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Mineral Precipitation in North Slope River Icings

DOROTHY K. HALL[1]

ABSTRACT. Powdered calcium carbonate ($CaC0_3$) patches averaging 4 cm in thickness were found on icings (aufeis fields) in the Canning and Shaviovik Rivers in northeastern Alaska. The presence of this material on aufeis suggests that much of the water which feeds the aufeis is coming from depth and has flowed through calcareous bedrock. Aufeis forms during the winter at or below the point where groundwater discharges, or when river water is forced upwards through cracks in river ice. Calcium carbonate in solution in the groundwater is excluded as the water freezes during ice growth. The $CaC0_3$ slush then accumulates on top of the ice as the aufeis ablates during the melt season. Four patches of $CaC0_3$ covering approximately 0.1% of the total area of the Canning River aufeis were observed during the July 1978 field study. It is estimated that approximately 540 m^3 of $CaC0_3$ precipitate were present in the Canning River aufeis in July of 1978. If similar percentages of $CaC0_3$ precipitate were present on other major aufeis fields on the eastern North Slope, approximately 18 000 m^3 of $CaC0_3$ may be present during a given year in the major North Slope aufeis fields. Most of this precipitate is deposited into the Arctic Ocean via river flow.

RÉSUMÉ. Des épendages de carbonate de calcium en poudre avec une epaisseur moyenne de 4 centimètres, s'observaint à l'époque de la congelation des fleuves Canning et Shaviovik en Alaska du Nord-est sur les bancs de glace. La localisation de ces dépots sur les bancs de glace suggère qu'une bonne part de l'eau qui nourrit ces "bancs", vient de la profondeur et a percolé à travers un massif calcaire. Le "banc" se forme pendant l'hiver à l'endroit de décharge de l'eau souterraine ou quand l'eau du fleuve est forcée de passer par dessus les fractures de la glace fluviale. Le carbonate de calcium en solution dans l'eau souterraine se dépose à l'époque du gel de l'eau et de la croissance de la glace. La boue de carbonate de calcium s'accumule au point le plus haut de la glace alors que les bancs de glace commencent à fondre. Quatre depots de CO_3Ca couvraient approximativement 0.1% de la surface totale des bancs de glace du fleuve Canning pendant l'étude sur le terrain, faite en Juillet 1978. Si les precipitations de CO_3Ca atteignaient approximativement 540 m^3 sur les bancs de glace du fleuve Canning en Juillet 1978. Les precipitations de CO_3Ca étaient aussi massives sur d'autres bancs de glace importants, approximativement 18,000 m^3 de carbonate peuvent se deposer au cours d'une année sur les principaux bancs de glace du "North Slope". La plus grande partie de ces precipitations se situe dans l'ocean Arctique, à partir de l'écoulement des fleuves.
Traduit par Alain de Vendegies, Aquitaine Company of Canada Ltd.

INTRODUCTION

In July 1978 the Canning and Shaviovik River aufeis fields (icings), in the eastern part of the North Slope of Alaska, were studied on the ground and with aerial and satellite photography. (Fig. 1). Aufeis is a mass of overflow river ice for which the source water can be groundwater or river water. Most of the large icings are sustained by the discharge of groundwater in addition to the overflow of river water (Childers *et al.*, 1973). The largest aufeis fields are

[1]Hydrological Sciences Branch, Code 924, NASA/Goddard Space Flight Center, Greenbelt, Maryland 20771

