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SHORT NOTES

SURFACE LOWERING OF ICE-CORED MORAINE BY WANDERING LAKES

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ABSTRACT. Lake wander is described as a new mechanism for surface lowering of ice-cored moraines. Evidence is provided from Flanders Moraine, Vestfold Hills, Antarctica (lat. 68° 38′ S., long. 78° 12′ E.). Lakes wander when steep ice scarps retreat due to collapse and melt. Rates of wander are *c.* 1.3 m year^{-1}. Rates of lowering due to lake wander on Flanders Moraine are *c.* 0.05 m year^{-1}, which is comparable to rates from elsewhere attributed to different processes.

RÉSUMÉ. *Ablation superficielle sur les moraines à coeur de glace près des lacs provisoires errants.* Le phénomène des lacs provisoires errants est décrit comme un mécanisme nouveau d'attaque superficielle des moraines à coeur de glace. On en rapporte la preuve par la Flanders Moraine aux Vestfold Hills en Antarctique (lat. 68° 38′ Sud, long. 78° 12′ E.). Les lacs se déplacent lorsque des blocs de glace escarpés disparaissent par effondrement et fusion. Les vitesses de divagation des lacs sont *c.* 1,3 m par an. Les vitesses d'ablation dues à l'errance des lacs sur la Flanders Moraine sont de *c.* 0,05 m par an, vitesse comparable à celle que l'on attribue ailleurs à différents processus.

ZUSAMMENFASSUNG. *Absinken der Oberfläche von Moränen mit Eiskern infolge wandernder Seen.* Seewanderung wird als ein neuer Mechanismus für die Senkung der Oberfläche von Moränen mit Eiskernen beschrieben. Als Biespiel dient die Flanders Moraine in den Vestfold Hills, Antarktika (68° 38′ S., 78° 12′ O.). Seen beginnen zu wandern, wenn steile Eisflanken infolge Einbruches und Schmelzens zurückweichen. Die Wandergeschwindigkeiten betragen *c.* 1,3 m pro Jahr. Die Absenkung an der Flanders Moraine infolge von Seewanderung erreicht *c.* 0,05 m pro Jahr, ein Wert, der mit Geschwindigkeiten von anderen Stellen zu vergleichen est, die unterschiedlichen Vorgängen zugeschrieben werden.

INTRODUCTION

Rates and mechanisms of lowering of moraines and debris-covered ice have been described from many glaciated areas of the world. Mechanisms proposed include ablation of the ice below the debris mantle (Østrem, 1959, 1964), direct melting of exposed ice (Johnson, 1971), melting beneath lakes (Driscoll, 1980), geothermal heating (Driscoll, 1980), melting of ice by running water (Watson, 1980), development of large cracks in the ice (Johnson, 1971), steps along shear planes (Johnson, 1971), mudflows of the silty unconsolidated moraine veneer (Johnson, 1971), development of kettle holes (Johnson, 1971), and combinations of two or more of these (Driscoll, 1980). A new mechanism—wandering lakes—is described here and evidence is provided from Antarctica.

LAKE WANDERING ON FLANDERS MORAINE

Three lakes (Fig. 1) on a stagnant ice-cored moraine, Flanders Moraine, in the south-east of the Vestfold Hills, Antarctica (lat. 68° 38′ S., long 78° 12′ E.), show lateral movement which has been measured for two lakes (Table I) and inferred for the third from nested arcs of lake-floor sediment (Fig. 1). The lakes occur in low points on the surface of the moraine, and as they wander across its surface, they

