NEARBY AND DISTANT ORIGINS OF GLACIER ICE ENTERING KANSAS

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ABSTRACT. Extensive exposures in a quarry in northeastern Kansas reveal Nebraskan gravel and silt, two Aftonian soils, two Kansan tills, each with a soil, and Illinoian (?) loess. Igneous and metamorphic erratics are numerous in the upper part of the Kansan till section, though absent from the lower part. It is believed that the first part of the Kansan ice sheet to reach the state of Kansas consisted of ice formed by direct precipitation along an ice-front zone from northward-moving Tropical-Gulf air masses. This locally-formed ice contained rock debris of local origia only. Ice that arrived later had formed in Canada and carried crystalline rock debris from distant northern sources. The stratigraphy in Kansas thus provides field evidence in support of Flint’s concept of ice-sheet expansion processes.

Field studies in past decades have provided general information about the glacial history of Kansas. The basic framework was established mainly by investigations made in neighboring Nebraska and Iowa (see for example, Kay and Apfel, 1928; Kay and Graham, 1943; Lugn, 1935) where it has been shown that ice sheets of Nebraskan and Kansan ages could have reached Kansas. Early work by Schoewe (1930, 1939) demonstrated that these glaciers advanced into only the northeastern corner of the state.

Later, Frye and Leonard (1949, 1952) described the exposure of two tills in a quarry at Iowa Point in northwestern Doniphan County, Kansas. The lower till had in its upper part a well-developed humic gle soil indicative of an episode of prolonged weathering prior to deposition of the upper till. On this basis the two tills were correlated with the Nebraska and Kansan glaciations respectively. Additional field exploration plus test drilling (Frye and Walters, 1950) indicated that the southernmost limit of Nebraskan ice lay in the vicinity of Atchison, although Schoewe (1927) had described evidence suggestive of the presence of Nebraskan till near Lawrence. Kansan ice reached a short distance south of a line connecting Kansas City, Lawrence, and Topeka.

Since World War II, the Army Corps of Engineers has been involved in an extensive program of bank stabilization and channel control along the Missouri River upstream from Kansas City. One consequence has been the opening of numerous quarries along the western edge of the Missouri River flood plain in Atchison and Doniphan counties. Most of these quarrying operations have created extensive exposures in unconsolidated deposits of Pleistocene age as well as in the underlying Upper Pennsylvanian limestones and shales.

DUAL LITHOLOGY OF TILL

Approximately half a mile east of the town of Doniphan (fig. 1) along the “River Road” (centering on NW¼NE¼sec. 9, T. 5 S., R. 21 E.), two quarries, situated end to end along a line oriented east-northeast, provide 2200 feet of exposure interrupted by a 300-foot unexcavated area near the middle of the line. The Pleistocene deposits revealed here have several notable aspects, not all of which are germane to the present discussion.
Fig. 1. Location of Doniphan quarry within area of study and in Kansas.

Thicknesses and sequences of Pleistocene units vary from one part to another of this pair of quarries. A typical stratigraphic section from near the northeastern end consists of a basal pebble gravel unit about 1 foot thick overlain by some 15 feet of faintly laminated silt and fine sand within which are scattered pebbles and one or more pebble-gravel lenses a few inches to a foot thick. The uppermost 6 to 8 feet of this laminated sediment have been altered to a dark gray humic gley soil with classic gumbo characteristics developed by prolonged weathering in a poorly drained situation. A lower, less well developed soil is present near the root zone of the gley. The upper soil is overlain by fresh till.

The basal pebble gravel contains a very few fragments of red quartzite believed to be from the Sioux Formation and locally lies on a glacially smoothed and striated bedrock surface. It is clear, therefore, that this unit was deposited during or shortly after an episode of glaciation, and it is believed to be of Nebraskan age. The fresh till above was deposited by Kansan ice and the two-part weathering of the sub-till silt and sand occurred during the Aftonian Interglacial Age.