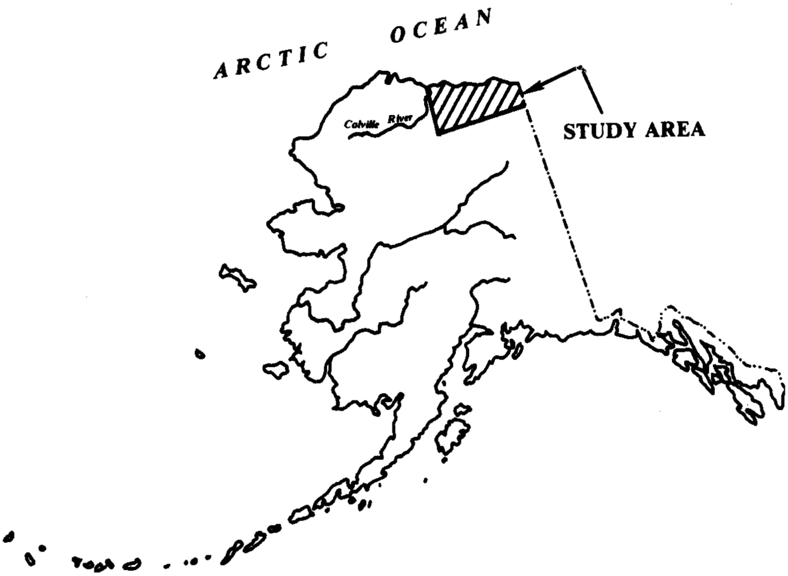

FIG. 1. Location map showing the eastern North Slope of Alaska.

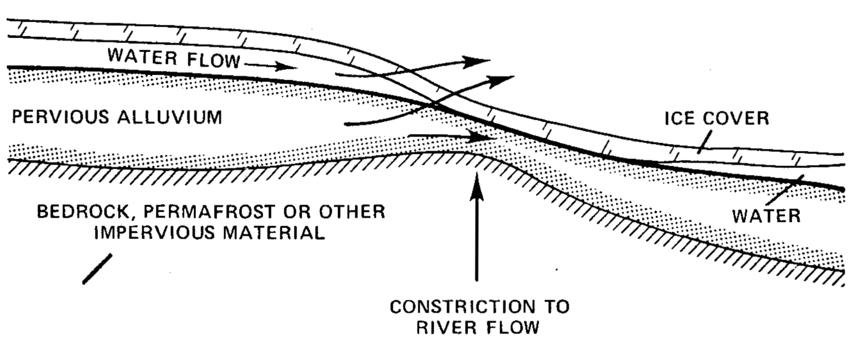

FIG. 2. Aufeis formation in a stream channel (from Carey, 1973).

found in permafrost areas, although the presence of permafrost is not a requirement for its formation. The formation of aufeis in a stream channel is illustrated in Fig. 2. In the fall the river ice freezes downward; if there is a constriction to river flow, water may become trapped between the ice cover and permafrost. Pressure builds as water continues to flow from the stream and/or spring. Eventually cracks form in the river ice cover and water is extruded upward through these cracks, downstream of the constriction, onto the existing ice and the surrounding terrain. This process continues throughout the entire winter until the source of groundwater or river water is depleted (Carey, 1973).

The purpose of the study was to analyze the hydrological significance of aufeis in North Slope rivers including the determination of the volume of

