[10]Gjaerevoll, O. 1963. Botanical investigations in central Alaska especially in the White Mountains. Part II. *Det Kgl Norske Videnskabers Selskabs Skrifter,* 4. 115 pp.

[11]Löve, D. and N. J. Freedman. 1956. A plant collection from SW Yukon. *Botaniska Notiser,* 109: 153-211.

[12]Viereck, L. A. 1967. Plants above 2,140 meters (7,000 feet) in the Alaska Range. *Bryologist,* 70: 345-347.

[13]Bakewell, A. 1943. Botanical collections of the Wood Yukon Expeditions of 1939-1941. *Rhodora,* 45: 305-316.

[14]Cody, W. J. and A. E. Porsild. 1968. Additions to the flora of continental Northwest Territories, Canada. *The Canadian Field-Naturalist,* 82: 263-275.

[15]Murray, D. F. 1971. Comments on the flora of the Steele Glacier region, Yukon Territory. Appendix C, in M. Fisher, ed. *Expedition Yukon.* Thomas Nelson and Sons (Canada) Limited, Toronto. pp. 178-81.

[16]Mulligan, G. A. 1971. Cytotaxonomic studies of *Draba* species of Canada and Alaska: *D. ventosa, D. ruaxes,* and *D. paysonii. Canadian Journal of Botany,* 49: 1455-1460.

[17]Hitchcock, C. L. 1941. A revision of the Drabas of western North America. *University of Washington Publications in Biology* 11. 132 pp.

[18]Drury, W. H. and R. C. Collins, 1952. The North American representatives of Smelowskia (Cruciferae). *Rhodora,* 54: 85-119.

[19]Yurtsev, B. A. 1969. News of the systematics of higher plants. *The Academy of Sciences of the U.S.S.R.,* 6: 302-320. Translation.

[20]Porsild, A. E. 1966. Contributions to the flora of southwestern Yukon Territory. *National Museum of Canada Bulletin,* 216, Contributions to Botany, IV. 86 pp.

[21]Gjaerevoll, O. 1967. Botanical investigations in central Alaska, especially in the White Mountains. Part III. *Det Kgl Norske Videnskabers Selskabs Skrifter,* 10. 63 pp.

Thin Gravel Deposits on Wave-Eroded Cliffs Near Barrow, Alaska

INTRODUCTION

The beach southwest of Barrow, Alaska, is limited to a foreshore which is backed by wave-eroded cliffs of the Quaternary Gubick Formation. These cliffs, which have an approximate elevation of 20 to 35 feet above mean sea level, are covered with a thin layer of coarse sand and gravel. This gravel unit ranges in thickness from a few inches to an intermittent covering of gravel. The unit extends inland about 10 feet in some places to about 300 feet in others.

A gravel deposit of these dimensions is of little or no importance to most scientific disciplines. However, its presence and method of formation are of extreme importance to the unravelling of the archaeological sequence along the coast of Northern Alaska.

The gravel units were first observed during the archaeological excavation of an Eskimo site at Walakpa, which is approximately 12 miles southwest of Barrow. At this location there is a sequence of gravel units interspersed throughout the stratigraphic column of the site. These gravel units were formed at the surface after a period of Eskimo occupation and then covered by a subsequent period of occupation, thus they served as a basis for separating one period of occupation from another either older or younger occupation level (Fig. 1).

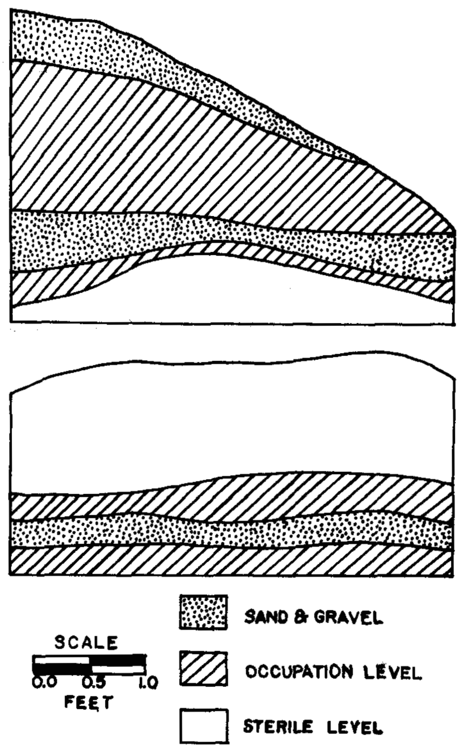

FIG. 1. Cross sections of the Walakpa site showing thin sand and gravel units.

