of late Arlington time began soon after the retreat of the early Arlington glacier and was more rapid than the processes of weathering then in operation. Time was insufficient to produce a weathered surface or soil on the Arlington drift surface or within the Arlington loess and loess-like silts.

Whether eastern South Dakota experienced one or two ice advances after the Arlington invasion has not yet been determined with certainty. There is reason to believe, however, that there were two advances: an earlier invasion in the James River valley, the De Smet, and a later one, spreading westward from the Minnesota River and Des Moines River valleys, the Mankato. The James River valley was invaded by a tongue of ice which extended southward nearly to the Missouri river and eastward to De Smet and Bristol, South Dakota. This glacier obliterated most of the surface features left in the pathway of the Arlington glacier in the James River valley, including the older Arlington loess. Precipitation was, without doubt, considerably increased outside the ice-covered area and some erosion of the surface outside the ice was begun. Erosion appears to have been relatively insignficant, however. A tongue of ice, the Mankato, also advanced down the Minnesota river and Des Moines River valleys to the location of the city of Des Moines in central Iowa. This ice extended into eastern Brookings County, most of Deuel and Grant Counties, and the eastern border of Codington, across western Roberts County into Marshall County, South Dakota, and beyond into

North Dakota. If it advanced after the retreat of the De Smet ice, which appears possible, it overrode the De Smet drift in Marshall County, South Dakota. Whatever the histories of the two ice lobes may be, they differ considerably in details. Melt water from the De Smet glacier at its maximum extent sorted out considerable quantities of sand and gravel which were carried along the eastern edge of the ice past De Smet southward into the East Fork of the Vermillion river. The retreat of the ice was marked by seven or eight stages of inactivity of the ice front during which recessional moraines were developed. The Mankato ice also retreated in several stages, five of which are represented in northeastern South Dakota by prominent moraines. Glacio-fluvial melt waters from the successive stands of the ice fronts carried immense quantities of sands and gravels into depressions and valleys where they were deposited. To the north, where the Mankato ice front crossed the Arlington drift, great deposits of gravel were deposited in the Watertown chute between the ice and the outer moraine of the Arlington and behind the moraine where gravels were poured into the Waubay lakes depression.

Some of the southward looping moraines of the De Smet retreat formed barriers behind which waters were temporarily ponded. The most important event of the kind in eastern South Dakota was the ponding of Lake Dakota behind the Redfield Hills and their morainic extension. This lake became extinct when the southern outlet was cut down to the level of the lake bottom and the waters drained out down the James River valley. Before this had occurred, however, wide areas of the upper James River valley were silted up with the cream colored loess-like silt so commonly noted in road cuts and shallow gullies throughout the Lake Dakota area.

During the De Smet and Mankato glaciations, the climate probably was considerably wetter than when the area was ice free. Ground water levels were doubtless raised and lake and pond levels were probably higher than now. Wave-cut cliffs so prominent a feature of the lake and pond basins on Arlington drift may well have been cut during such times of high precipitation. Accelerated erosion during this time may account also for the removal of much of the Arlington loess in an area immediately to the west of the Mankato moraines.

Following the retreat of the Mankato glacier but little change has been made in the surface of eastern South Dakota. Most of the soil of the region, however, has been formed since the ice melted back. Erosion of the steeper slopes, removing both soil and loess in many places, left boulders and drift at the surface.

Selenium Bearing Materials of Northeastern South Dakota

BEDROCK. The bedrock which underlies most of northeastern South Dakota is the Pierre shale of the Cretaceous period. Chalky beds under dark gumbo-like shale believed to be Pierre, which is overlain by Kansan till, outcrop at Sisseton in Roberts County, South Dakota. Along Brown Valley between Lake Traverse and Big Stone Lake, characteristic outcrops of dark shale, containing fossiliferous concretions and secondary selenite crystals characteristic of the Carlile shale, occur under an old till believed to be Kansan. Most of the Pierre shale is covered by glacial and related deposits but it outcrops in small patches in many places. Most of the outcrops are along the James River valley northeast, northwest, and southeast of Redfield, in Spink County, South Dakota, where most of it appears to be below the position of the Mobridge member. In two places at least, buff chalky marl, identical in appearance and character to the Mobridge member of the Pierre, outcrops south and southeast of Redfield. The chalky beds here lie approximately 200 feet above the position of the Niobrara as logged in the deep well at the State School and Home for Feeble-Minded at

Redfield (9). The outcrop of chalk in the SW¼ SW¼, Sec. 2, T. 115 N., R. 64 W., Spink County, South Dakota, lies at an elevation of approximately 1320 feet above sea level whereas in a road cut in the SW¼ SW¼, Sec. 14, T. 116 N., R. 64 W., Spink County, South Dakota, is at an approximate elevation of 1360 feet. The Mobridge in the Redfield Hills may attain a thickness of 40 feet or more in the higher hills. This member of the Pierre may also occur north of Redfield under Lake Dakota silts. Since the dip of bedrock from Sisseton toward Redfield is probably less than two feet per mile, the Mobridge member of the Pierre may lie immediately under the drift in places on the Coteau des Prairies. The chalky beds occur under the glacial drift in locations where the bedrock is near the surface between Redfield and Lake Preston, Kingsbury County. The Lake Preston well penetrates only 80 feet of glacial deposits before passing into the Pierre shale. The Pierre shale is 550 feet thick at this location and the base of the Mobridge member should occur at about 200 feet above the base of the Pierre. The position of the contact of the glacial drift and the Mobridge member of the Pierre is entirely concealed but it probably occurs in localities where it lies at about 1340 to 1380 feet above sea level. The contact would occur at this altitude in the general area of northwestern Kingsbury and southern Clark Counties. Pierre shale has also been reported in the escarpment west of Sisseton in Roberts County.[1]

PLEISTOCENE DEPOSITS. Pleistocene deposits constitute the surficial material of the area studied (Figure 1 and Plate I) except for small areas where bedrock outcrops. They consist of glacial till; glaciofluvial deposits of silt, sand, and gravel, most of which are outwash and valley train deposits; deposits of loess; and loess-like silt of aeolian and lacustrine origin. In addition alluvial deposits and soils of recent origin occur.

[1]Purrington, Dean R., Soil Conservation Service, personal communication, July, 1944.

Nebraskan Drift. The Nebraskan, which is drift of the oldest glaciation, is not known to outcrop within the area studied but old till under Kansan till farther south along the Big Sioux river in Moody County is probably Nebraskan. Although the Nebraskan glacier no doubt covered all of the area, the drift has either been removed by erosion or covered by later deposits. It may be of considerable extent under younger deposits in eastern South Dakota (10).

Kansan Drift. Drift deposited over the area by the melting of the Kansan ice sheet is the oldest Pleistocene deposit which occurs widespread in northeastern South Dakota. It lies at or near the surface along the Big Sioux river between the western or outermost moraine of the Mankato drift and the eastern border of the Arlington drift (Plate I). Within this area, however, it is covered by the thin Iowan drift along the eastern border and elsewhere by sands, gravels, silts, loess, and alluvium of later age. It has been uncovered by erosion outside of the main area of outcrop and it is at the surface in many places in Grant and Roberts Counties, South Dakota.

Kansan till as commonly seen is hard, reddish to dark brown, and where well exposed is deeply jointed. Where it is highly oxidized the till is yellowish buff or yellowish brown, very hard when dry and sticky and plastic when wet. In favorable situations it is leached to a depth of five or more feet. Limestone pebbles are absent but in most places secondary or original carbonates are present. The original color of unoxidized and unleached Kansan till is dark blue-gray as indicated by outcrops outside the area studied. Samples of till taken at a depth of 175 to 262 feet under 40 feet of yellow boulder clay, probably oxidized Kansan till, from a well in the SW¼ SW¼, Sec. 21, T. 113 N., R. 55 W., Hamlin County, South Dakota, were blue-gray.

The surface of the Kansan drift has been deeply eroded since deposition and presents, for the most part, a gently rolling erosional topography. Because of erosion, the maturely weathered, oxidized, and leached upper portion is rarely seen. The oxidized zone appears near the surface under soil, later glacial sand and gravel, and other mantle. In the area studied, the Peorian loess, so commonly present over Kansan drift, occurs very rarely. In most of the area, the Kansan drift is covered by thin sand, very thin loess, and loessial soil. In Moody County, however, yellow Peorian loess several feet thick lies on the Kansan drift. Boulders which commonly lie at the top of the Kansan drift are in many cases deeply sandblasted and some show wind shaping.

Wisconsin Drift. The Wisconsin drifts of different ages (Figure 2) resulting from successive advances and retreats of the Wisconsin ice sheet are divisible into at least three drifts: Iowan, Arlington, and Mankato. A fourth, the De Smet drift, appears on the map (Plate I). Field work is insufficient to show that this drift can be correlated with the Mankato drift. If the De Smet and Mankato drifts prove to be contemporaneous, the name De Smet may either be abandoned or retained for the drift of the Dakota lobe.

Early Wisconsin, Iowan Drift. An interrupted band of Iowan drift occurring mostly to the east of the Big Sioux river has been mapped by Leverett (11). Boundaries of the areas of Iowan drift shown in Plate 1 are essentially the same as those mapped by Leverett. The Iowan drift has a surface of gently rolling topography, very similar to that of the Kansan drift, however, the valleys in Iowan drift in many cases appear less well drained than those in Kansan drift. The thin but fairly uniform veneer of younger Iowan drift upon the older stream-eroded Kansan drift gives an observer the impression of constructional topography imposed upon erosional topography. Evidence indicates that the Iowan drift is of much more recent origin than the Kansan drift (12), although no terminal or recessional morainic features have been developed on it.

The Iowan drift is buff to yellowish brown, pebbly and friable or mealy in texture. It thus resembles the later Wisconsin drifts much more closely than the hard, reddish to dark brown Kansan till. Near the surface of the Iowan drift, large boulders are concentrated in a pebble band and these, like those on the Kansan drift are in many cases sandblasted and some show wind shaping. Very little loess is found on the Iowan drift. The pebble band near the top of the Iowan drift is covered by thin sand, gravel, and one or two feet of loessial soil.

Peorian Loess. Peorian loess which occurs widespread over the upper Mississippi and Missouri valleys is mostly absent over the area studied. Normally it lies on eroded Kansan and other pre-Iowan deposits. However, Peorian loess occurs in eastern Moody, Minnehaha, Lincoln, and Union Counties. The Peorian loess is usually yellowish gray, but the unleached and unoxidized deposits, which are rarely seen, are gray. White and gray calcareous concretions, known as loess kindschen, are common just below the leached zone. Particles of Peorian loess range in size from medium sand to clay, but most of them are of silt size (13). It characteristically stands in vertical columns in outcrops.

Mid-Wisconsin, Arlington Drift. Lying between the Big Sioux river and a definite moraine passing just west of De Smet a young loess and silt-covered drift occupies a broad north-south band, 28 to 30 miles wide (Plate I). Because of typical development in the vicinity of Arlington, Kingsbury County, South Dakota, this drift may be appropriately named the Arlington drift. It is this drift which forms much of the lake region of eastern South Dakota. It obliterates the drainage pattern of all streams west of the Big Sioux river. The eastern boundary rises prominently above the Big Sioux River valley in a belt of morainic topography, two to five miles wide, called the Altamont moraine by Chamberlin (14) and later by Todd (15) but now known not to be contemporaneous with that late Wisconsin moraine. On this moraine, knob-like hills and kettle-like depressions are very numerous. In many localities ten or more kettles may be seen in a single square mile. Behind the terminal moraine, where the topography becomes more gently rolling, kettles become swales and knob-like hills become swells. Other places which are higher are as rugged in topography as the terminal moraine. Both kettles and swales, even where very small are characterized by fairly steep walls composed mostly of till. The slopes of the walls range from 15° to 34° and average about 22°. The slopes above the walls are much more gentle and range from 1° to 5°. Bottoms of kettles and swales are flat where lack of water permits observation. Noses of till projected toward the basins are truncated by steep slopes, so that the basins appear to be rounded and the sides cut by wave action. This feature is not a characteristic in small basins outside the Arlington drift area, but it has been observed to be more or less common wherever the Arlington drift has been identified.