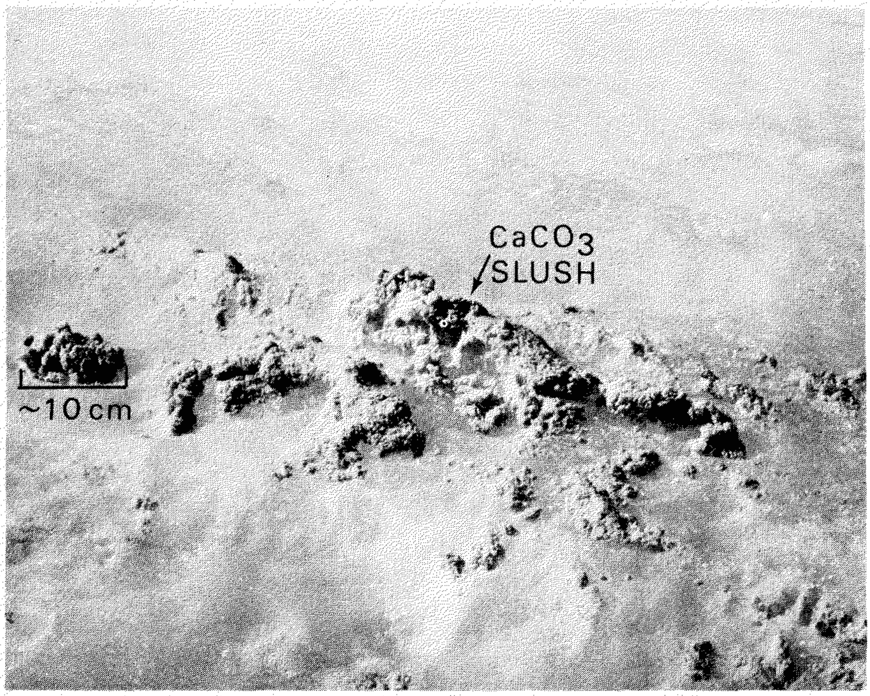

FIG. 3. Calcium carbonate slush on the Shaviovik River aufeis field, July 15, 1978.

aufeis in selected rivers, its dissipation patterns and its origin and composition.This paper deals with mineral precipitation within aufeis and the geological implications. Calcium carbonate ($CaC0_3$) found on the aufeis indicates that significant chemical weathering of calcareous bedrock may be occurring in this region of continuous permafrost throughout the year. The chemical composition of spring waters (Childers *et al.*, 1973) and aufeis waters (van Everdingen, 1974) also indicates that solution of rock material is not uncommon in the Arctic.

FIELD INVESTIGATION

On 15 July 1978 a field party landed on a gravel bar in the Shaviovik River (69°50'N, 147'43'W) in northeastern Alaska in order to gain access to the nearby aufeis. Measurements of aufeis thickness, structure and composition were made. On 18 - 21 July 1978 similar but more extensive measurements were made of the Canning River aufeis (69°57'N, 146°15'W). Patches of a yellowish-white precipitate were found on and within the ablating ice on both the Canning and Shaviovik River aufeis fields (Fig. 3). X-ray diffraction analysis was later performed in the laboratory and the material was determined to be pure calcium carbonate (calcite).

On both the Canning and Shaviovik River aufeis fields, the accumulated $CaC0_3$ varied from 1 - 10 cm in thickness and caused irregular ablation of the ice in its vicinity. This material was also observed in calving ice 18 cm below the surface of the Canning River aufeis, which was an average of 1.1 m in thickness. The difference in albedo between the ice and the calcium carbonate is probably the reason for the irregular ablation in the immediate vicinity of the $CaCO_3$.

The areal extent of the Canning River aufeis was determined to be 4.5 km^2 as measured from air photos taken on 12 July 1978. Four patches of $CaCO_3$ slush were observed on the Canning River aufeis, covering approximately 0.1% of the total area of the surface of the aufeis. The Shaviovik River aufeis had $CaCO_3$ accumulations which were comparable in thickness and coverage to those found on the Canning River aufeis. The average aufeis thickness on the Shaviovik River was 1.0 m at the time of the field study on 15 July 1978. Other aufeis fields on the North Slope of Alaska are known to have $CaCO_3$ on the aufeis (Williams and van Everdingen, 1973; van Everdingen, 1974).

Several assumptions have been made regarding the amount of $CaCO_3$ in aufeis on the North Slope as a result of the July 1978 field work on the Canning and Shaviovik Rivers. On the Canning River aufeis, it is assumed that the ice had melted down by ~0.5 m by the date of the field measurements. This is based on the height (0.5 m) of a mass of candle ice which was observed on the aufeis. It had been protected from ablation by thick, overlying sod. An average thickness of 1.6 m is assumed for the 1978 maximum thickness of the Canning River aufeis. If there were an equal concentration of $CaCO_3$ present in the 1.1 m of the remaining ice, then a vertical thickness of ~12 cm of $CaCO_3$ could be expected in the patches after the Canning River aufeis had melted entirely. However, there probably would not be an equal concentration of $CaCO_3$ in a vertical section of aufeis. More detailed field measurements could be made to quantify the amount of $CaCO_3$ in a vertical section of ice, and also in the upstream and downstream portions of the aufeis. But for the purpose of this study, an equal concentration is assumed.