One theory of the origin of these gravel deposits is that they were formed by vertical sorting due to frost action. This mechanism consists of freeze and thaw cycles that move the larger particles upward while the fine material is moved downward.[1] These Polar Desert soils usually develop on high ground where they are exposed to intense wind action. In certain places the sandblasted gravel forms a continuous desert pavement.[2] In short, soils are formed by repeated freeze and thaw action in the presence of adequate moisture and by removal of fines by wind action.

The above-mentioned theory does not adequately explain the formation of the gravel deposits observed at Walakpa, because 1) the particles themselves do not have a polished surface caused by sandblasting; they closely resemble beach deposits in both surface texture and compositions; and 2) most importantly, in the excavations it was observed that a gravel unit, in many cases, was underlain by an occupation level at a depth of only a few inches (Fig. 1). If vertical sorting did occur, then the larger artifacts would be moved upward and deposited with the gravel. In the Walakpa site the artifacts show little or no movement by freeze and thaw; therefore, a new theory on the origin of these gravel deposits was proposed.

DEPOSITION OF GRAVEL

During nine months of the year the Arctic Ocean is frozen. Throughout the three summer months the ice near the coast melts, breaks into floes, and drifts away from the shore. Occasionally, the wind or currents may force either loose pack ice or solid winter ice onto the beach. This phenomenon of ice-push can occur at any time of the year. The ice moves over the beach as a smooth unbroken sheet, or it will buckle and break into blocks. In 1961 Hume[3] observed the effects of an ideal case of smooth gliding movement on Point Barrow. The ice advanced up to 140 feet over a low sandy beach. However, buckling of ice seems to be more common than smooth flow. Buckled ice ridges have been reported to extend 20 to 30 feet above mean sea level.[3]

The Alaska coast north of the Arctic Circle is probably subjected to ice action at one time or another. However, during any one year it is doubtful if more than 5 per cent of the coast is attacked by ice-push, although certain areas, such as Barrow, are subjected to much more intensive ice action. In some cases ice may push sediment even beyond the reach of major storm waves.[3]

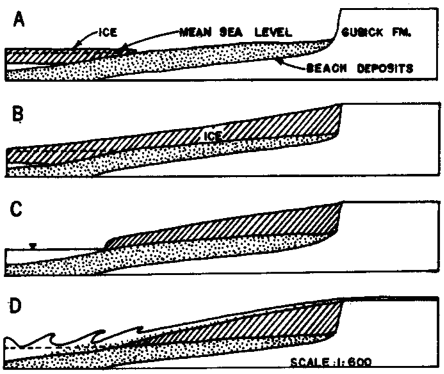

FIG. 2. Sequence of events in deposition of thin gravel units on arctic beach cliffs. A: Normal state of ocean and beach; B: Ice-push onto beach; C: Ice-free ocean and ice ramp; D: Storm waves transporting sand and gravel up the ice ramp.

During periods of intense activity the ice may push as far as the wave-eroded cliff and completely cover the beach for a short distance (Fig. 2B). After this ice-push occurs, a change of wind direction will cause the ice to drift away from the shore, leaving an ice ramp on the beach (Fig. 2C). During a subsequent storm, the storm waves move beach sand and gravel up the ramp and onto the beach cliff where the gravel is initially deposited around blocks of tundra that have been eroded by the wave action (Fig. 2D). Over a period of several years, erosion by wind and precipitation spreads the gravel in a thin surface unit.