The Kansan till in this typical stratigraphic section is about 18 feet thick. The roots of a former soil profile are present in the upper 10 to 12 feet. Detailed study near the top of this till has revealed the presence of an erosion surface which separates the main till body and its deep weathering profile from thin, discontinuous remnants of a second till sheet which also underwent weathering before deposition of a 12-foot thickness of loess, at the top of which is a thin modern soil. The Kansan till section is actually a composite section that includes deposits of two distinct advances of Kansan ice separated by an interval of erosion and weathering. Definitive evidence as to ages is lacking at this site, but it is believed that the main weathering of the Kansan till occurred
during the Yarmouth Interglacial Age. The overlying loess may be of Illinoian (Loveland) age.

The lower half of the composite Kansan section consists of sandy till with numerous intercalated stringers and lenses of fine to medium sand. Diversity of orientation of these sand bodies indicates a moderate degree of ice-push deformation during continuing till deposition. The size and number of sand masses decrease upward; the upper part of the till section has a clay matrix.

More outstanding than contrasts in grain-size distribution and sediment sorting between the lower and upper parts of the composite section is a very marked contrast in lithology of the constituent particles (Dort 1964). The lower part consists of fragments of limestone and dolomite, plus a little shale, some chert, and miscellaneous pieces of calcite and iron oxide. Visually outstanding are scattered large boulders of limestone. All constituents could have had a relatively local origin; certainly all came from the same general suite of Paleozoic sedimentary rocks of dominant carbonate composition.

The upper part of the lower Kansan till and all of the upper Kansan till, on the other hand, contain numerous pebbles, cobbles, and small boulders of igneous and metamorphic rocks. Visually outstanding are the pieces of red to reddish lavender quartzite believed to have been derived from the Precambrian Sioux Formation which outcrops in contiguous parts of Iowa, South Dakota, and Minnesota. Also represented are several varieties of granite, intermediate and basic igneous rocks, gneisses, and greenstones typical of the Canadian Shield terrain. All these are in addition to limestones and dolomites similar to those in the lower part of the composite section.

The change from till with no igneous and metamorphic rock fragments to till with a high percentage of these erratics is abrupt. However, at the level of change there is no other noticeable feature, no bedding plane, no weathering zone, no intercalated loess or outwash. Thus the single layer of the lower Kansan till appears to have two distinct parts, and it is this duality of rock-fragment content that requires explanation.

This duality of till lithology in which rock fragments from distant northern sources are confined to the upper part of a till section is present through much of the nearly half-mile-long exposure at the quarries near Doniphan. It is clearly demonstrable also in exposures of supposed Kansan age till in the western outskirts of the city of Atchison 6 miles southwest. And it is suggested at poor exposures ranging in location from 10 miles south of Atchison to equally far north. It is not, therefore, a phenomenon of isolated occurrence at a single quarry, and an acceptable explanation of its origin must be of regional scope.

POSSIBLE EXPLANATIONS

The occurrence of contrasting tills deposited one after the other is not a rare occurrence. If the difference is basically one of appearance based on compactness and to some extent texture, a frequent explanation is that the lower part (compact and commonly with a clay matrix) is lodgment till plastered onto the ground surface beneath moving ice and the upper part (of loose texture and often with a sand matrix) is ablation till which was gently let down as the ice melted away. In the exposures near Doniphan and Atchison the essential
contrast is in composition rather than texture. Furthermore, the more compact till is above that having a loose texture. Therefore the lodgment versus ablation origin of the deposit is not a sufficient explanation.

An explanation of contrasting till lithologies in stratigraphic succession is often that two lobes of glacial ice advanced across terrains underlain by contrasting types of bedrock and reached a single point of deposition from two directions. No specific information is available regarding lobate patterns along the front of the Kansan stage ice sheet, but the absence of prominent highlands or lowlands, other than the Missouri River Valley, in a generally northerly direction from northeastern Kansas seems to reduce the likelihood that major lobes existed. Furthermore, the geology within 200 miles north of Kansas, the possible sphere of influence of a major lobe along the front of a continental ice sheet, is in general the same in that it consists mainly of Paleozoic carbonate rocks with some interbedded fine-grained clastic formations, plus Mesozoic clastic rocks to the north. And so the observed contrasting till lithologies cannot be explained by the activity of different lobes of the ice sheet.