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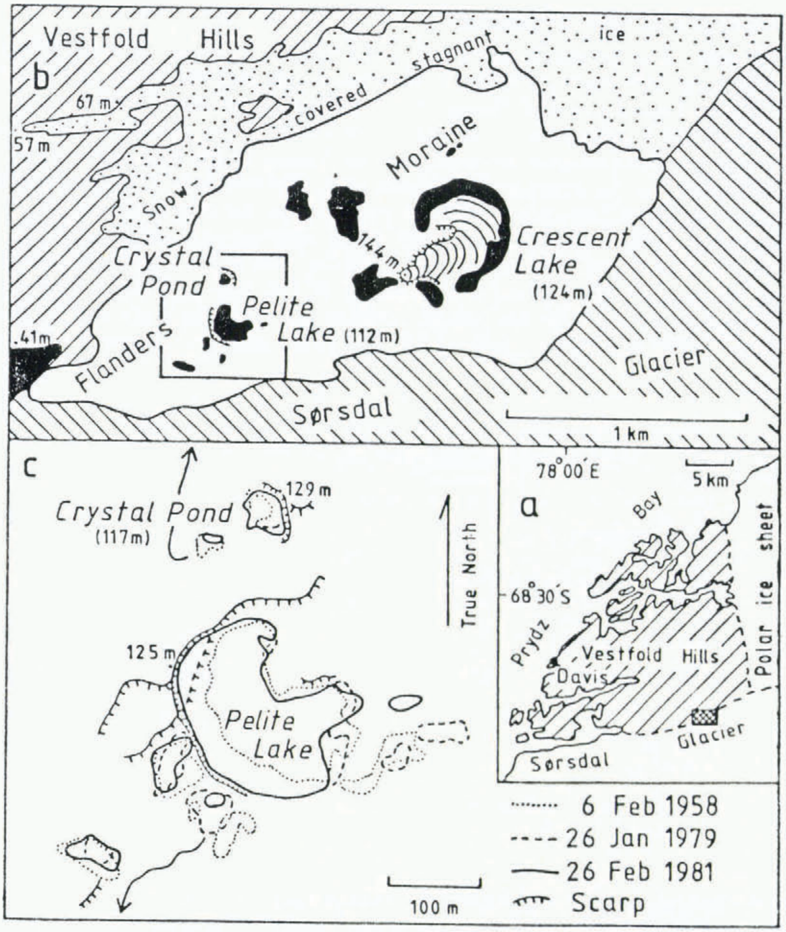

Fig. 1. Location maps of Vestfold Hills (a), Flanders Moraine (b), and Pelite Lake and Crystal Pond (c), showing descending arcuate ridges at Crescent Lake, and changes in the margins of Pelite Lake and Crystal Pond.

inevitably consume higher ice. Wander occurs as a result of the rapid retreat of ice slopes on shores that are too steep to support a stable mantle of insulating till, and by the collapse of near-vertical ice cliffs after formation of thermo-erosional niches at water level. In Pelite and Crescent Lakes, movement is occurring on the side where the bank is steepest, leaving behind a gently sloping bank of lake-floor sediments. This implies that the lakes do not necessarily deepen as they wander.

Crescent Lake has lowered its bed by at least 20 m during a lateral movement of *c.* 500 m, leaving behind descending arcuate steps of lacustrine sediment thick enough to insulate the underlying ice. Each tread probably represents a temporarily stable stage in the lake separated by rather sudden lowerings of water level. The water level in Pelite Lake fell suddenly by 4 m over 1 week in the austral summer 1980–81 when a low point in the lake margin was breached. However, sufficient water remained in the lake to ensure its continued lateral movement. Such events may also drain ice-based lakes completely; one small lake near Crystal Pond was drained completely between 1958 and 1979. Several lakes south-east of Pelite Lake drained completely between 1979 and 1981, probably when Pelite Lake partially drained. Localized elevated patches of lacustrine sediments on the surface of Flanders Moraine show the former presence of lakes and relief inversion as the well-insulated lake floors become elevated surfaces.

