A Middle Pleistocene (isotope stage 10) glacial sequence in the Stikine River valley, British Columbia

Ian S. Spooner, Gerald D. Osborn, R. Barendregt, and E. Irving

Abstract: In the Stikine River valley, northwestern British Columbia, glacial and nonglacial sediments are preserved beneath Middle Pleistocene basalt-flow remnants that originated from Mount Edziza. The magnetic polarity is consistently normal, indicating that the sediment and the basalts were probably deposited within the Bruhnes normal polarity chron (<780 ka). The sediments record a regional glacial advance. Initial ice advance in the Coast Mountains blocked the westward drainage of the Stikine River and formed an advance-phase glacial lake. Sediments deposited in this lake form a coarsening-upwards sequence; debris-flow diamicton units that originated from the valley sides are common. The lacustrine sequence culminates in a poorly sorted ice-marginal gravel deposited as ice encroached upon the study area. There is little record of ice retreat. The basalts are deposited on fluvial and (or) glaciofluvial gravels, indicating that postglacial reincision was taking place at the time of eruption. Hence, the sediments were deposited in the glacial period immediately prior to the emplacement of the basalt. Evidence is presented that indicates that glacial conditions occurred between 341 and 352 ka, which corresponds to pre-Illinoian isotope stage 10.

Résumé : Dans la vallée de la rivière Stikine, région nord-ouest de la Colombie-Britannique, des sédiments glaciaires et non-glaciaires ont été préservés sous les vestiges des coulées basaltiques du Pléistocène moyen produites par le mont Edziza. La polarité magnétique uniformément normale révèle que les sédiments et les basaltes furent probablement déposés durant la Chronozone polaire normale de Bruhnes (<780 ka). Ces sédiments documentent une avancée glaciaire régionale. La progression glaciaire initiale dans la chaîne Côtière a bloqué l'écoulement vers l'ouest de la rivière Stikine et a engendré la formation d'un lac glaciaire durant cette phase d'avancée. Les sédiments déposés dans ce lac forment une séquence à granocroissance ascendante; les unités de diamictons formées de coulées de débris ayant pris naissance sur les versants de la vallée sont fréquentes. La séquence lacustre est culminante dans le gravier mal trié à la marge du glacier, elle a été déposée lors de l'empiètement du glacier dans la région étudiée. La phase de retrait du glacier est pauvrement documentée. Les basaltes sont déposés sur les couches de graviers fluviaux ou fluvio-glaciaires, ce qui indique une ré-incision postglaciaire au moment de l'éruption. En conclusion, les sédiments furent déposés durant la période glaciaire qui a précédé immédiatement la mise en place du basalte. Nous présentons des arguments qui indiquent que les conditions glaciaires sont apparues entre 341 et 352 ka, ce qui correspond au Stade isotopique 10 pré-Illinoien. [Traduit par la rédaction]

Introduction

In this paper, we describe the stratigraphy and paleomagnetism of Pleistocene deposits of the Stikine River valley near Telegraph Creek, British Columbia. This study was undertaken to determine the timing and extent of pre-Fraser (pre-Late Wisconsinan) glaciations and to develop the chronostratigraphy for northwestern British Columbia. The study area (Fig. 1) was selected because of the known occurrence of glacial, fluvial, and volcanogenic sediments under and between Pleistocene-aged basalt flows (Souther 1992).

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Geological setting and history

The two sites examined are located along the canyon walls of the lower Tahltan River and the Stikine River, respectively, both of which flow through the Stikine Plateau (Fig. 1). The Stikine Plateau lies within the Whitehorse Trough of the Intermontane Belt, which consists mainly of Lower Triassic to Middle Jurassic volcanic rocks (Souther 1992; Gabrielse and Souther 1962). The Whitehorse Trough lies between the plutonic and metamorphic rocks of the Coast Plutonic Complex to the west and those of the Omineca Crystalline Belt to the east. The northeasterly trending Stikine Arch crosses the area and forms the northern margin of the Bowser Sedimentary Basin. Basalt flows found within the Stikine River canyon, and tributary river canyons (Tuya, Tahltan, and Klastline rivers; see Fig. 1) originated from the Mount Edziza Volcanic Complex, a Plio-Pleistocene volcano that is part of the Stikine volcanic belt.

The dominant physiographic feature in the region, the Stikine River canyon (and ancillary canyons on the Tahltan, Tuya, and Klastline rivers), is up to 800 m deep. Quaternary and late Tertiary basalt flows are found along the canyon walls, from just upstream of the Klastline River mouth to

37 km downstream of Telegraph Creek (Read and Psutka 1985). The basalt flows rest on and therefore have preserved both older basalts and sediments and in many areas define abandoned paleochannels of the Stikine River (Read and Psutka 1985).