The possibility must be considered that ice reached northeastern Kansas from two completely different source areas and for this reason advanced from different directions across areas of different bedrock geology. The full sequence of development of dispersion centers in Canada and possible ice-movement directions is yet to be determined for the Wisconsin stage and is essentially unknown for earlier stages. (The discovery by J. D. Winslow and H. G. O'Connor of a small boulder of Minnesota-type hematitic iron ore in the till at the Doniphon quarry is evidence of the direction of ice flow during at least one part of Kansas time.) Nevertheless, the unsuitability of such an explanation for the contrasting lithologies of Kansan till in northeastern Kansas is demonstrable. Ice could flow from Canadian dispersion centers to northeastern Kansas and not cross outcrops of the Sioux quartzite (fig. 2). On the other hand, it would be virtually impossible for Kansas to receive any Canadian ice that had not crossed exposures of igneous and metamorphic rocks of the Canadian Shield. Therefore all till deposited by ice coming from Canadian sources should contain erratics of crystalline rocks.

If ice sheets reaching Kansas did cross areas where igneous and metamorphic rocks now crop out, the absence of these rock types in the lower part of Kansan till might be explained by the assumption that these rocks were not exposed at the surface when the glacier first crossed this area. For example, the present Sioux quartzite outcrops might have been protected at the beginning of Kansan time by a continuous cover of Paleozoic sedimentary rocks, but this hypothesis is invalid because fragments of Sioux rocks are present in deposits of Nebraskan age. A more plausible idea is that a protective covering of Nebraskan till had to be removed by early Kansan ice before the quartzite or rocks of the Canadian Shield could be glacially eroded. Conceivably some areas of crystalline rock were covered and protected at the start of Kansan time, but it is unlikely that all such areas which might have served as sources of erratics were unavailable to glacial erosion. Furthermore, the Nebraskan till which is being called upon to protect the crystalline rocks would itself have contained fragments of those rocks, and those fragments could easily have be-
come incorporated into the Kansan drift. Not all would have been destroyed by weathering during the Aftonian Interglacial Age.

Chemical weathering processes can selectively destroy rock fragments of certain compositions present in a till while leaving other fragments relatively untouched. However, it is difficult to conceive of a weathering process that would completely remove all quartzites and granitic and other crystalline rocks while not affecting the carbonate rocks. Furthermore, to fit the Kansan stratigraphy exposed in the Doniphan quarry, such a process would have to work from below because the igneous and metamorphic erratics are present only in the upper part of the till sheet. The same general arguments negate attempts to explain the contrasting till lithologies by some type of post-depositional reworking. Although the lower part of the till does contain numerous lenses of fluvial sand, selective removal of all erratic rock types does not appear possible by fluvial action.

**Dual Formation of Ice**

Flint (1943) argued that a fundamental process in the expansion of the North American continental (Laurentide) ice sheet was the addition of ice to the glacier margin by direct precipitation and consequent windward growth. Following the lead of Leverett who stated (1916, p. 68) that “because of storms coming from the southwest the ice-sheet grew westward”, Flint reasoned that
warm, moist Tropical-Gulf maritime air masses, moving northward across north-central United States and adjacent Canada, would be cooled both by coming in contact with the ice front and by being forced upward over the glacier and its associated wedge of cold air. There would thus be combined convectional and adiabatic cooling of the air masses and a major zone of precipitation would be present along the ice margin.

This marginal and near-marginal precipitation would provide major increments of snow to nourish the ice sheet and cause farther advance of the front. In fact, Flint believed that the Pleistocene glacial terminus is farther north in the Dakota area than in the Mississippi lowland, not only because increasing altitudes hindered advance into this western area, but also because the rain-shadow effect of the Rocky Mountains reduces Pacific air-mass precipitation here and the moist Tropical-Gulf air masses do not penetrate this far west. Similar ideas were expressed by Demorest (1943) though in less detail. Later, Flint and Dorsey (1945) reiterated the hypothesis, noting that the presence of cold air over a growing ice sheet would cause outward displacement of storm tracks and the associated zone of maximum precipitation.