This phenomenon is probably uncommon, even with the large amount of ice movement in the Barrow area. Along the coast between Barrow and Sinaru (a distance of about 20 miles), only two areas were observed where this event had occurred in the last few years. At the first area observed, near the south side of Nunavak Bay, gravel was deposited approximately 35 feet above sea level and extended inland about 20 feet. The second area where an ice-ramp caused the deposition of gravel is located near Sinaru. Here the gravel was deposited along with large sections of sod at an elevation of approximately 25 feet and extended inland nearly 100 feet. The sections of tundra that were eroded and transported by the water have a maximum dimension of 3 feet, and the gravel transported has a maximum diameter of ¾ inch (Fig. 3).

The maximum inland extension of the gravel deposit was observed in excavations at Walakpa, where the gravel extended over 300 feet inland. This large landward extent was probably caused by the downward slope of the land inland from the bluff.

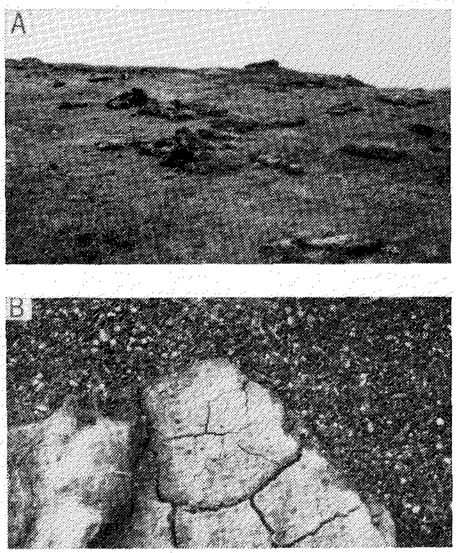

FIG. 3. Section of beach-cliff near Sinaru where ice ramp has caused deposition of gravel. A: Tundra sod and gravel moved by wave action; B: Close-up view of sod and gravel.

CONCLUSION

The ice ramp is probably short-lived because of the intense wave action and the interference of pack ice moving shoreward during the storm. However, in the few hours that the ice ramp exists, a large volume of sand and gravel may be transported and deposited on the tundra surface. Even though this event is brief and only occurs for a short lateral distance, the entire coast would experience this type of ice and wave action over a long period of time. Hence a continuous or semi-continuous gravel unit is deposited above the wave-eroded cliffs.

The presence and method of deposition of the sand and gravel units at the Walakpa site give further evidence that vertical sorting has not occurred. This in turn suggests that the artifacts found in an occupation level belong only to that occupation level; i.e., the tool assemblages found can be attributed to a single period of cultural deposition. The observations are of extreme importance to the unravelling of the archaeological sequence along the arctic coast of Alaska.

Owing to the uncommon occurrence of this phenomenon the author has only pieced together the sequence of events necessary for the deposition of these gravel units. However, they have been observed by Silas Negovanna who is a native of the area (personal communication).

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REFERENCES

[1]Corte, A. E. 1961. The Frost Behavior of Soils: Laboratory and Field Data for a New Concept: 1. Vertical Sorting, *U.S. Army Cold Regions Research Engineering Laboratory, Research Report* 85, 22 pp.

[2]Tedrow, J. C. F. 1966. Polar Desert Soils, *Soil Science Society of America Proceedings*, pp. 381-87.

[3]Hume, J. D. and M. Schalk. 1964. The Effects of Ice-Push on Arctic Beaches, *American Journal of Science*, 252: 267-73.

Microclimate and Plant Growth at Isachsen and Mould Bay*

In discussing the botany of the northwestern Queen Elizabeth Islands[1] I noted that the available climatic data did not suggest a significant difference between the summer climate of Isachsen and of Mould Bay; yet Mould Bay harbours plant species that are absent from Isachsen, and specimens from there are less depauperate than those from Isachsen. It seemed probable that Mould Bay, which is better protected from winds off the Arctic Ocean, might have less of the very low stratus that often covers Isachsen and which

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