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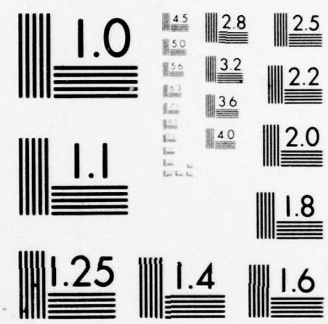

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Several glacier-fed lakes were investigated in order to better understand the relationships between inflow properties, various physical characteristics of the lakes, and the processes and patterns of sedimentation within the lakes. The lakes are all located in mountainous terraines in Banff and Yoho National Parks near the Alberta-British Columbia border in western Canada. The lakes are all relatively small (< 5 km long) and are fed by overland meltwater streams draining alpine glaciers. The field work was begun in the summer of 1973. This report presents

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20. ABSTRACT CONTINUED

a brief summary of the methodology and principal results of the project. Detailed results have been, and will be, published in professional journals. A total of eight lakes were investigated, four of them in detail (Hector, Bow, Peyto, Lower Waterfowl). These lakes are each characterized by one of three kinds of suspended sediment transport patterns that were recognized in this study: overflow/interflow, underflow, and homogeneous dispersal.

A Final Report on

SEDIMENT DISTRIBUTION PROCESSES IN GLACIER-FED LAKES AND DELTAS

BY

Norman D. Smith
University of Illinois at Chicago Circle

November, 1977

A brief report summarizing some of the main results of research supported by the U.S. Army Research Office under the following grants:

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INTRODUCTION

Several glacier-fed lakes were investigated in order to better understand the relationships between inflow properties, various physical characteristics of the lakes, and the processes and patterns of sedimentation within the lakes. The lakes are all located in mountainous terraines in Banff and Yoho National Parks near the Alberta-British Columbia border in western Canada. The lakes are all relatively small (< 5 km long) and are fed by overland meltwater streams draining alpine glaciers. The field work was begun in the summer of 1973, supported by a university seed grant, and continued over the next four summers under ARO sponsorship (including one no-cost extension that covered part of the 1977 summer).

The paragraphs that follow are a brief summary of the methodology and principal results of the project. Detailed results have been, and will be, published in professional journals. A total of eight lakes were investigated, four of them in detail (Hector, Bow, Peyto, Lower Waterfowl). These lakes are each characterized by one of three kinds of suspended sediment transport patterns that were recognized in this study: overflow/interflow, underflow, and homogeneous dispersal.

METHODS

Inflow discharges were monitored in the usual way by stage recorders positioned near the inlets. Stream velocities for constructing discharge-stage rating curves were obtained by wading with a rod-mounted Price current meter. Measurements of suspended sediment concentration, water temperature, and electrical conductivity permitted calculation of inflow density, stream suspended sediment load, and dissolved load over the durations in which the temporary gaging stations were maintained. Summer inflow records thus obtained were as follows: Hector - 2 years, Bow - 2 years, Peyto - 1 year, Lower Waterfowl - 1 year). Lake bathymetry maps were constructed from lead-line soundings and fathometer surveys. Sedimentation rates were measured directly by sediment traps placed on the lake bottom and were marked and retrieved by strings attached to floats. Lake water samples were collected repeatedly at varying depths and analyzed for suspended sediment content, turbidity, and conductivity to assess the patterns of water mass movements and sediment transport within the lake columns. Water temperature profiles were frequently obtained by thermister probe to aid interpretations of major water motions and density stratification. Lake currents were studied with drogues and, where strong enough, by remote current meter. Selected water samples were chemically analyzed for pH and major ionic components to determine the saturation states of the water with respect to calcite and dolomite, two of the main detrital constituents of the lake sediments. Gravity cores were collected for analyses of sedimentary structures, mineralogy, and sediment texture. Transmissivity surveys were conducted occasionally to identify preferred paths of suspended sediment transport through the lakes. All lake sampling and measuring was done in lightweight rowboats (non-motorized due to park regulations).

Results indicated that 3 principal types of inflow and resulting sediment distribution patterns occur among the lakes studied: Underflow, overflow/interflow, and homogeneous dispersal. The dominant variables that appear to ultimately control sedimentation patterns are influent suspended sediment concentration, lake depth, bathymetry, and wind directions.