Prominent features of the Arlington drift in addition to the small basins are large basins, including Lake Poinsett, Lake Preston, Lake Thompson, Whitewood Lake, Lake Albert, Lake Norden, Waubay Lakes, and others. These basins commonly trend southwest-northeast. They seem to have no relationship to the general topography and may be related to valleys or depressions which antedate the advance of the Arlington ice sheet.

The Arlington till is buff to light brown and only moderately pebbly. However, large boulders in many cases up to several feet in diameter occur in morainic areas, particularly on steeper slopes where they have been uncovered by slopewash. In exposed positions some of these show a brilliant wind polish but, so far as has been observed, none are deeply sandblasted or wind shaped like those of the Kansan and Iowan drifts. The till is notably calcareous to its upper limit.

Arlington Loess and Silts. Loess and loess-like silt lie on the Arlington drift except on the steeper slopes and near later Wisconsin moraines. Beneath dark gray to black soil the loess and silt is brown in the upper foot or two, but below it is yellow to buff. In the thicker deposits, below the upper brown loess or silt, the color is mostly yellow or buff except in or near basins. In the thickest deposits, below a depth of three or four feet, the color is buff-gray to gray, and in many cases it is mottled with brown, reddish brown, and red. Outcrops indicate that brown, reddish-brown, and red concentrations of oxidized iron occur about vertical tubes probably left by the decay of plant roots. The loess and silt is highly calcareous and a concentration of carbonates occurs in them at a depth of two to four feet below the soil surface. A sample of loess-like silt from below the leached zone, collected six miles south of Webster in Day County, South Dakota, contained 33.0 percent carbonates most of which was calcium carbonate. Where the deposit is thickest near basins, thin laminations may be seen on recently rainwashed surfaces and thin beds of poorly to well sorted sand from a fraction of an inch up to a few inches in thickness have been observed. Four miles west of Lily in Day County, South Dakota, three feet of till, apparently reworked by creep, lies within several feet of laminated buff and gray silt of late Arlington age.

The Arlington loess and loess-like silt is thin over moderately gentle hills and it thickens near and in depressions. It is two to three feet thick including the soil derived from it. In borings and outcrops it reaches a thickness of twelve feet in and near depressions. It is absent on steeper slopes. Near later moraines it appears to be absent although a large area of it occurs within fifteen miles of the outer moraine of the Des Moines lobe of the Mankato in southeastern Day County. Patches of Arlington loess and loess-like silt have also been observed in northeastern Day County within fifteen miles of the same moraine.

Arlington Loess. The Arlington loess, in outcrops and in auger boring samples, appears to be silty in texture. Unlike the Peorian loess, however, it contains a considerable amount of clay. Samples of Arlington loess and the loess indistinguishable from it in character which lies on bedrock along the Missouri river and to the west of the Missouri river were taken for mechanical analysis to determine their clay content. Mechanical separations by subsidence methods were made (Figure 3). No deflocculent was used. The following three grades were separated: 1. coarser than 1/128 mm., 2. from 1/128 to 1/256 mm., 3. less than 1/256 mm. One typical sample contained 26 percent in the clay grade (finer than 1/256 mm.) and another contained 48.8 percent clay. Comparison of the texture of this loess with that lying on older deposits at Pierre, South Dakota, and south of Ft. Pierre, South Dakota, show that the western deposits also contain much clay. One sample of calcareous loess collected in the northern part of the city of Pierre, lying partly on Pleistocene gravel and partly on Pierre shale contained 21.2 percent clay and another sample of calcareous loess lying directly on the Pierre shale in the NW¼ NW¼, Sec. 13, T. 4 N., R. 79 W., Stanley County South Dakota, contained 28.9 percent clay (Figure 3). The loess west of the Missouri river is believed to have its source chiefly in the calcareous Mobridge member of the Pierre formation. The Arlington loess and loess-like silts appear to have been deposited soon after the retreat of the Arlington ice sheet since evidence of an intervening period of weathering is entirely lacking. They appear to be older than the De Smet moraine and the Mankato drift of the Des Moines lobe since they are not developed on these drifts. The deposits on the hills are windlaid in character and topographic position but those in and around basins appear to be in part waterlaid or at least modified by water, possibly after wind transportation.

It should be noted that similar loess and loess-like silts occur widespread outside of

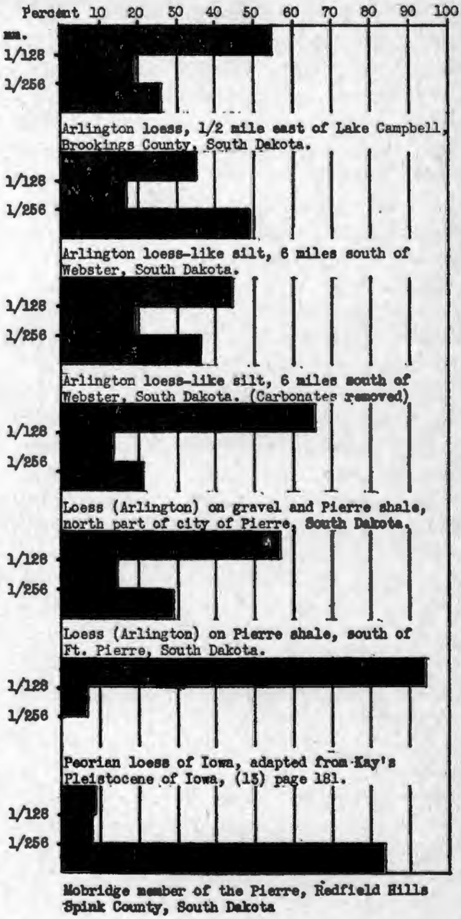

Figure 3. Particle size distribution of samples of Arlington loess, Arlington loess and loess-like silt, Peorian loess and Mobridge clay.

De Smet and Mankato deposits. Loess on glacial deposits and glacial gravel, indistinguishable from the Arlington loess, have been observed in Walworth, Potter, Hughes, Brule, and Hand Counties. It is probably the same loess reported in many places by Shearer (10). This loess is reported to occur also in western Jerauld County.[2] A windblown deposit, indistinguishable from the Arlington loess, occurs wide-

[2]Avery, Glen, Soil Conservation Service, personal communication, August, 1944.

spread on the Cretaceous driftless surface west of the Missouri river. It has been observed in Gregory, Tripp, Lyman, Jones, and Stanley Counties and it doubtless occurs in other areas west of the Missouri river. Here it is believed to be derived chiefly by wind action from the calcareous Mobridge member of the Pierre formation. The calcareous weathered Mobridge aggregates by flocculation into sand- and silt-sized particles. The larger particles are readily wind-drifted and the smaller silt-sized particles are transported in suspension as aeolian dust which when deposited is loess.

Undrained depressions, oriented northwest-southeast, believed to be blowouts due to wind erosion, are common on areas west of the Missouri river underlain by the Mobridge member of the Pierre. A sample of the Mobridge as it occurs at Redfield, South Dakota, has been mechanically analyzed to show the calcareous clay available in this member (Figure 3). The similarity of the brown loess west of the Missouri river derived from the Mobridge member of the Pierre formation and the Arlington loess suggests a common source and suggests that the western loess may also be Arlington in age.

The Arlington loess differs in color, physical characteristics, and in topographic distribution from the Peorian loess which contains but little clay (Figure 3). The Arlington loess is thin over the hills and it thickens in depressions. The Peorian loess, on the other hand, is thickest on hill tops.

The Arlington loess is the parent material of the agriculturally valuable Kranzburg soil series, which is being mapped in many places on Arlington drift.[3] The west-river loess is the parent material of the Reliance[2] soil series, a series very similar in physical properties to the Kranzburg.

Occurrence of loess in South Dakota younger than Peorian had been noted by Todd before 1898 (16). Post-Peorian loess in Nebraska has also been described, reaching a maximum thickness, in central Nebraska, of 250 feet (17). Post-Peorian Wisconsin loess is also well known in Illinois where it overlies Tazewell drift (Figure 2), (18). Like the Arlington loess of South Dakota, this deposit of loess and loess-like silt is brown, silty clay or clayey silt and is commonly only three or four feet thick but it likewise thickens in depressions. Unlike the South Dakota deposit, the Illinois loess is mostly noncalcareous. The difference in leaching between the Arlington loess and Tazewell loess seems significant but it is possibly commensurate with differences in rainfall in the two regions.

Late-Wisconsin or Late-Mid-Wisconsin, De Smet Drift. A moraine passing immediately west of the towns of De Smet, Clark, and Bristol, South Dakota, is the eastern boundary of a drift sheet which is younger than the Arlington drift (Plate I). This moraine was traced by Todd (15, 19, 20, 21, 22) and it has been checked where possible by field work and on aerial photographs. Since there is evidence that this moraine is younger than the known Mankato of the Des Moines lobe, it seems best to refer to it as the De Smet drift unless it is later proven to be the exact equivalent of the Mankato. The moraine at this position in Day County has been called the Bristol moraine by Rothrock (23), however, it apparently is a composite of four moraines. It was believed by Chamberlin (14) and Todd (15) to be the Gary moraine with which it is now known not to be equivalent.

The moraine is a prominent ridge-like feature throughout its length in the mapped area (Plate I), where it varies from two to five miles in width. The greatest width and the greatest prominence is attained to the north where it rides up over the western escarpment of the Coteau des Prairies and the Arlington drift, and where the moraine appears to be the accumulation of at least four successive stands of an ice sheet (15). Todd published detailed descriptions of the glaciated plains and moraines developed on this drift (15, 16, 19, 20, 21, 22).

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[2]Ibid p. 9.

[3]Lumb, E. R., Soil Conservation Service, personal communication, August, 1944.

The De Smet drift differs widely from the Arlington drift which lies to the east of it in the mapped area. Where drainage is good the drift is mostly buff to light brown pebbly till. In many places, however, especially in poorly drained localities the upper six or seven feet are medium to dark brown over gray and brown mottled till. Clay is a much more abundant constituent in the De Smet till than in the Arlington till. When wet, in many places the De Smet till becomes very plastic and sticky or gumbo-like; when dry, poorly drained localities show a surface efflorescence of white salts of sodium and magnesium. The De Smet till is calcareous but it does not appear to be so conspicuously calcareous as the Arlington till. Claypan or Solonetz soils are commonly developed from it. Possibly the peculiarities of the De Smet drift are due to a considerable admixture of the gumbo forming, soda- and magnesia-rich member of the Pierre shale over which the De Smet glacier moved.

Late-Wisconsin, Mankato Drift. The Mankato drift of the Des Moines glacial lobe occurs east and north of the Big Sioux river. At the southern part of the map (Plate I) it lies about twenty-two miles east of the Big Sioux river. The western boundary continues northwestward until at the north line of Codington County it lies at a distance of only eight miles east of the Big Sioux river. The boundary lies immediately east of Hurricane Lake, Roberts County, South Dakota and extends northward into North Dakota. This western boundary is the prominent moraine named the Bemis moraine by Leverett (11). The Bemis moraine which is the western boundary of the Mankato drift is shown on the map (Plate I). It has been checked wherever possible in the field and on aerial photographs and is essentially the same as mapped by Leverett. North of Hurricane Lake, this moraine was considered by Leverett to be an interlobate moraine between the Dakota and Des Moines lobes, but the Mankato overrides the Arlington drift and the continuation of the moraine northward across the De Smet boundary suggests that it overrides that drift also. From the outer moraine eastward a succession of recessional moraines, the Bemis, the Altamont, the Gary, the Antelope, and the Bigstone moraines have been mapped by Leverett (11).