Leighly (1949) emphasized the importance to ice-sheet growth of receipt of water vapor from the south. He noted that in addition to constituting a barrier to westerly and southwesterly winds, the presence of an expanding ice sheet would slightly modify patterns of air mass movement and cause increased flow of tropical maritime air into the continental interior to provide greater snowfall there. Upham (1895) thought that precipitation would be greatest for a distance of 100 to 200 miles inward from the windward border of an ice sheet, the zone storms would pass over during the first 3 to 10 hours of over-ice movement.

Continuing a step beyond Flint's hypothesis, the present writer considers that once local precipitation has begun to add significant volumes of new ice along the periphery of an ice sheet, the first ice to flow forward from that specific marginal position will be largely ice that had just formed at that place. Furthermore, it might be expected that the process would intensify as the marginal precipitation fell on ice of local origin instead of ice coming from the center of the ice sheet. Additionally, as the ice front advanced south it would approach ever nearer the main source of moisture for precipitation, the Gulf of Mexico. The situation would be reached, therefore, at which all the ice initially arriving at a given location would have formed a short time previously a short distance away. Only after this locally formed ice had passed and had been removed by melting would ice arrive that was formed from precipitation near the center of the ice sheet.

A necessary corollary of the foregoing extension of Flint's hypothesis is that the debris being carried by the frontal part of an advancing continental ice sheet would have been picked up by the ice formed locally in the marginal zone of the glacier. The rock types included would consequently be those present in outcrop not far away. Debris from distant sources would be imported by ice reaching a given locality only after the opening phase of a glacial episode had passed.
The hypothesis is offered (Dort, 1964) that the dual nature of the composite Kansan till in the northeastern part of the state of Kansas is the direct and expectable consequence of the process and sequence discussed above. The front of the Kansan glacier which advanced into Kansas consisted of ice formed by precipitation in western Iowa or easternmost Nebraska, and it was carrying fragments of the Paleozoic carbonate and clastic rocks that outcrop there. This first ice (fig. 3) brought no Sioux quartzite and no igneous and metamorphic rocks from the Canadian Shield because this ice had not come from that far away. Therefore, the till deposited in Kansas by this initial flow of ice contained no erratics of far-northern origin.

Later, however, as southward flow of ice from Canadian dispersion centers continued and the locally formed ice had passed by and melted away, erratics were brought to Kansas. The younger and therefore upper part of the till deposited by this ice sheet contained numerous fragments of igneous and metamorphic rocks torn from exposures to the far north. The arrival of this distantly formed ice could be abrupt, thereby causing a sharp lithologic break even though the process of till accumulation continued unchanged.

If a glaciation consisted of two or more pulsations it would be expected that the influence of ice-front nourishment would strongly affect till lithology only during the initial advance of the first stade. Subsequent readvance after recession would bring forward again mainly ice containing debris from distant
sources and only a minor increment of locally-formed ice. It is therefore not surprising that the upper Kansan till in the Doniphan quarry has a high percentage of igneous and metamorphic erratics throughout its thickness.

APPLICATION TO OTHER GLACIAL AGES

Flint’s original statement (1943, p. 346) “refers only to the Wisconsin, although it seems likely that if it should prove to be valid for that age it would also hold for earlier ages”. Leverett (1916, p. 69), although discussing the sequence of Wisconsin ice-sheet expansion, thought that “the same sort of westward growth of the ice-sheet may have taken place in the Illinoian stage of glaciation”. The evidence offered in the present paper is derived from exposures of till of Kansan age. It therefore appears on the basis of both theoretical considerations and field observations that the process of ice-sheet expansion through marginal precipitation has indeed occurred, probably during each major re-formation and advance of the Laurentide Ice Sheet.

REFERENCES