Rates of lowering due to lake wandering

Lakes with an area >1 ha occupy a minimum of 14 ha or *c.* 7% of the 208 ha of Flanders Moraine. Adding the smaller lakes and innumerable ponds would probably raise the figure to *c.* 15–20%. If these lakes are as mobile as Pelite Lake and Crystal Pond, i.e. change by 50% in 20 years, then the entire surface of the moraine will be affected in *c.* 200 years. The average depth of the lakes is unknown but it is certainly more than 5 m and probably more than 10 m. Taking an average depth of 10 m, the entire moraine would be lowered by this amount in 200 years, i.e. *c.* 0.05 m year^{-1}. If we include lowering due to other causes: creek melt, direct ablation below debris, etc., then the rate may well double.

Crude confirmation of these calculations comes from observed rates of scarp retreat on Flanders Moraine. Pickard (in press) found total retreat of *c.* 2 m year^{-1} for Pelite Lake and Crystal Pond after 9 weeks monitoring at 35 sites. This is very similar to the 20-year rate determined from air photograph interpretation (Table I). Crescent Lake has moved *c.* 500 m and has lowered the surface 20 m in its path. At 2 m year^{-1}, this lateral movement would take *c.* 250 years, which is consistent with the calculation above.

Table I. Changes in Pelite Lake and Crystal Pond, 1958–79, determined using air photographs

	Pelite Lake	*Crystal Pond*
Average retreat of cliff 1958–79 (m)	28	nd
Maximum retreat of cliff 1958–79 (m)	38	17
Mean retreat (m year^{-1})*	1.3	0.8
Area 1958 (ha)	1.63	0.08
Area 1979 (ha)	2.35	0.11
Change (ha)	0.72	0.04
% change	44	57

* Measured at 20 sites.
nd Not determined.

Flanders Moraine is probably a relict from the Chelnok Glaciation (Adamson and Pickard, in press), when ice surged northward from Sørsdal Glacier. Other evidence suggests that this occurred between 1 000 and 2 000 years ago. The ice covered the highest hills (160 m a.s.l.) in the south-eastern corner of the Vestfold Hills. Taking 200 m as the minimum altitude of the ice surface implies that *c.* 60 m has melted. At a linear rate of 0.05 m year^{-1}, this gives a minimum age of 1 200 years for the Chelnok Glaciation. This is consistent with the age suggested by Adamson and Pickard (in press).

Discussion

Over most of the area of Flanders Moraine, the ice is protected from rapid melting by 1–3 m of till which forms a substantial insulating layer. One of the important effects of lake wander is to disturb this insulating layer of till and to expose the underlying ice to direct insolation, to flowing melt water, and to lake water. The lakes are laterally mobile hot spots which locally accelerate melting of the stagnant ice as they wander across its surface. Comparison with results from elsewhere is difficult because of differences in climate and techniques used. Even so, the various rates are of the same order (Table II).

Driscoll (1980) discussed surface lowering of moraines on Klutlan Glacier due to lakes but proposed deepening rather than wandering as a mechanism. Watson (1980) described collapse of ice cliffs into lakes on the same moraines but also failed to mention wander as a mechanism. For 5 months each summer the mean daily temperature of Klutlan Glacier is above zero, and the mean minimum is above zero for 3 months (Driscoll, 1980). This is considerably warmer than Flanders Moraine (Burton and Campbell, 1980); consequently the rate of lake wander on Klutlan Glacier would be more rapid. Possibly, shear zones

TABLE II. RATES OF SURFACE LOWERING OF CLEAN AND DEBRIS-COVERED ICE

Location	Period of measurement	Thickness of debris m	Rate m week^{-1}	Rate m year^{-1}	Author
Mawson, Antarctica	9 years	—	0.04	0.5	Budd, 1967
Davis, Antarctica	1.7 years	—	—	0.46	Pickard, unpublished
Isfallsglaciären, Sweden	3 weeks	—	0.32	—	Østrem, 1959
Kaskawulsh Glacier, Yukon	3.5 weeks	—	0.38	—	Loomis, 1970
		—	0.60	—	Johnson, 1971
Adams Inlet Glacier, Alaska	50 years	—	—	7.9	Field, 1947
Isfallsglaciären, Sweden	3 weeks	0.06	0.21	—	Østrem, 1959
		0.20	0.07	—	Østrem, 1959
Kaskawulsh Glacier, Yukon	3.5 weeks	0.22	0.42	—	Loomis, 1970
Kame, Adams Inlet, Alaska	? < 10 weeks	4.0	—	0.24	McKenzie, 1969
		0.8	0.07	—	McKenzie, 1969
Klutlan Glacier, Yukon	600 years*	variable	—	0.3	Watson, 1980
	400 years*	variable	—	0.003–0.3	Driscoll, 1980
	950 years*	variable	—	0.2	Driscoll, 1980
Flanders Moraine, Antarctica	200 years*	1–3.0	—	0.05	This paper