Outwash and Valley Train Deposits. Gravels and sands carried out from ice-fronts as outwash and valley train deposits are abundant. The largest are associated with the Iowan, Arlington, De Smet, and Mankato moraines. These deposits do not appear on the map (Plate I) but their magnitude and location may be determined from maps by Leverett (11) and Todd (19, 20, 21, 22). For the most part these deposits occur along the Big Sioux valley and its tributaries but outwash and valley train deposits are also associated with the outer moraine of the De Smet glaciation. Some of these deposits, such as those of Six Mile Creek, Brookings County, Hidewood Creek, Deuel County, and Stray Horse Creek, Hamlin County, appear to originate in or on Iowan drift and are probably Iowan in age. Sand under silt sloping away from the outer edge of the Arlington drift is believed to be Arlington in age. Other gravels which make up the most copious and abundant deposits are outwash and valley train gravels from the Mankato ice fronts. Those from the Bemis moraine are important but those from the Antelope moraine are enormous and are believed to be the major deposits along the Big Sioux valley occurring between the northwardly narrowing area between the Arlington and Mankato drifts and in the Waubay Lake region, where Mankato gravels were poured into a depression behind the outer moraine of the Arlington drift. Most of the lake basins in Mankato deposits occur in these outwashes and in inter-morainic outwashes. Mankato gravel channels cut out Arlington drift and the overlying loess and silt where channels cut across the older deposits. An excellent exposure showing this relation was seen six miles south of Webster, in Day County, in a road cut, where a channel ten feet deep is cut into Arlington silts and is filled with Mankato gravels.

Lake Dakota Silts. A large area of creamy yellow to light buff silt covers the flat, low lying depression in the James River valley in Spink, Brown, Day, and Marshall Counties (Plate I). These even-textured silts are loess-like, and are massive. In the northern part of Brown County sands are associated with the silts. Shore features, such as wave-cut cliffs and beaches are mostly absent but gravels near Aberdeen and elsewhere may be beach gravels. The suggestion has been made by some, that the Lake Dakota deposits may be windblown (10, 24). However, the distribution of these silts at the bottom of the upper James River basin and their absence elsewhere on the surrounding drift gives credence to Todd's interpretation of the silts as deposits in a temporary glacial lake (15).

Selenium Content

In order to determine the selenium content of the various deposits described, many composite samples were taken from auger borings. A few samples were also taken as composite channel samples from fresh outcrops. Analyses for selenium content were made and the results are tabulated in Tables 2 to 31. Sample analyses were tabulated by formations and these data have been summarized in Table 1. The following information is contained in this table: (1) The total number of feet of each deposit. (2) The average selenium content per foot. (3) The number of feet of each deposit which contained less than, more than, twice, and three times the average selenium content. (4) The percent of each formation containing less than, more than, twice, and three times the average selenium content. (5) The maximum and minimum content of selenium.

These data indicate that all glacial and related formations contain selenium in amounts much less than found in such Cretaceous formations as the Niobrara and the Mobridge (Interior) member of the Pierre (1, 2). Averages of all analyses for any one formation are low, but those of one, the post-Arlington loess and silt, and the soil on these deposits are sufficiently high to be noteworthy. The maximum selenium content of samples from many of the deposits are great enough to warrant further study.

SELENIUM IN BEDROCK. Although outcrops of bedrock are extremely rare in northeastern South Dakota, several samples have been collected for analysis. These samples represent the Cretaceous Niobrara and Pierre formations which underlie the glacial drift and undoubtedly are the main sources of the selenium contained in glacial drift and associated materials. Analyses of these bedrock samples are tabulated in Table 2. All of these samples contained selenium, but most of them contained relatively small amounts. A sample of upper Niobrara which lies immediately under Pierre shale was collected at Sisseton, Roberts County, South Dakota, and contained less than 1.0 p.p.m.[4] selenium. Underlying and unexposed Niobrara, however, may be expected to contain much more selenium than was found in this sample, as the upper Niobrara is generally highly seleniferous. Dark Pierre shale, except that immediately underlying the Mobridge member in certain localities, does not contain selenium in large amounts. The selenium content of outcropping Pierre shales in the glaciated area is comparable to the selenium content of the shales where they outcrop widely. Samples of the Mobridge member of the Pierre, however, as they are exposed in the Redfield Hills contain selenium in notable amounts. A composite sample of three feet of this member exposed south of Redfield

[4]p.p.m.—parts per million.

Table 1. Summary of Selenium Content in Glacial and Related Deposits in Northeastern South Dakota

DEPOSITS	DEPTH SAMPLED	SELENIUM CONTENT* MAXIMUM	MINIMUM	AVERAGE	BELOW AVERAGE		ABOVE AVERAGE		TWICE AVERAGE		THREE OR MORE TIMES AVERAGE	
	feet	*p.p.m.*	*p.p.m.*	*p.p.m.*	*feet*	*percent of total feet*	*feet*	*percent of total feet*	*feet*	*percent of total feet*	*feet*	*percent of total feet*
Kansan and Iowan till (undifferentiated)	13.5	3.70	0.31	1.33	6.5	48	7.0[a]	52	1.0	7	1.0	7
Arlington glacial till	104.0	4.92	0.20	1.38	63.0	51	41.0	49	12.75	10	3.0	2
Arlington loess	7.5	3.24	0.27	.76	5.5	73	2.0	27	1.0	13	1.0[b]	13
Soil on Arlington loess	4.33	1.87	0.66	1.06	3.33	77	1.0	23	0	0	0	0
Arlington basin loess and loess-like silts	87.75	6.04	0[c]	1.60	51.5	57	34.25	43	10.0	12	0.5	1
Soil on Arlington basin loess and loess-like silts	20.0	8.90	0.59	3.05	13.5	67	6.5	33	4.5	27	0[d]	0
De Smet till	23.0	5.38	0.27	1.13	19.0	83	4.0	17	2.0	9	2.0	9[e]
De Smet outwash and terrace deposits	17.5	1.44	0.12	0.64	9.0	51	8.5	49	1.5	9	0	0
Mankato till	5.0	0.86[f]	0.86[f]	0.86[f]								
Wisconsin outwash, valley train, and terrace deposits outside of Arlington and Mankato drifts	29.0	3.72	0	0.65	22.5	78	6.5	22	2.25	7.8	2.25	7.8[g]
Lake Dakota silts	8.0	2.92[h]	1.17	1.83	5.0	62.5	3.0	37.5	0	0	0	0
Mankato lake silts, terrace above Lake Hendricks	5.0[i]	1.75	0.86	1.22	2.0	40	3.0	60	0	0	0	0
Soil on Wisconsin outwash valley train, terrace deposits outside Arlington and Mankato drifts	9.0	1.91	0	0.66	7.0	78	2.0	22	2.0	22	0	0
Soil on De Smet outwash	2.0	1.51	1.05	1.28[j]	1.0	50	1.0	50	0	0	0	0
Mankato outwash or lake terrace deposits	4.0	4.45[f]	4.45[f]	4.45[f]								

*Selenium determinations reported in this bulletin were made by the method of KLEIN, A. K. Report on selenium. Jour. Assoc. Off. Agr. Chem. 24:363-380. (1941).
[a]Includes 4 with average content.
[b]One foot 4 times average.
[c]Three feet only at map location No. 15.
[d]Fifteen percent within 0.25 p.p.m. of three times average.
[e]Two feet with more than 5 times average.
[f]One sample only.
[g]Of the total sample 2.25 feet were more than 4 times average and 1.5 feet were more than 5 times average.
[h]Frankfort, South Dakota, map location No. 4.
[i]One section of two samples.
[j]Two one-foot samples.

Table 2. Selenium in Bedrock in Northeastern South Dakota.

MAP LOCATION	LOCATION	FORMATION AND KIND OF ROCKS	APPROX. ELEV.	THICKNESS	SELENIUM CONTENT
No.			*ft.*	*ft.*	*.pp.m.*
—	Sisseton, Robert County, South Dakota	Uppermost Niobrara, light gray to nearly white chalky marl	1239	5	0.31
6	SW¼, Sec. 7, T. 115 N., R. 60 W., Spink County, South Dakota	Pierre shale, dark to nearly black	1350	5	1.21
....	NW¼, Sec. 11, T. 107 N., R. 65 W., Jerauld County, South Dakota	Pierre shale, brown mudstone	1545	4	1.56
8	Sec. 21, T. 114 N., R. 62 W., Spink County, South Dakota, along James River	Pierre shale*	1220		2.09
5	SW ¼, Sec. 2, T. 115 N., R. 64 W., Spink County, South Dakota	Pierre, Mobridge member soft yellow or light tan chalk, weathered	1320	3	6.4
3	SW¼, SW¼, Sec. 14, T. 116 N., R. 64 W., Spink County, South Dakota	Pierre, Mobridge member, buff to white and gray chalk	1320	5	15.0
31	SE¼, Sec. 18, T. 110 N., R. 52 W., Brookings County, South Dakota	Pierre (?), Mobridge member (?). Inclusion of buff chalk, 2 x 3 feet in Arlington till, weathered			0.86

*Collected by M. E. Kirby.

in the SW¼, Sec. 2, T. 115 N., R. 64 W., Spink County, South Dakota, although weathered and probably partly leached, contained 6.4 p.p.m. selenium, well within the range of average selenium content of this rock underlying areas known to be toxic. A sample composited from five feet of only slightly weathered Mobridge exposed in SW¼ SW¼, Sec. 14, T. 116 N., R. 64 W., Spink County, South Dakota, contained 15.0 p.p.m. This concentration is above the average for this member in many toxic areas. The Mobridge member of the Pierre, lying beneath the glacial drift under the Redfield Hills and elsewhere, is a most likely source for selenium in the drift.

SELENIUM IN THE GLACIAL TILLS. All samples of glacial till analyzed contained selenium varying in amounts from 0.20 p.p.m. in a sample of the Arlington till up to 5.38 p.p.m. in a Mankato till sample from the Dakota lobe. The average selenium content per foot of glacial till was 1.26 p.p.m. The highest average selenium content of the tills sampled is that of the Arlington till with 1.38 p.p.m. Nearly half of the total feet of Arlington till contained more than the average; ten percent twice the average; and two percent three or more times the average amount of selenium. Although a relatively few feet of Kansan and Iowan till were sampled the average selenium content suggests that these tills do not vary widely from the average of all till in the area. In these older tills which were analyzed, the average selenium content, 1.33 p.p.m., closely approximates that of the Arlington, 1.38 p.p.m. (Table 1). Small amounts of selenium are prevalent in the Kansan as indicated by the content of a five-foot composite sample of blue, unleached, and unoxidized till collected at the bottom of University Hill, Vermillion, in southeastern South Dakota, which contained 2.31 p.p.m. selenium. The selenium content of the Mankato till from the Des Moines lobe is only 0.86 p.p.m. The fact that only five feet of this deposit was sampled and that relatively large amounts of selenium were found in lacustrine or outwash deposits of the Mankato age, suggests that the Mankato till of this lobe cannot be presumed to be less seleniferous than other till of the region.