Early advance of the regional ice sheet in the Coast Mountains (relative to ice advance in the Skeena Mountains) during the Fraser Glaciation (Late Wisconsinan) resulted in the damming of the Stikine River to the west of the study area and the formation of an advance-phase Glacial Lake Stikine (Ryder and Maynard 1991). Glacial Lake Stikine sediments consist of a 300 m thick succession of silt and sand that is overlain by Late Wisconsinan Fraser till.

The early Holocene was characterized by rapid incision of Late Wisconsinan sediments and periodic eruptive activity which resulted in the deposition of the Big Raven basalt (8610 ± 80 ^{14}C years BP), which probably originated in the Klastline River valley (Fig. 1) (Read and Psutka 1985). Big Raven volcanic flows are preserved at the mouths of the Klastline and Tahltan rivers and overlie about 100 m of poorly sorted, unconsolidated sediment. Fluvial incision and eruptive activity have continued through the middle and late Holocene, though the eruptions are local and poorly dated (Spooner et al. 1993).

Previous research

Because the Stikine River valley served as a route to the Klondike gold fields and contains gold itself, it became an early subject of study (Dawson 1898). Johnson (1926) noted the intercalated nature of the basalt flows and sediments preserved within the canyons and suggested that the gravels preserved beneath the basalts may hold further placer potential. Watson and Mathews (1944), Kerr (1948), and Gabrielse and Souther (1962) undertook regional surveys of the Stikine Plateau. Souther (1992) concentrated on the geology of Mount Edziza and the Spectrum Range. Alley and Young (1978) produced a regional geomorphic survey of the Stikine Plateau. Read and Psutka (1985) produced an extensive study of the stratigraphy and structure exposed in the Stikine River canyon. Many of the dates (K–Ar and ^{14}C) and nomenclature in this paper were first proposed in that report. Ryder (1987) described the neoglacial history of the Stikine region, and Ryder and Maynard (1991) produced an evaluation of the glacial geomorphology of northern British Columbia. The latter described the thick unconsolidated sediment succession in the Stikine Plateau region as having been deposited in Glacial Lake Stikine during the initiation of the Fraser Glaciation, as early advance of the Coast Mountain ice blocked the westward drainage of the Stikine River.

Regional stratigraphy

In the vicinity of the confluence of the Stikine and the Tahltan rivers, isolated volcanic-flow remnants are preserved along the canyon walls of these rivers. The flows have been identified morphologically as belonging to the Big Raven Formation and the Klastline Formation (Read and Psutka 1985; Souther 1992). The former was deposited during the early Holocene (8610 ± 80 ^{14}C years BP) and retains its unglaciated, clinkery top.

The Klastline Formation is a Middle to Late Pleistocene series of basalt flows that are presently found from the Klastline–Stikine confluence to 55 km downstream along the Stikine River. Eruptions occurred from 440 to 110 ka (Read and Psutka 1985) and are believed to have originated on the north and east sides of the Edziza Plateau from at least three separate sources. The Klastline Formation in the Stikine River valley may be coeval with either Klastline Formation or Kakiddi Formation eruptive activity on Mount Edziza (Souther 1992). The Klastline Formation has been subdivided into the Junction Member, which is characterized by its swirly jointed nature, and the overlying Village Member, which has regular columnar jointing (Read and Psutka 1985). Flows described in this paper belong to the Village Member, which consists of at least five distinct grey porphyritic vesicular basalt flows that, in places, collectively reach a thickness of 100 m (Read and Psutka 1985). Stratigraphic correlation of single flows is difficult, as the Village Member is preserved commonly as isolated flow remnants.

A well-sorted sand and gravel sequence has been preserved between various Village Member remnants and is referred to as the Days Ranch Member (Read and Psutka 1985). Some Village Member flow remnants are also found resting directly on top of each other with little or no interflow sediment.

A heterogeneous sediment assemblage that contains clay- to gravel-sized sediment with interspersed diamictons is exposed locally along the walls of the Stikine, Klastline, and Tahltan rivers. This sediment assemblage commonly rests on Triassic bedrock, but can also be found between Village and

Fig. 1. Location of study area and sections. Both sites are located on the central Stikine Plateau in northwestern British Columbia. The Tahltan Canyon section (1) is located in a 200 m deep gorge; the Stikine Canyon section (2) is located at the western end of the Grand Canyon of the Stikine.