* Periods over which lowering is estimated.

in the ice of the Klutlan Glacier moraines would effectively prevent lakes wandering great distances as they would drain along the shear zones.

Surface lowering is usually the result of a combination of processes. Partition between these processes is not possible except in favourable circumstances. Driscoll (1980) has attempted to quantify the component of lowering due to different processes but most studies do not. This is due partially to the difficult climates of such areas but also to very real problems of experimental design. On any one moraine, the dominant process probably changes over each melt season. It will also vary on a daily basis and due to weather changes. Under these conditions, accurate apportioning of contribution is well-nigh impossible.

Where lakes exist on ice-cored moraines, they should be regarded as a potentially rapid mechanism for surface lowering. Lake wander is less susceptible to the vagaries of weather changes and can even proceed over winter.

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REFERENCES

Adamson, D., *and* Pickard, J. In press. Late Quaternary ice movement across the Vestfold Hills, Antarctica. [Paper presented at fourth International Symposium on Antarctic Earth Sciences, Adelaide, 1982.]

Budd, W. F. 1967. Ablation from an Antarctic ice surface. (*In* Ōura, H., *ed. Physics of snow and ice: international conference on low temperature science.... 1966.... Proceedings*, Vol. 1, Pt. 1. [Sapporo], Institute of Low Temperature Science, Hokkaido University, p. 431–46.)

Burton, H. R., *and* Campbell, P. J. 1980. The climate of the Vestfold Hills, Davis Station, Antarctica, with a note on its effect on the hydrology of hypersaline Deep Lake. *ANARE Scientific Reports*. Ser. D. Meteorology. Publication No. 129.

Driscoll, F. G., *jr*. 1980. Wastage of the Klutlan ice-cored moraines, Yukon Territory, Canada. *Quaternary Research*, Vol. 14, No. 1, p. 31–49.

Field, W. O. 1947. Glacier recession in Muir Inlet, Glacier Bay, Alaska. *Geographical Review*, Vol. 37, No. 3, p. 369–99.

Johnson, P. G. 1971. Ice cored moraine formation and degradation, Donjek Glacier, Yukon Territory, Canada. *Geografiska Annaler*, Vol. 53A, Nos. 3–4, p. 198–202.

Loomis, S. R. 1970. Morphology and ablation processes on glacier ice. *Proceedings of the Association of American Geographers*, Vol. 2, p. 88–92.

McKenzie, G. D. 1969. Observations on a collapsing kame terrace in Glacier Bay National Monument, south-eastern Alaska. *Journal of Glaciology*, Vol. 8, No. 54, p. 413–25.

Østrem, G. 1959. Ice melting under a thin layer of moraine, and the existence of ice cores in moraine ridges. *Geografiska Annaler*, Vol. 41, No. 4, p. 228–30.

Østrem, G. 1964. Ice-cored moraines in Scandinavia. *Geografiska Annaler*, Vol. 46, No. 3, p. 282–337.

Pickard, J. In press. Retreat of ice scarps on an ice-cored moraine, Vestfold Hills, Antarctica. *Zeitschrift für Geomorphologie*.

Watson, R. A. 1980. Landform development on moraines of the Klutlan Glacier, Yukon Territory, Canada. *Quaternary Research*, Vol. 14, No. 1, p. 50–59.