Samples from borings and outcrops show wide vertical and lateral variation in selenium content. These variations are due in part to variations in the original selenium content with textural and lithologic differences. Redeposition of selenium after concentration, or secondary enrichment is responsible for many variations in selenium content. Both lateral and vertical variations are shown in Tables 3 to 31.

Table 3. Samples of Lake Dakota silts exposed 1.5 miles west of Frankfort and in Frankfort, Spink County, S. D. (map location No. 4, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	THICKNESS	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-16	Silt, buff to cream colored, fine, uniform textured, thinly laminated	5	1.17
42-G-17	Silt, buff to cream colored, under soil two feet thick	3	2.92

Table 4. Sample of black Pierre shale from outcrop on Lake Mirage, 8.5 miles south of Doland, Spink County, S. D. (map location No. 6, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	THICKNESS	SELENIUM CONTENT
		ft.	*p.p.m.*
	Till, buff, pebbly	10±	not sampled
	Boulder bed of granites laid flatwise to three feet in diameter	2	not sampled
42-G-15	Shale, dark, nearly black when wet, 1.5 inch bentonite at about the middle	5	1.21

Table 5. Sample of Mankato till in barrow pit 3 miles north of Clear Lake, Deuel County, S. D. (map location No. 7, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	THICKNESS	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-37	Till, buff, gray and rusty mottled, fine, tough, contains secondary salts	5	.86

SELENIUM IN OUTWASH, VALLEY TRAIN, AND TERRACE DEPOSITS. The selenium content of glacio-fluvial deposits and glacio-lacustrine deposits associated with the Arlington and Mankato tills varies both vertically and laterally. In many cases, variations are related to texture of the deposits. Silts, as a rule, contain more selenium than sands, and sands with interstitial clay and silt contain more selenium than clean uniformly sorted sands, even where the different textures are interbedded. Although the number of locations sampled scarcely permits broad generalizations and comparisons the data indicates that the selenium content of the glacio-fluvial and lacustrine deposits is comparable with that of the tills from which they were derived. The maximum amount of selenium (Table 1) occurred in a four-foot boring sample of Mankato outwash or temporary glacial lake deposit washed out from the Mankato ice front. This sample contained 4.45 p.p.m. of selenium.

Table 6. Sample of Arlington Silt and Outwash Gravel from Roadcut 1.5 Miles South and 4 Miles West (on Highway 81) of Castlewood, Hamlin County, S. D. (map location No. 9, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	THICKNESS	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-38A	Silt, khaki buff	4	.55
42-G-38B	Silt, gray	3	1.17
	Gravel, exposed	7-8	not analyzed

SELENIUM IN THE ARLINGTON LOESS. Loess on hills of Arlington drift contains selenium in variable amounts. Samples analyzed ranged between 0.27 p.p.m. and 3.24 p.p.m. of selenium. Since only 7.5 feet were sampled the range may actually be somewhat greater. Evidence indicates that the average selenium content is less than that of the equivalent basin loess and loess-like silts, probably because of greater leaching at higher levels and concentration downslope.

SELENIUM IN THE ARLINGTON BASIN LOESS AND LOESS-LIKE SILTS. The selenium content of the Arlington loess and loess-like silts which lie on the Arlington till, at and near the bottoms of basins of glacial origin, is established by adequate sampling and analyses. Analyses show a wide range in selenium content from no selenium up to 6.04 p.p.m. The average of 1.60 p.p.m. selenium per foot is somewhat higher than that of the Arlington till. A set of borings made in the SW¼ SW¼, Sec. 33, T. 111 N., R. 53 W., Kingsbury County, South Dakota, (Figure 4) through loess and silts into the Arlington till shows an increase in selenium content in both the loess and the till below, from the hilltop toward the depression. The section and the analyses of the samples suggests that selenium is leached from deposits at higher elevations and carried in solution downslope, where it is deposited by evaporation and other processes. Two borings (Figure 5) through the loess and silt in the NE¼ NE¼, Sec. 28, T. 112 N., R. 56 W., Kingsbury County, 180 feet apart, the higher boring beginning 10 feet above the lower, corroborate the view that selenium is dissolved, carried to lower elevations and there concentrated. The loess at the higher position is 7.5 feet thick, not including the soil, and it averages 1.09 p.p.m. selenium. At the lower position the loess and silt is 10 feet thick without the soil and averages 3.97 p.p.m. selenium, more than three times the average at the higher elevation. The increase is actually much greater since the loess and silt at the lower position is 1.33 times as thick as at the higher position. Furthermore, the soil in the higher boring yielded 1.44 p.p.m. whereas soil at the lower boring contained 3.94 p.p.m. and was twice as thick. Additional evidence of selenium leaching from higher levels is provided by analyses of water from the first location cited. Ground water from the upslope side of the pond (Figure 4) contained 760.0 p.p.b.[5] selenium but that from the downslope side contained only 80.9 p.p.b. This is a concentration of about nine to one. The water of the pond contained 21.9 p.p.b. of selenium.

SELENIUM IN GLACIAL LAKE SILTS. Two composite samples from an outcrop under a terrace above Lake Hendricks (map location 12) on the Des Moines lobe in Minnesota near the South Dakota line, and two from Lake Dakota silts (map location 4) contained selenium. The lowest selenium content was 0.86 p.p.m. and one sample, a three-foot composite of Lake Dakota silts contained 2.92 p.p.m. selenium. Another sample, a six-foot composite, which may be either lacustrine or outwash (map location 12) contained 4.45 p.p.m. selenium.

[5] p.p.b.—parts per billion.

SLENIUM IN SOILS ON THE ARLINGTON BASIN LOESS AND LOESS-LIKE SILTS. The highest average amount of selenium (3.05 p.p.m.) occurring within the area was in samples of soil developed on the loess and loess-like silts in depressions on the Arlington till. The maximum content (8.90 p.p.m.) was also found in a sample of this soil. The average is nearly three times that of the soil developed on the equivalent loess at higher elevations. The maximum content (8.90 p.p.m.) is nearly five times the maximum content of the upland loess (1.87 p.p.m.). The higher values in these soils at lower positions is probably related to the migration of selenium in ground water.

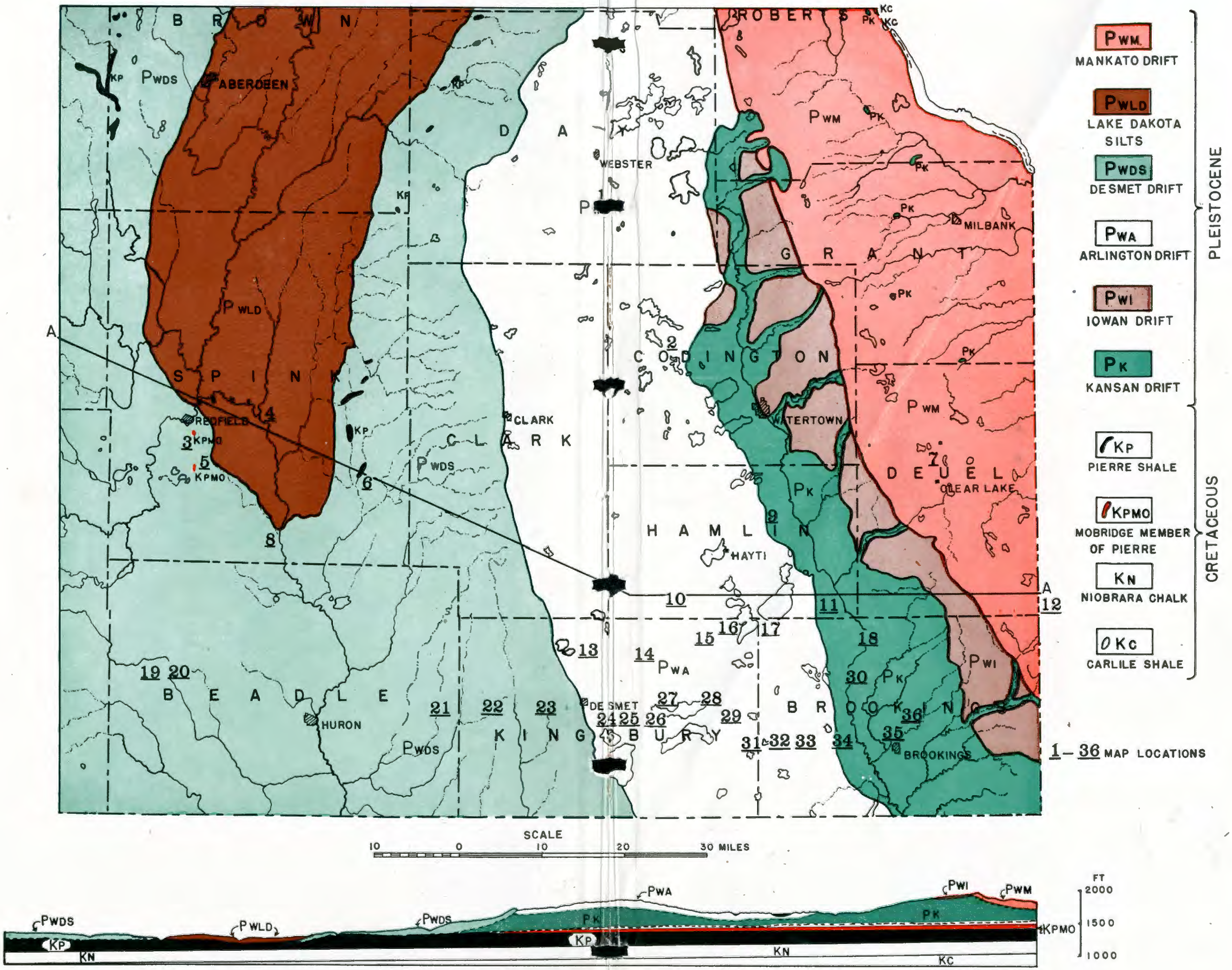
Table 7. Samples of Arlington loess-like silt exposed in wave-cut cliff under terrace 15 to 20 feet above water in pond in NE¼ SE¼, Sec. 29, T. 113 N., R. 54 W., Hamlin County, S. D. (map location No. 10, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
	Soil, black	2-3	not sampled
42-G-33A	Silt, buff	3	.97
42-G-33B	Silt, gray, with root tubes, rusty mottling	4	1.01
	Log of well on Robert Fuhr farm in SW¼ SW¼, Sec. 21, T. 113 N., R. 55 W., Hamlin County, S. D. samples of material between 35 and 135 feet were collected by Mr. Fuhr and were used for selenium analysis.		
	Loam, black	0-5	
	Gravel	5-35	
42-G-32	Clay, blue (Arlington)	35-135	1.83
	Clay, yellow (oxidized Kansan)	135-175	
	Clay, blue (unoxidized Kansan)	175-262	
	Sand	262-263	
	Clay, blue	263-316	
	Sand	316-320	

Table 8. Samples of soil and Arlington silt from borings, west line of SW¼, Sec. 33, T. 113 N., R. 51 W., Hamlin County, S. D. Boring 42-G-26 in NW¼ SW¼, Sec. 33, T. 113 N., R. 51 W.; 42-G-27 550 feet south of boring 42-G-26; and 42-G-28 south side of SW¼ SW¼, Sec. 33, T. 113 N., R. 51 W. (map location No. 11, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-26	Soil, brown loam	0-0.75	.27
42-G-26	Silt, brown to light brown, salts concentrated in lower part	.75-2	.23
42-G-26	Sand, silty	2-3	.20
42-G-27	Soil, black, becoming brownish-black in lower 6 inches	0-2	1.91
42-G-27	Soil, black, brown cast	2-3.75	.27
42-G-27	Silt, buff, sandy lower 4 inches	3.75-4.5	2.7
42-G-27	Silt, buff brown, rusty, water at bottom	4.5-6.75	.54
42-G-27	Sand, poorly sorted, brown, interstices clay filled	6.75-8	.11
42-G-27	Sand, pebbly, poorly sorted, brown, interstices clay filled	8-10.5	1.05
42-G-27	Sand, coarse, poorly sorted, interstices clay filled	10.5-12	3.72
42-G-27	Sand, poorly sorted, gray, considerable clay	12-13.5	.78
42-G-28	Soil, brown, slightly modified silt	0-1.5	.59
42-G-28	Silt, buff, small pebbles	1.5-2.5	.27
42-G-28	Sand, gray, interstices largely clay filled, plastic when wet, poorly sorted, pebbles to .75 inch in diameter	2.5-3.5	.23

PLATE I



GENERALIZED CROSS SECTION ALONG LINE A – A.