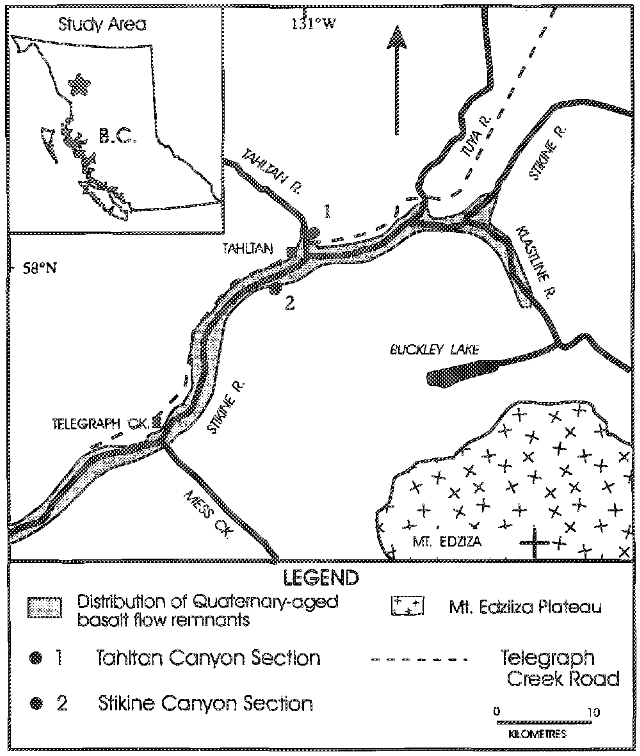
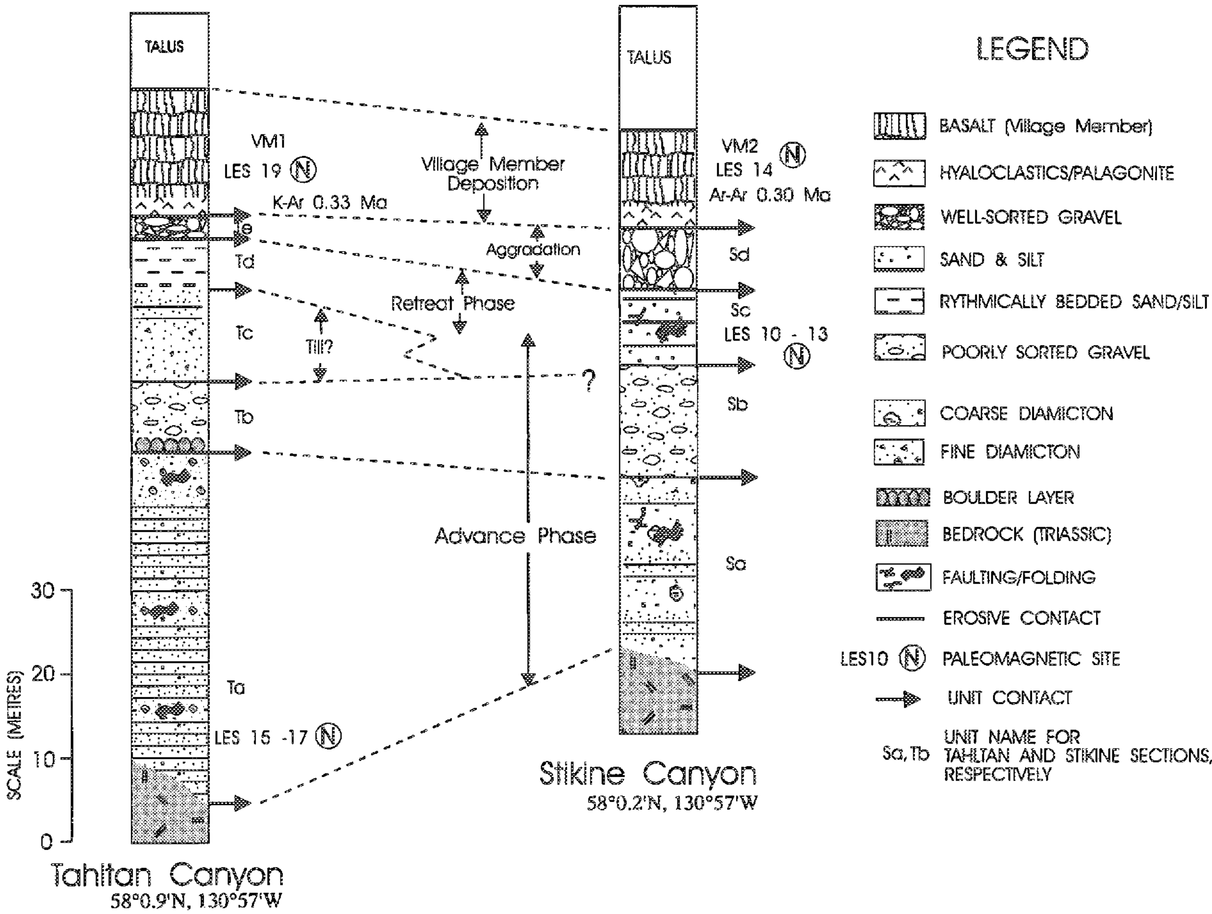