Utilizing the above assumptions, the four $CaCO_3$ patches on the Canning River aufeis comprise a total of approximately 540 m^3 of $CaCO_3$ precipitate. (More patches of calcium carbonate slush were probably present at the maximum areal extent of the aufeis field prior to extensive melting.) Most of this material was transported into the Arctic Ocean via river flow during the brief melt season although some $CaCO_3$ was observed to have been blown by the wind from the ice onto nearby terrain.

If the major aufeis fields in the eastern North Slope of Alaska had an amount of $CaCO_3$ equivalent to that on the Canning River aufeis, then 18 000 m^3 of this material may be present annually on the major aufeis fields in the eastern North Slope. This is based upon an estimate of 150 km^2 for the extent of major aufeis fields in northeastern Alaska reported in Hall and Bryan (1977). This estimate does not include the contribution of $CaCO_3$ from the many small icings; nevertheless it provides a rough approximation of the annual amount of $CaCO_3$ redistribution in northeastern Alaska.

MECHANISM

Groundwater flowing through taliks (unfrozen zones in continuous permafrost) is high in carbon dioxide (CO_2) due to its low temperature. The amount of CO_2 in water increases with decreasing water temperature. As the CO_2 combines with the cold water, carbonic acid (H_2CO_3) is formed:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

Carbonic acid is then available to dissolve calcareous bedrock which is present beneath the surficial sediments and along the path of groundwater flow in the eastern Brooks Range, northern foothills and eastern Arctic Coastal Plain (Beikman and Lathram, 1976; Detterman, 1974; Holmquist, 1975). The solubility of $CaCO_3$ increases with increasing CO_2 content in the water. Calcium carbonate dissolved from the limestone bedrock is carried in solution in the groundwater which eventually forms the aufeis, as discussed earlier. Water flowing through cracks created by pressure in the ice freezes upon exposure to the cold air. The $CaCO_3$ is excluded during ice crystal growth. The $CaCO_3$ in solution may actually lower the freezing point of the water causing the aufeis source water to flow farther downstream before freezing during aufeis growth. Upon ablation of the ice during the melt season, calcium carbonate accumulates on the surface of the ice as a residual deposit.

DISCUSSION

Calcium carbonate precipitate and precipitates of other minerals in Siberian icings have been observed by Bukayev (1973) and Bondarev and Gorbunov (1973), and they have noted that aufeis often is found in conjunction with tectonic fractures. Alekseyev (1973) noted that groundwater recharge occurs in areas of karsted dolomites and limestones which feed Siberian aufeis through a system of fractures. Groundwater recharge into limestones has been reported by Childers *et al.* (1973) in Alaska as well. Groundwater recharge through calcareous rock in the Brooks Range and upper foothills may be the source of water for aufeis in the foothills and on the coastal plain of Alaska.

Significant chemical weathering occurs on the North Slope of Alaska in spite of the lack of flowing surface water during nine months of the year. Solution cavities may exist in bedrock below the eastern North Slope of Alaska and in the Brooks Range, as discussed by Zenone and Anderson (1978). Hydraulic underground communication through a system of fractures, solution channels or taliks may be occurring in the eastern Brooks Range and northeastern foothills.

The composition of the aufeis gives important information on rock type and groundwater quality below, and indicates that a deep source of groundwater feeds the aufeis because calcareous rock is not found in the surficial sediments of the eastern Arctic Coastal Plain.

CONCLUSION

It appears that even with limited organic acid available to dissolve limestone in the Arctic, substantial erosion of limestone bedrock occurs due to the intrapermafrost flow of CO_2-rich water throughout the year. The presence of $CaCO_3$ precipitate on aufeis adds to a growing body of evidence which indicates that chemical solution of rock material in the Arctic is occurring at depth and is not restricted to freeze/thaw processes operating close to the surface. The possibility also exists that more extensively dissected calcareous bedrock than previously recognized may exist in the eastern Arctic Coastal Plain, as evidenced by the thousands of cubic meters of calcium carbonate in solid form emanating from North Slope aufeis each year.

ACKNOWLEDGEMENTS

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