Table 9. Composite samples from roadcut of Mankato lacustrine sands and silts, 2 miles north of Lake Hendricks, Minnesota. (map location No. 12, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	THICKNESS	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-35A	Silt, lake, from terrace two miles north of Hendricks, Minnesota, and directly east of Astoria, S. D., brown and gray, (reduced) mottled, secondary carbonates, kindschen in lower part	3	.86
42-G-35B	Sand and silt, mostly sand	2	1.75
	Roadcut sample taken 1.25 miles east of Hendricks road on Minnesota Highway No. 68		
42-G-36	Silt, buff, secondary carbonates in lower part	4	4.45

Table 10. Samples of soil, Arlington silt and Arlington till from NE¼ NE¼, Sec. 28, T. 112 N., R. 56 W., Kingsbury County, S. D. (map location No. 13, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-13A	Soil, black, gypsum in lower few inches	0-2	3.94
42-G-13A	Clay, dark, silty, secondary $CaSO_4$ or $CaCO_3$	2-3.67	4.49
42-G-13A	Silt, gray, with kindschen	3.67-4	2.96
42-G-13A	Silt, gray-brown, ferruginous spots	4-8	6.04
42-G-13A	Silt, ferruginous	8-12	1.76
42-G-13A	Till, brownish ferruginous spots, few pebbles	12-16	3.57
	Second boring 180 feet north, up slope, beginning 10 feet above top of 42-G-13A boring		
42-G-13B	Soil, dark, silty	0-1.5	1.44
42-G-13B	Silt, buff, lacustrine, secondary $CaCO_3$ at bottom	1.5-3	.88
42-G-13B	Silt, buff, secondary $CaCO_3$ or $CaSO_4$	3-4.25	1.09
42-G-13B	Silt, buff, somewhat ferruginous	4.25-7	1.01
42-G-13B	Silt, buff, very ferruginous, $CaCO_3$ kindschen in lower part	7-9	1.37
42-G-13B	Till, buff, ferruginous	9-10	3.55

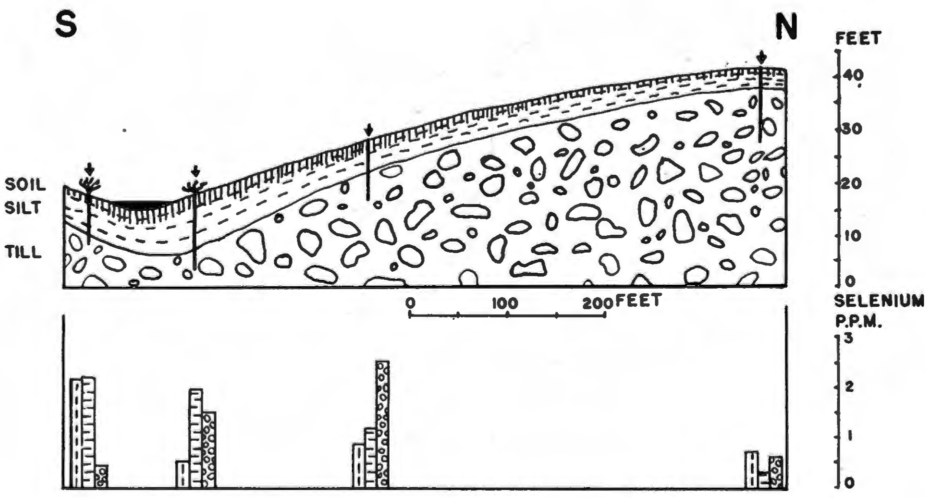


Figure 4. Cross-section showing four auger borings in SW¼ SW¼, Sec. 33, T. 111 N., R. 53 W., Kingsbury County, South Dakota. (Table 24) (map location No. 29, Plate I)

Table 11. Boring samples of deposits encountered 8 to 10 feet below top of silt-covered terrace in SW¼, Sec. 22, T. 112 N., R. 55 W., Kingsbury County, S. D. (map location No. 14, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-34	Soil wash, four inches; buff silt; secondary salts at bottom	0-1	.39
42-G-34	Silt, buff, with secondary salts, silty fine gravel, poorly sorted, buff or brown in lower six inches	1-2	.43
42-G-34	Gravel, much clay, mottled gray and brown secondary carbonates, gray patches, bottom foot mottled buff or brown and light gray with rusty spots	2-4	3.98
42-G-34	Silt, khaki-colored, few rusty spots	4-5	1.72
42-G-34	Till, buff, tough, contains small pebbles	5-6.5	.32

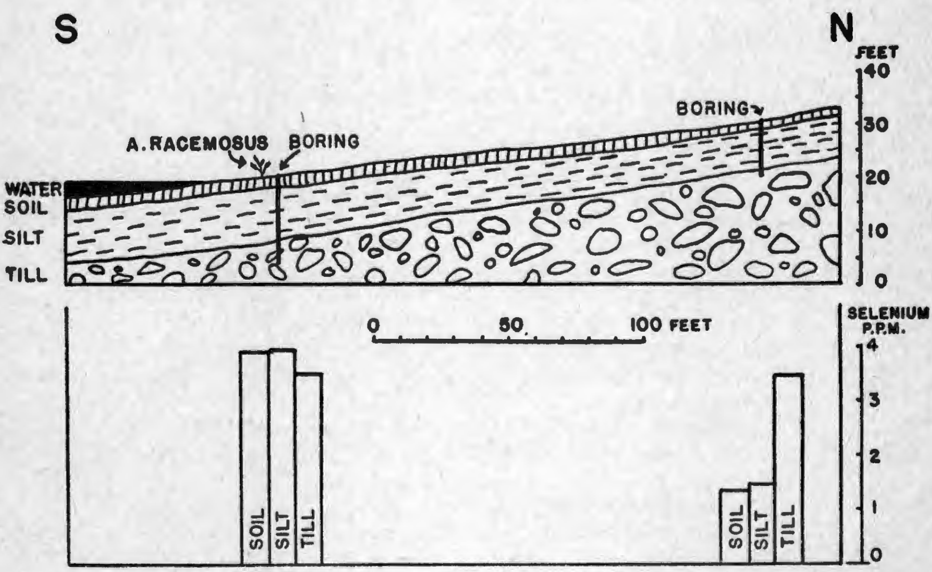


Figure 5. Cross-section showing two auger borings through silt and till in NE¼ NE¼, Sec. 28, T. 112 N., R. 56 W., Kingsbury County, South Dakota. (Table 10) (map location No. 13, Plate I)

SELENIUM IN GROUND WATER. Ground water samples of size adequate for analysis were obtained from four of the borings made in the area. All contained selenium. Two of these were obtained from borings north and south of the pond in the SW¼ SW¼, Sec. 33, T. 111 N., R. 53 W., Kingsbury County, South Dakota (Figure 4), where the ground water surface lies within the basin loess and silt. The ground water from the boring south of the pond contained 80.9 p.p.b. selenium and the water sample from north of the pond contained 760.0 p.p.b. selenium. The water came to within five feet two inches of the surface at the south side of the pond, which was three feet eight inches below the level of the water in the pond. At the north, water raised in the boring to within four feet two inches of the surface which was two feet eight inches below the surface of the pond. The former boring was made twenty feet south of the pond and the latter thirty feet north of the pond.

Water was obtained from a boring in the NE¼ NE¼, Sec. 13, T. 112 N., R. 54 W., Kingsbury County, at a depth of five feet in Arlington till. This water contained 24.2 p.p.b. selenium. In another boring a little more than one-fourth mile south of the last

Table 12. Samples of glacial till from borings along north-south road east of Sec. 13, T. 112 N., R. 54 W., Kingsbury County, S. D. 42-G-22 in NE¼ NE¼, Sec. 13, T. 112 N., 54 W.; 42-G-23 in SE¼ NE¼, Sec. 13, T. 112 N., R. 54 W.; 42-G-24 in NE¼ SE¼, Sec. 13, T. 112 N., R. 54 W.; 42-G-25 in NW¼ SW¼, Sec. 18, T. 112 N., R. 53 W. (map location No. 15, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-22	Soil, dark brown, rubbery, clay, lower three inches contain secondary salts	0-1	.78
42-G-22	Till, buff or gray brown, calcareous, iron oxide spots at bottom	1-2	.94
42-G-22	Till, buff or brownish gray, $CaCO_3$ in white spots, iron oxide patches abundant in lower part	2-3.5	.74
42-G-22	Till, mottled brown, reduced light gray patches, limonite spots and white spots of $CaCO_3$	3.5-5	2.11
42-G-22	Till, buff, with rusty spots, sugary gypsum in lower three inches, water at five feet below surface	5-6.5	1.79
42-G-22	Till, buff or light gray brown, much mottled with limonite and light gray, limonite reduced in lower few inches	6.5-7.75	2.22
42-G-22	Till, light to medium gray, rusty brown mottled	7.75-8.5	.82
42-G-22	Till, mostly dark gray with occasional nearly black spots and rusty mottling here and there	8.5-10.5	1.17
42-G-22	Till, gray, rusty patches here and there, mostly unoxidized till	10.5-13.5	1.6
42-G-23	Soil, black, becoming lighter and brownish tinged toward bottom	0-1.5	.98
42-G-23	Silt, nearly black, humus-stained	1.5-2.5	.59
42-G-23	Silt, buff, loess-like	2.5-3.5	1.09
42-G-23	Till, buff, pebbly in lower part, secondary gypsum in lower inch	3.5-5	.20
42-G-23	Till, buff, pebbly, little secondary salts near top, rusty spots throughout	5-7	.51
42-G-23	Till, buff, secondary carbonates	7-8	3.32
42-G-23	Till, buff, passing into mottled till at base	8-9	.47
42-G-23	Till, buff, some rusty spots	9-10.5	.35
42-G-24	Soil, black	0-1.5	.59
42-G-24	Soil, brown, nearly black	1.5-3	.27
42-G-24	Silt, gray to buff gray, water at top	3-4.5	.43
42-G-24	Silt, gray to buff, much iron oxide stained, brown to ocher yellow	4.5-6.5	.12
42-G-24	Silt, gray, high iron oxide content in limonite pellets and rusty mottling	6.5-9.5	.00
42-G-24	Till, upper half-foot silt, much limonite stained	9.5-12.5	.66
42-G-25	Soil, brown silt loam, nearly black in top three inches	0-1	1.87
42-G-25	Silt, yellow to buff, salt concentration in lower three inches	1-3	.63
42-G-25	Till, sandy, some secondary salts, few limonite spots in lower few inches	3-4	.27
42-G-25	Till, sandy, buff or brown, some secondary salt spots, occasional rusty spots	4-5	.00
42-G-25	Till, light brown, bright red iron oxide spots, mottled with rusty spots	5-8	.35

in the NW¼ SW¼, Sec. 18, T. 112 N., R. 53 W., Kingsbury County, water was obtained three feet below the surface in basin loess or silt of Arlington age. The water in this boring contained 24.9 p.p.b. selenium. The positions of the last two borings are shown in Figure 6. No selenium was detected in a water sample taken from a well of unknown depth on the hill between these borings.