UNDERFLOW (Peyto)

Of the 8 lakes examined, only Peyto Lake is characterized by frequent underflows. Peyto inflow contains the highest suspended sediment concentrations observed in the study (ave. 720 mg/l, measured range 138-2,156 mg/l), and thus also displays the highest density, resulting in underflow as the stream enters the lake. Variations in water temperature and concentration of dissolved solids are unimportant sources of density variation in Peyto inflow as well as inflow to the other lakes. The lake is up to 50 m deep and virtually isothermal in summer. Incoming suspended sediment is mostly distributed by underflows whose distributions are controlled by bottom topography, although interflows and overflows may occur during periods of low discharge (and low sediment concentration).

Direct measurements of underflows near the stream inlet show that underflow velocities pulsate quickly and vary with changes in discharge. Velocity calculations based on steady flow theory yield higher values than the observed Peyto velocities. This difference could be due to underestimation of the frictional coefficient (Darcy-Weisbach f), incorrect estimate of the α-value (a measure of velocity profile shape), or to positioning of the current meter. Measurements of 2 underflow velocity profiles and other required variables yielded calculated frictional coefficients of 0.22 and 0.31, significantly higher than the commonly assumed values of between .01 to .04. These results suggest that frictional drag at the fluid-fluid boundary may have been improperly accounted for in previous calculations of underflow velocities.

Most bottom sediments are well laminated, but only rarely can classic annual varves be recognized. Most laminations probably result from inflow fluctuations arising from short-term weather changes (temperature and rainfall).

<u>OVERFLOW/INTERFLOW (Hector, Bow)</u>

Hector and Bow Lakes typify the overflow/interflow mechanism, also dominant in 3 of the lakes not studied in detail (Moraine, Emerald, Louise).

Both lakes are thermally stratified in summer, and influent suspended sediment concentrations are relatively low (usually < 400 mg/l); thus, inflow is distributed across the lakes as surface overflows and shallow interflows above the hypolimnion. Highest sediment concentrations occur within the epilimnion, usually 3 to 20 m below surface. Sediment is mostly distributed by epilimnial currents induced by wind shear; these currents are often complex but tend to show prevailing right-hand tendencies (Coriolis effect). Winds at both lakes are mainly katabatic and directed downlake, thus, there is a preferred tendency for sediment transport along the right-hand margins. This tendency is manifested in several right-to-left as well as downlake proximal-to-distal trends in bottom sediment characteristics: decreases in grain size, sedimentation rates, dolomite/calcite ratios, total carbonate, and varve thickness. Some fine sediment is also distributed by weak (< 1 cm/sec) hypolimnial currents which are somewhat affected by bottom topography.

Like Peyto Lake, laminae in the bottom sediments are produced by inflow variations that are largely dependent upon air temperature. In Hector Lake, 5 orders of inflow, and thus sediment input, variation capable of producing laminae are recognized: diurnal, subseasonal (short-term weather changes), nival melt vs. glacial melt, annual, and exceptional inflow events. Annual laminations (i.e., classical varves) are the most readily recognized of these, and occur in about 2/3 of Hector Lake and 3/4 of Bow Lake bottom sediments, the proportions of which are governed by the ratio of sediment influx to area of lake bottom.

HOMOGENEOUS DISPERSAL (Lower Waterfowl)

Lower Waterfowl is the lowermost in a series of 3 lakes drained by a single meltwater stream (Mistaya River), hence, differs from the others in that it is not fed directly by a glacier. Influent sediment concentrations are therefore low (ave. 9 mg/1, measured range 6-14 mg/1), and water density varies little. The lake is shallow (10 m max.) and thoroughly mixed by wind, preventing the development of thermal or chemical stratification. The resulting absence of density stratification in the lake permits inflow to enter as an axial jet because of the virtual equality of influent and ambient water density. Suspended sediment is quickly dispersed throughout the lake by complex currents generated by winds from several directions. Water samples and transmissivity surveys both show that suspended sediment is distributed nearly uniformly throughout the lake, thus, the prominent sedimentation trends observed in the other lakes are lacking here. For example, proximal-to-distal deposition rates decrease by a factor of only about 2 compared to 30 for Peyto and 10-20 for Bow and Hector. Neither bathymetry nor Coriolis force appear to play major roles in sedimentation patterns, unlike the other lakes of this study. Sediment cores display mostly massive clays and silts.