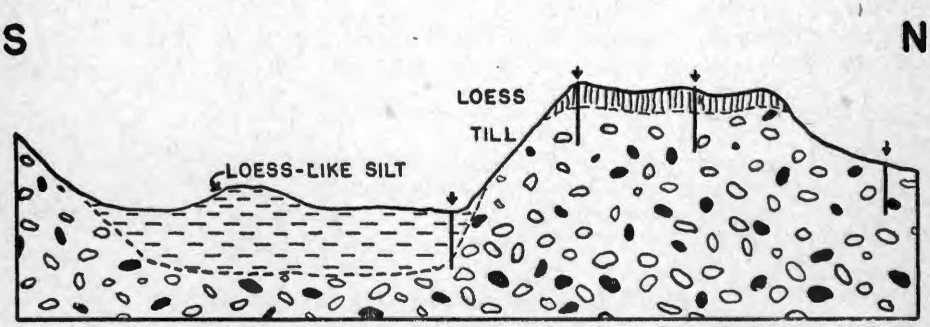


Figure 6. Cross-section showing auger borings along north-south road east of Sec. 13, T. 112 N., R. 54 W., Kingsbury County, South Dakota. See table 12 for complete description of location. (map location No. 15, Plate I)

Table 13. Samples of Arlington loess, till and silt collected in outcrop and borings on ridge extending into Lake Albert, Sec. 2, T. 112 N., R. 53 W., Kingsbury County, S. D. (map location No. 16, Plate I)

SAMPLE NO.	DESCRIPTION OF MATERIAL	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
	(Outcrop Samples)		
42-G-9B	Soil, loessial, 65 feet above lake level	1-3	not analyzed
42-G-9B	Till	3-8	.5
42-G-9B	Till	8-13	.4
42-G-9B	Till	13-18	1.25
42-G-9B	Till	18-23	3.51
	(Boring Samples)		
42-G-11A	Soil, dark, nearly black	0-1	.71
42-G-11A	Loess, buff or brownish buff	1-2	3.24
42-G-11A	Till, buff, pebbly	2-4	1.68
42-G-11A	Till, buff, pebbly, reddish in lower part	4-6	1.75
42-G-11A	Till, pebbly, reddish	6-10	1.87
42-G-11A	Till, pebbly, reddish, possibly thin gravel	10-12	.86
	(Outcrop in draw toward north end of ridge)	THICKNESS	
42-G-9A4	Soil, black, mucky, 22 feet above lake level	3	1.17
42-G-9A3	Silt, gray	3	2.34
42-G-9A2	Silt, gray, kindschen in lower part, pebbly at base	5	2.57
42-G-9A1	Till, brown, somewhat sticky, lower part gray, unoxidized	6	.5

Table 14. Samples of Arlington silt and outwash from boring in NE¼ NE¼, Sec. 17, T. 112 N., R. 50 W, Brookings County, S. D. .35 mile south of northeast corner on north-south road. (map location No. 18, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-29	Soil, black	0-2	.27
42-G-29	Silt, gray, rusty mottling, very plastic	2-4.5	.12
42-G-29	Silt, gray, much yellow to dark brown iron oxide staining and mottling, sandy in lower part	4.5-5.5	.39
42-G-29	Sand, yellow to brown, limonite stained, mostly fine, little coarse, interstices clay filled	5.5-7.5	.31
42-G-29	Sand, poorly sorted, interstices clay filled, rusty patches	7.5-9	.27
42-G-29	Sand, poorly sorted, brown, brownish-red stained	9-10	.59
42-G-29	Till, blue gray, rusty at top	10-10.5	.98

Table 15. Miscellaneous samples analyzed for selenium.

SAMPLE NO.	DESCRIPTION OF SAMPLE	THICKNESS	SELENIUM CONTENT
		ft.	*p.p.m.*
Composite sample of glacial till sampled 5.8 miles east of Wessington, Beadle County, S. D., Highway 14. (map location No. 19, Plate I)			
42-G-52	Till	5	2.07
Composite sample glacial till sampled 8 miles east of Wessington, Beadle County, S. D. Highway 14 (map location No. 20, Plate I)			
42-G-53	Till	5	5.38
Composite sample, unleached, unoxidized Kansan till, University Hill, Vermillion, Clay County, S. D.			
42-G-54	Till, dark bluish-black to black	5	2.31
Composite sample, lake silt collected 2.9 miles west of Wessington Springs, Jerauld County, S. D.			
	Silt, lacustrine (?), under gravel	3±	.49

Table 16. Auger boring samples of De Smet till from roadcut north of highway in SE¼ SW¼, Sec. 35, T. 111 N., R. 59 W., Beadle County, S. D. (map location No. 21, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-41	Till, gumbo checking on surface, gray and brown mottled, secondary salts	0-3	.31
42-G-41	Silt, light, rusty brown, with root tubes, waterlaid	3-4	.51
42-G-41	Till, brown, with much rusty brown mottling, plastic, contains secondary salts	4-5	.66
42-G-41	Till, brown, very much rusty mottling, mottling from limonite brown to nearly black	5-6	.43
42-G-41	Till, light brown, much rusty mottling in upper part, water at bottom	6-7.5	1.13
42-G-41	Till, buff or light brown, dark brown around pebbles	7.5-8.5	.63

SELENIUM IN SURFACE WATER. Two samples of surface water were analyzed, one from the pond in the SW¼ SW¼, Sec. 33, T. 111 N., R. 53 W., Kingsbury County, South Dakota, (Figure 4), and the other from a pond in the NE¼ NE¼, Sec. 28, T. 112 N., R. 56 W., Kingsbury County (Figure 5). Both of these ponds lie in depressions in Arlington till overlain by Arlington loess or silt. Both contained selenium, the former 21.4 p.p.b. and the latter 85.5 p.p.b. Comment has been made on the fact that the pond at the first location is above the surrounding ground water levels.

Table 17. Auger boring samples of soil and De Smet till made 2.35 miles west of Manchester, Kingsbury County, S. D., on U. S. Highway 14. (map location No. 22, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-21	Soil, black loam	0-1.5	.86
42-G-21	Clay, probably modified glacial till, dark brown, humus stained, gypsum pockets	1.5-4	.98
42-G-21	Till, brown, pebbly, some gypsum in upper few inches, ferruginous spots	4-7	.27
42-G-21	Till, buff to light brown pebbly, limonite patches	7-8.5	.47
42-G-21	Till, buff, ferruginous spots	8.5-9	.70
	Astragalus racemosus Pursh sample 1941		1,500.00

Table 18. Auger boring samples of soil and De Smet outwash taken in NW¼ NW¼, Sec. 36, T. 111 N., R. 57 W., Kingsbury County, S. D., on low terrace 4 miles west of De Smet, S. D. (map location No. 23, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-40	Soil and silt; black soil, ¼ foot; buff silt, ¾ foot	0-1	1.05
42-G-40	Silt, buff, with secondary salts	1-2.5	.55
42-G-40	Gravel, rusty, with secondary salts	2.5-3.5	1.33
42-G-40	Gravel, slightly rusty, some weathered granite	3.5-5	1.44
42-G-40	Gravel, like above	5-8	1.21

Table 19. Auger boring samples of soil and De Smet outwash taken NW¼ SE¼, Sec. 36, T. 111 N., R. 56 W., Kingsbury County, S. D., 100 feet west of bridge, north of road just outside of right-of-way. (map location No. 24, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-39	Soil, black to gray, sandy in lower six inches	0-1	1.51
42-G-39	Sand, light gray, much secondary salts	1-2	.66
42-G-39	Sand, gray, much secondary salts but less than in overlying sand	2-3	.97
42-G-39	Sand, gray	3-4	1.05
42-G-39	Sand, buff, gray, and brown mottled	4-6	.23
42-G-39	Sand, buff and gray mottling, some brown mottling, water at 7.5 feet below surface	6-7.5	.12
42-G-39	Sand, buff to light brown, stained, somewhat coarser than above	7.5-10	.39
42-G-39	Silt, gray with rusty to dark brown mottling	10-11.5	.39
42-G-39	Silt, light gray with rusty to dark brown mottling	11.5-13.5	.90

Table 20. Auger boring samples of soil, Arlington silt and till from SE¼ SE¼, Sec. 31, T. 111 N., R. 55 W., Kingsbury County, S. D. (map location No. 25, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-31A	Soil, black, salts in lower two inches	0-1	2.06
42-G-31A	Soil, very dark, much granular gypsum	1-2.25	2.26
42-G-31A	Silt, light gray, buff mottled, much gypsum	2.25-3	3.71
42-G-31A	Silt and sandy silt, buff to brown, considerable granular gypsum, ferruginous mottling	3-4.25	1.79
42-G-31A	Till, light gray and ferruginous mottling	4.25-4.5	4.92
	Boring beside *Astragalus racemosus* Pursh plant, two feet lower than 42-G-31A		
42-G-31B	Soil, black, some gypsum in lower three inches	0-1.5	5.35
42-G-31B	Silt, gray, much granular gypsum, secondary carbonates in lower three inches	1.5-3	1.17
42-G-31B	Till, sandy on top, more clay in lower part, rusty brown to light gray, some granular gypsum	3-4.5	1.99
42-G-31B	Till, sand and clay, brown, plastic, water at six feet	4.5-6.75	1.56
42-G-31B	Till, definite at 6.75 feet, buff to brown, ferruginous spots, reduced light gray patches	6.75-8	3.28
42-G-31B	Till, gray and brown mottled, much ferruginous material	8-10	1.09
42-G-31B	Till, brown, much rusty limonite, some granular gypsum in upper part	10-12	4.68
42-G-31B	Till, brown, numerous rusty spots	12-13.5	2.18

Table 21. Auger boring samples of Arlington silt, clay and till from SW¼ SW¼, Sec. 34, T. 111 N., R. 55 W, Kingsbury County, S. D. (map location No. 26, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-30A	Silt, gray	0-1	2.85
42-G-30A	Silt, gray kindschen in upper six inches, ferruginous mottling in lower part	1-2	1.68
42-G-30A	Silt, slightly sandy, buff, lower three inches very ferruginous, gray patches	2-3.75	.24
42-G-30A	Gravel, fine, poorly sorted, much clay binder, reddish brown, very ferruginous	3.75-5	.51
	Boring started six feet below top of 42-G-30A, twelve feet from 42-G-30A		
42-G-30B	Clay, gypsum crystals, reduced patches at bottom	0-1.25	1.05
42-G-30B	Silt, brown, granular gypsum, light gray reduced patches	1.25-1.75	1.01
42-G-30B	Clay, brown, probably glacial till, granular crystals of gypsum, small pyrite crystals	1.75-3	1.05
42-G-30B	Clay, brown, probably glacial till, much iron oxide, some gypsum, light gray mottling, few small pebbles	3-4.5	2.73
42-G-30B	Clay, brown, plastic, probably glacial till, very fine, few small reduced patches	4.5-5.5	.90
42-G-30C	Clay, brown, abundant gypsum, ferruginous group mottling	0-1	.98
42-G-30C	Clay, brown, much gypsum (small crystals), very ferruginous patches	1-1.5	5.94
42-G-30C	Till, very fine, rusty, dark brown mottling, some black (manganese?) spots	1.5-3.5	1.91
42-G-30C	Till, buff to light brown, limonite yellow to dark brown to black (manganese?), less mottling than above	3.5-4.5	1.05
42-G-30C	Till, brown, plastic, small pebbles, some iron oxide mottling	4.5-5.5	1.68
42-G-30C	Till, light brown, small pebbles numerous, few red limonite spots	5.5-7.5	.90

Table 22. Samples of soil, Arlington silt and till from natural outcrop in gully north or Lake Preston in the SE¼ SW¼, Sec. 30, T. 111 N., R. 54 W., Kingsbury County, S. D. (map location No. 27, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	THICKNESS	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-12S	Soil, black, modified lake silt	3	8.9
42-G-12S	Silt, gray, thinly laminated, iron-stained along joints	1.5	2.46
42-G-12S	Silt, gray, like above, kindschen abundant in lower three feet	5	.31
42-G-12S	Till, brown, pebble concentrate at top, mottled with gray near top along the joints	2	.19
42-G-12S	Till, brown, pebbly, very rusty in spots, contains root tubes along which iron oxide is concentrated	5-8	.54

Table 23. Samples of soil and Arlington silt exposed in cutbank on east end of Lake Preston where roadcut opens upper part of terrace, which lies about 25 feet above present (1941) lake level, Kingsbury County, S. D. (map location No. 28, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-20	Soil, black	0-1.25	1.95
42-G-20	Silt, buff, high salt concentration	1.25-3.5	1.91
42-G-20	Silt, gray, mottled with rust	3.5-5	.66

Table 24. Boring samples of soil, Arlington silt and till, from SW¼ SW¼, Sec. 33, T. 111 N., R. 53 W., Kingsbury County, S. D. (map location No. 29, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-18A	Soil, black	0-1.5	.9
42-G-18A	Silt, brown and black mottled, dark, nearly black	1.5-4.5	.27
42-G-18A	Silt, gray, reddish, and brown mottled	4.5-7.5	1.72
42-G-18A	Silt, dark and light gray, mottled with rusty and brown spots	7.5-10.5	2.3
42-G-18A	Till, rusty and brown mottled, some gray reduced patches	10.5-13.5	1.56
42-G-18A	Till, brown	13.5-14.5	.98
42-G-18B	Soil, black	0-2	.94
42-G-18B	Silt, buff, secondary salts present	2-3	2.69
42-G-18B	Silt, rusty, salt concentration greatest at bottom	3-5	.51
42-G-18B	Till, mottled brown, rusty, 2-3 inches of sand with clay at top, brown and light gray, pebbly	5-7	.7
42-G-18B	Till, brown changing to drab in lower part	7-9.5	3.2
42-G-18B	Till, buff to brown	9.5-13	3.0
42-G-18C	Soil, black	0-2.5	2.1
42-G-18C	Silt, dark, nearly black, rather tenacious	2.5-4.5	3.2
42-G-18C	Silt, drab, water six feet below surface	4.5-6	1.02
42-G-18C	Silt, gray, becoming rusty in lower part	6-8	2.18
42-G-18C	Till, buff, gray, and brown mottled, pebbly	8-10.5	.39
42-G-18D	Soil, brownish black	0-.83	.66
42-G-18D	Loess, buff and brown, salt concentration in lower inch	.83-2.25	.35
42-G-18D	Loess, gray, salt concentration	2.25-3.25	.27
42-G-18D	Till, brown, becoming rusty in bottom inch, some gray mottling	3.25-4.5	.47
42-G-18D	Till, buff and brown, bright red patches, limonite brown, ocher yellow appears	4.5-5.5	.86
42-G-18D	Till, buff and brown, limonite brown, ocher yellow, ironstain on pebbles	5.5-7.0	.74
42-G-18D	Till, buff and brown mottled, few red spots, many iron-stained patches, much dark brown iron oxide in lower six inches	7-12	.78
42-G-18D	Till, brown with many iron oxide patches	12-13.5	.86

Table 25. Composite samples from outcrop of till in the NE¼ SE¼, Sec. 12, T. 111 N., R. 51 W., Brookings County, S. D. (map location No. 30, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-47A	Till, buff, pebbly, pebbles most numerous at top, calcareous	0-2.5	2.31
42-G-47B	Till, buff, pebbly, calcareous	2.5-5	1.21
42-G-47C	Till, gray to rusty gray	5-7	1.83

Table 26. Auger boring samples of soil, Arlington silt and Arlington till from SE¼ SW¼, Sec. 18, T. 110 N., R. 52 W, Brookings County, S. D. (map location No. 31, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-10A	Soil, modified silt, calcareous	0-1	1.5
42-G-10A	Silt, brown, traces of secondary $CaCO_3$	1-2	1.4
42-G-10A	Silt, mottled gray to reddish brown $CaCO_3$, concretion (kindschen)	2-3	.9
42-G-10A	Silt, gray, heavily iron-stained (lower part), calcareous, root tubes	3-4	.4
42-G-10A	Silt, gray lacustrine	4-5	.6
42-G-10A	Silt, gray lacustrine on hard rock	5-6	.4
42-G-10B	Silt, red and gray mottled, sticky highly calcareous	0-1	2.5
42-G-10B	Silt, gray mottled, highly calcareous	1-2	1.7
42-G-10B	Silt, gray, iron-stained, sticky, highly calcareous	2-3	2.7
42-G-10B	Silt, gray, lower part heavily iron-stained highly calcareous	3-4	3.3
42-G-10B	Silt, reddish brown, calcareous	4-5	2.2
42-G-10B	Silt, gray, slightly iron-stained, calcareous	5-6	2.5
42-G-10B	Silt, brown, sticky, calcareous	6-7	2.7
42-G-10B	Silt, brown, secondary carbonates	7-8	1.9
42-G-10B	Silt and sand, few pebbles, brown, calcareous, saturated with H_2O	8-9	2.4
42-G-10B	Till, sandy, small pebbles	9-10	1.3
42-G-10B	Till, sandy and sticky brown clay, calcareous	10-11	1.8
42-G-10B	Till, pebbly clay, sticky	11-12	1.5

Table 27. Samples of soil and Arlington till exposed, north side of road in roadcut, 1.75 miles east of Brookings County line. (map location No. 32, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-19	Soil, pebbles and cobbles scattered throughout, black and sandy in upper part, brownish-black below	0-2.17	1.41
42-G-19	Till, zone of salt concentration, gray colloids on joints, pebbly, brown, rubbery, gray reduced patches in lower four to six inches	2.17-4.17	1.13
42-G-19	Till, brown and gray mottled, reddish brown and bright red patches in spots	4.17-8.5	.86
42-G-19	Till, buff to brown, pebbly, light gray along joints. White powdery gypsum on joints, some gray patches	8.5-12	1.21
42-G-19	Till, buff to light brown, some reduction and little gypsum	12-17	1.17

Table 28. Boring samples of Arlington silts on outwash in Volga, west side, north of highway, Brookings County, S. D. (map location No. 34, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-43	Soil, black	0-1	.00
42-G-43	Silt, buff to light brown	1-2	.31
42-G-43	Silt, buff or khaki colored	2-4	.51
42-G-43	Silt, buff, sandy in lower six inches	4-6	.00
42-G-43	Sand, buff, silty	6-7	1.09

Table 29. Sample of till 1.3 miles north of first section line north of Brookings, Brookings County, S .D. (map location No. 35, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-44	Till, buff or gray, mealy, pebbly, highly calcareous, with secondary carbonates	0-1	.98

Table 30. Samples of till outcropping in NE¼ SE¼, Sec. 2, T. 110 N., R. 50 W., Brookings County, S. D. (map location No. 36, Plate I)

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-45	Till, yellow or buff, under pebbly concentrate, highly calacreous	0-1	3.70
Samples of till from section exposed in NW¼ NW¼, Sec. 1, T. 110 N., R. 50 W., Brookings County, S. D.			
42-G-46	Soil and loess	1-2	
42-G-46	Concentrate, pebbly	2-2.5	
42-G-46	Till, buff, mealy	2.5-6.5	
42-G-46	Till, brown, breaks in small polygonal pieces, calcareous (Kansan)	6.5-10.5	1.33

Table 31. Composite sample of glacial till and Pierre shale from outcrop in the NW¼, Sec. 11, T. 107 N., R. 65 W., Jerauld County, S. D.

SAMPLE NO.	DESCRIPTION OF SAMPLE	DEPTH	SELENIUM CONTENT
		ft.	*p.p.m.*
42-G-51	Till, gray to buff	0-3	.66
42-G-50	Shale, brown mudstone under till	3-4	1.56

SELENIUM IN "INDICATOR" PLANTS. A consistent selenium "indicator" plant, *Astragalus racemosus* Pursh, has been collected at numerous places in the area (Plate I). The plant occurs on the Arlington till, on the Arlington loess and loess-like silt, and on the De Smet drift. In keeping with the view that selenium is necessary for the growth of this plant (25) and that specimens of the plant are rarely completely free of the element, all specimens collected in the area contained more or less selenium (Table 32). The selenium content, however, is commonly much less than that of specimens collected from highly seleniferous Cretaceous formations, such as the Niobrara or the Mobridge member of the Pierre. Some specimens from the glaciated area, however, are comparable with the moderately high content of specimens collected on Cretaceous formations and none, possibly because of the limited number of localities available, are as low as those which occasionally occur on the Cretaceous formations (2).

All specimens of *Astragalus racemosus* Pursh collected on the Arlington till were growing well above the water level including one case where a plant was found growing on a steep bank sixty-two feet above the level of Lake Albert in the northeast corner of Kingsbury County. The average selenium content of eight of these plants growing at various positions in the Arlington till and above drainage was 209.3 p.p.m. The minimum content was 37.8 p.p.m. selenium and the maximum amount was 351.8 p.p.m. selenium. Many specimens of the plant in toxic areas fall within this range or below the minimum of these specimens on glacial drift (2).

Astragalus plants were collected from three locations on the De Smet drift (Plate I) and (Table 32). The samples contained 131.6, 320.0, and 1,570.0 p.p.m. selenium. The lowest concentration of these was only

Table 32. Selenium content of *Astragalus racemosus* Pursh growing in Pleistocene deposits

DEPOSIT	MAP LOCATION	DATE SAMPLED	TOPOGRAPHIC POSITION	SELENIUM CONTENT
				p.p.m.
Arlington till	16	July, 1942	high	312.8
Arlington till	16	July, 1942	high	45.6
Arlington till	16	July, 1942	high	277.7
Arlington till	16	July, 1942	high	37.8
Arlington till	16	July, 1942	high	154.5
Arlington till	16	July, 1942	high	154.2
Arlington till	17	June, 1944	high	340.2
Arlington till	2	July, 1942	high	351.8
Arlington loess*	31	July, 1941	high	16.0
Arlington loess	31	July, 1942	high	64.9
Arlington loess	26	July, 1942	low	575.0
Arlington loess	26	July, 1943	low	381.0
Arlington loess	25	July, 1942	low	400.0
Arlington loess	25	July, 1942	low	500.0
Arlington loess	24	July, 1941	low	310.0
Arlington loess	29	July, 1942	low	2,000.0†
Arlington loess	29	July, 1943	low	2,374.0†
Arlington loess	29	June, 1944	low	3,134.0†
Arlington loess	33	June, 1944	low	401.7
Arlington loess	1	July, 1944	low	5.5
De Smet drift	22	July, 1941	low	1,570.0
De Smet drift	23	July, 1941	low	320.0
De Smet drift	21	July, 1943	medium	131.6

*Include loess-like silts.
†See Figure 4.

slightly lower than the average of those collected from the Arlington till. The average for these plants growing on the De Smet drift is somewhat more than three times that of the average for those growing on the Arlington till. The average value is comparable with the selenium content of *Astragalus racemous* Pursh in toxic areas on the Cretaceous formations (2). The greater selenium content is probably not related to the geological formation on which plants were grown but rather to more favorable topographic position and movement of selenium in the subsoil.