SUMMARIZED COMPARISONS

A manuscript which compares and contrasts sedimentation in these 3 kinds of lakes is now being prepared for submission to a professional journal. The highlights of this manuscript are summarized in the following paragraph.

The lakes being compared are of roughly similar size and are mainly fed, either directly or indirectly, by glacial meltwater. Key factors which determine the processes and patterns of sedimentation in these lakes are inflow sediment concentration and discharge variability, lake depth and bottom topography, thermal character of lake water, and dominant wind patterns. Peyto inflow has the highest suspended concentrations, thus, inflowing sediment is dispersed mainly by underflows. Although the lake is deep (∿ 50 m), it is isothermal, probably in large part due to disruptions caused by the underflowing water and complex counter-currents that result. Sedimentation trends tend to reflect bottom topography as the underflows seek the deepest portions of the lake. Wind effects and Coriolis deflections appear to be negligible. Sedimentation rates are relatively rapid, with laminae in bottom sediments produced mainly by short-term discharge fluctuations. Hector and Bow Lakes are also deep (> 45 m), but unlike Peyto they develop a stable thermal stratification in summer. Inflows contain relatively low concentrations of suspended sediment, thus they spread across the lakes as overflows and shallow interflows within the epilimnion. Downlake katabatic winds generate epilimnial currents which are deflected rightward by the Coriolis force, resulting in pronounced right-hand sediment transport and depositional trends in the bottom sediment. Bottom topography has little effect on observed sedimentation patterns. Sediments are well laminated and classical varves are easily recognized. Lower Waterfowl Lake receives the lowest suspended concentrations. The shallow unstratified lake has virtually the same density as the inflow; thus, inflow mixes 3-dimensionally, and suspended sediment is homogeneously distributed both laterally and vertically through the lake. The lake is continually mixed by winds blowing from several directions. Bottom deposits are mostly unlaminated and show only weak downlake and crosslake sedimentation trends.

<u>UPPER WATERFOWL LAKE</u>

This lake and its delta was studied in 1974 with the view toward understanding the depositional environments, sediments, and post-glacial history. The results have been published (see "REPORTS").

REPORTS

A. Articles

1. Smith, N. D., 1975, Sedimentary environments and Late Quaternary history of a "low-energy" mountain delta: Canad. Jour. Earth Sci., v. 12, p. 2004-2013.

2. Kennedy, S. K., and Smith, N. D., 1977, The relationship between carbonate mineralogy and grain size in two alpine lakes: Jour. Sed. Petrol., v. 47, p. 411-418.

3. Smith, N. D., Sedimentation processes and patterns in a glacier-fed lake with low sediment input (submitted to Canad. Jour. Earth Sci.).

B. Articles in preparation

1. Kennedy, S. K., and Smith, N. D., Sedimentation in Bow Lake, Alberta (manuscript now being revised).

2. Smith, N. D., and Vendl, M. A., Comparison of sediment transport mechanisms in several glacier-fed lakes.

C. Abstracts

1. Some aspects of sedimentation in a small proglacial lake: Program Ann. Mtg. North-Central Sect. Geol. Soc. Amer., p. 521-522, 1974 (with S. K. Kennedy).

2. Facies development in two contrasting types of mountain lake deltas: Program Ann. Mtg. Geol. Assoc. Canada/North-Central Sect. Geol. Soc. Amer., p. 860, 1975.

3. Sedimentation in a glacier-fed mountain lake: Program Ann. Mtg. Amer. Assoc. Petrol. Geol., p. 70, 1975.

4. Sediment transport mechanisms in several Banff Park lakes: Prog. Ann. Mtg. Geol. Assoc. Canada, p. 77, 1976.

5. Sedimentation in glacier-fed Peyto Lake, Alberta: Prog. Ann. Mtg. North-Central Sect. Geol. Soc. Amer., p. 661, 1977 (with M. A. Vendl).

D. Theses

Kennedy, S. K., 1975, Sedimentation in a glacier-fed lake: M.Sc. thesis, U. Illinois at Chicago Circle, 55 p.

Vendl, M. A., Sedimentation in glacier-fed Peyto Lake, Alberta: M.Sc. thesis, U. Illinois at Chicago Circle (expected March 1978; thesis is virtually completed).