Several samples of *Astragalus racemous* Pursh grown on Arlington loess and loess-like silts have been analyzed for selenium. Analyses of these exhibit the widest range in selenium content of any plants growing on Pleistocene deposits. The lowest concentration of selenium was found in a sample collected in 1944 (map location 1) which contained only 5.5 p.p.m. selenium whereas the highest concentration was in a sample collected in 1944 (map location 29) which contained 3,134.0 p.p.m. selenium. This high concentration is well within the range of the higher values for the same species growing on toxic Cretaceous areas (2). The selenium content of samples of *Astragalus racemosus* Pursh taken from toxic Cretaceous areas seldom exceeds the maximum content of these plants found on Pleistocene deposits. In preceding paragraphs reference has been made to the greater average selenium content of the Arlington loess and loess-like silts and the relation of topography to selenium content of soils and parent materials. The lower values of selenium in *Astragalus racemosus* Pursh were from plants at high topographic position, whereas the higher concentrations were in plants growing in poorly drained or undrained depressions.

Solubility of Selenium in Pleistocene Deposits

In spite of evidence indicating that selenium is dissolved and concentrated downslope, it appears that but little water soluble selenium occurs in Pleistocene deposits. Several determinations of soluble selenium from various deposits have been made, and the results have been tabulated (Table 33). The percentage of the total selenium which is soluble varies in these analyses from zero to 25.4 percent. Some samples from very different deposits contained no soluble selenium. A sample of Lake Dakota silts, contained a relatively large percentage of soluble selenium, in fact more than one-fourth of the selenium in the sample was water soluble. This is more than three times the percentage of soluble selenium in the second most soluble sample, a sample of Arlington loess, and more than six times that of the third most soluble sample. It thus appears that most of the selenium contained in Pleistocene deposits is not soluble in pure water. Possibly soluble selenium compounds are dissolved as fast as they are formed. That which has been in solution and has been deposited downslope may be precipitated in an insoluble form. It may be that part of the selenium is in the form of

Table 33. Solubility of selenium in various Pleistocene deposits.

SAMPLE NO.	DEPTH	DEPOSIT	TOTAL SELENIUM	SOLUBLE SELENIUM	
	feet		*p.p.m.*	*p.p.m.*	%
42-G-11A	1-2	Arlingon loess	3.24	0.24	7.4
42-G-17	2-5	Lake Dakota silt	2.92	0.75	25.4
42-G-18B	7-9.5	Arlington till	3.2	0.13	4.1
42-G-27	10.5-12	Arlington outwash	3.72	0.14	3.8
42-G-27	2-4	Arlington gravel interbedded with silt	3.98	0.00	0.0
42-G-36	4-8	Mankato lake silt	4.45	0.00	0.0
42-G-45	3-5	Kansan till	3.70	0.00	0.0

sodium compounds and part of it in the form of calcium compounds in which case the more soluble sodium compounds would be leached out more rapidly than the calcium compounds. The amount of soluble selenium (25.4 percent) contained in the sample of Lake Dakota silt is fairly large. Olson, Whitehead, and Moxon (26) have found as much as 65 percent of the selenium in a subsoil, from a toxic area, in a soluble form. Under conditions where selenium is moving downslope and accumulating in poorly drained depressions, one would expect to find a higher percentage of the element in a soluble form in the area of accumulation than higher up on the slope. This condition was actually demonstrated at map location 29, Plate I, Figure 4, and Table 32 where *Astragalus racemosus* Pursh plants were collected which contained over 2,000 p.p.m. of selenium.

Sources of Selenium in Pleistocene Deposits

The glacial deposits of northeastern South Dakota as previously indicated are a mixture of coarse to fine rock materials obtained by glacial erosion from the rock surface over which the glaciers passed. The selenium which they contain was thus obtained from the rocks over which the glaciers moved. Deposits associated with the glacial drifts are clays, silts, sands, and gravels which were, for the most part, sorted out by glacial and interglacial waters and by wind. Loess, carried in suspension by wind, may have been derived, perhaps in a large part, from sources other than the drift area and may possibly include in addition to the portion removed from the drift, much material from the driftless area to the west of the Missouri river. Thus the glacial drifts, and the areas over which the glaciers moved, are the sources from which the selenium of all the Pleistocene deposits, excepting part of that in the loess, were obtained.

Examination of the glacial deposits of the area shows that the coarse materials of the drift, and of the sands and gravels are, with rare exceptions, of material foreign to the region, from far northern, chiefly Canadian sources. These apparently contain little, if any, selenium and cannot be considered to be sources of more than traces of the element. Most, if not all, of the selenium is contained in materials of a texture less than 1/16 mm. in diameter, the textural range of silt and clay, indeed, most of it is in the clays of less than 1/256 mm. in size. The fine silts and clays probably constitute about half the materials of the till and more than ninety percent of the loess and silts.

Mechanical separations of seven kinds of glacial and associated materials were made by the subsidence method (27) into grades: one coarser than 1/128 mm., one from 1/128 to 1/256 mm., and one finer than 1/256 mm. (Figure 7). By the method used the coarser grades were recovered and weighed and the finest grade determined by difference. Selenium determinations were made on the coarser grades and selenium of the 1/256 mm. grade was determined by difference from the selenium content of the whole sample. Aggregates present in the samples were not broken by crushing other than in the hand and no attempt to redistribute aggregated material was made. In many cases, therefore, some selenium is trapped in aggregates and appears in the analyses in textural grades coarser than it should. The analyses show conclusively that most of the selenium if not all, occurs in grades finer than 1/128 mm. and that the element is associated with the clays in whatever deposit they occur.

All of the glaciers responsible for deposition of the drifts of South Dakota passed over areas underlain by beds of soft Cretaceous clays and chalky clays. Of these, the Niobrara formation and the Mobridge member of the Pierre formation are highly calcareous and contain much selenium

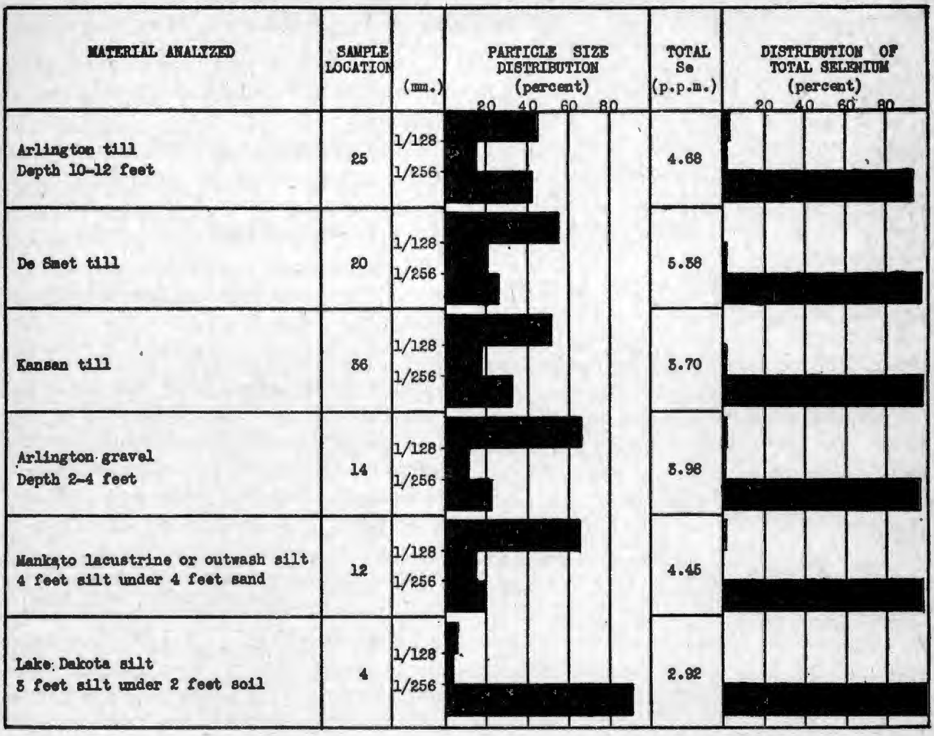


Figure 7. Chart showing distribution of selenium in samples of materials separated into fractions of different particle size.

where they have been investigated (2). The Kansan and Iowan glaciers passed over the outcrop of the Niobrara in northeastern South Dakota and Minnesota and possibly in North Dakota and Canada. These earlier glaciers may also have crossed the Mobridge member of the Pierre formation. The Arlington glacier passing down the James River valley and deploying eastward, over the area studied, overrode an area of Mobridge marl, a remnant of which occurs in the Redfield Hills (Plate I). Undoubtedly this glacier passed over the Mobridge now buried beneath the drift northwest of Lake Preston. It is probable that much of the selenium of the highly calcareous Arlington has been incorporated into the drift from these chalky deposits of the James River valley and elsewhere in the pathway of the glacier.

The finer half of the drift probably contains all of the selenium and this finer material contains more than enough selenium to account for that in the loess and silts of the area. However, the fact that loess, so like the Arlington loess, that it cannot be distinguished from it, lies on the driftless area west of the Missouri river, strongly suggests that selenium in the Arlington loess may be in part at least, wind transported in aeolian dust derived in large part from the Mobridge member of the Pierre.

Summary

Selenium "indicator" plants, *Astragalus racemosus* Pursh, were found growing in several locations on Pleistocene deposits in east central South Dakota. A preliminary survey indicated that it would be necessary to consider the geological relationships in a systematic study of the occurrence and distribution of selenium in this area.

Field and laboratory investigations indicate that new interpretations of the age and correlations of Pleistocene deposits must be made. Wisconsin deposits previously presumed to be equivalent to Mankato drift are older and are post-Iowan, pre-Mankato in age. The post-Peorian, pre-Mankato drift which we have named the Arlington drift, is probably widespread on older deposits.

Chalk beds which outcrop in the Redfield Hills have been correlated with the Mobridge (Interior) member of the Pierre formation. This chalk occurs under large areas of glacial deposits of South Dakota.

A total of 220 samples of 15 different glacial and associated deposits have been taken largely from auger borings and analyzed for selenium. These samples represent about 337 feet of the deposits. Seven samples of bedrock formations were also analyzed.

Selenium was found to occur, in small amounts, in all glacial and associated deposits in northeastern South Dakota and in western Minnesota.

The greatest amounts of selenium occur in Arlington loess and loess-like silts in poorly drained locations. Soil developed on the Arlington loess and loess-like silts contain considerably more and in most cases about twice as much selenium as the parent material.

Considerable amounts of selenium were found in the outcrops of the Mobridge (Interior) member of the Pierre, in the glaciated area of South Dakota.

Mechanical analyses of a number of samples of Pleistocene deposits have shown that the selenium occurs largely in the clay fraction.

Selenium is leached from Pleistocene deposits, transported downslope, and deposited at lower levels. Most selenium occurs at and near locations of poor drainage, both surface and subsurface. Maximum amounts of selenium in poorly drained locations of Pleistocene deposits are comparable with the average amounts of selenium in Cretaceous deposits of toxic areas.

Underground waters and standing water in the Arlington drift area contain selenium, varying in amount with the topograpic position of the water table.

Astragalus racemosus Pursh, a selenium "indicator" plant, grows on Arlington till, De Smet till, and Arlington loess and loess-like silt. Most of the plants contain relatively small amounts of selenium, except those growing in poorly drained locations, where the content ranges well into the averages of those in toxic areas on Cretaceous formations.

The very localized distribution of selenium in Pleistocene deposits greatly limits the possibility of selenium poisoning in livestock in northeastern South Dakota.

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