Fig. 2. General section stratigraphy and paleomagnetism for the Stikine and Tahltan canyon sections. Much of the sediment under the Village Member 1 (VM1) and Village Member 2 (VM2) basalts is interpreted as having been deposited in advance-phase (Ta, Tb, Sa, Sb) and retreat-phase (Td, Sc) glacial environments. Unit Tc may be a till, and units Te and Sd are postglacial fluvial gravels. The basalts and sediments both exhibit normal polarity; VM1 has been dated at 330 ± 30 ka and VM2 at 300 ± 100 ka.



Junction member basalts; it is believed to contain sediments of a wide range of ages and has been given the informal designation Pal (Pleistocene alluvium) by Read and Psutka (1985). The two sections that are discussed in this paper contain Pal sediments.

Stratigraphic descriptions

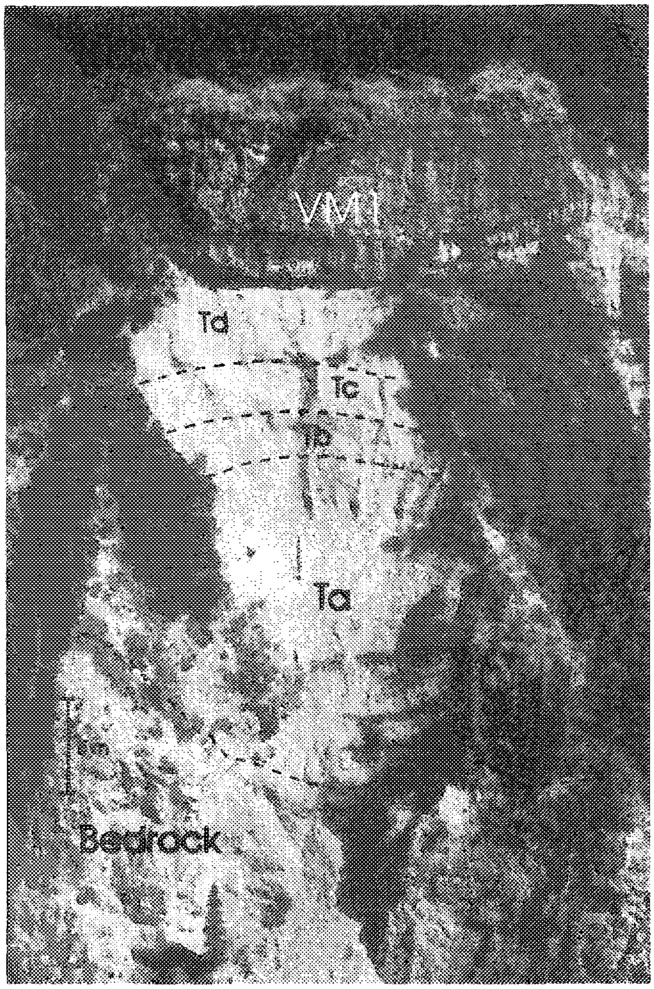
Tahltan Canyon section

This section is located on the Tahltan River and consists of a dissected Village Member basalt flow, VM1, that overlies fine- to coarse-grained sediments that rest on Triassic bedrock (Figs. 2, 3). The capping basalt has been K–Ar dated at 330 ± 30 ka. The top of the basalt flow is striated and polished, whereas the base of the basalt has a generally concave-up profile (Fig. 3). Abundant fracturing, palagonite and glassy quench rinds at the base of the basalt indicate that the basalt was deposited in water or on ice.

The basal stratigraphic unit (Ta, Fig. 4) is 30 m thick and consists of horizontally bedded, partly cross-laminated, partly parallel-laminated, and partly massive sand facies with diamicton beds interspersed throughout. These sediments rest on Triassic bedrock. The parallel- and cross-laminated beds dominate the lower portion of this unit and contain sporadic, 1–2 cm thick clay laminae that often contain load and dewatering structures. Laminated and massive beds average about 70 cm thick and are separated by erosional boundaries that often contain a lag of pebbles or coarse sand. The sand facies are, in places, truncated and deformed by the overlying diamictons. Paleocurrent directions averaged 350°. The diamictons contain rounded and angular nonstriated bedrock clasts and angular silt clasts (rip-ups); minor normal faulting and folding are common. The diamicton beds dominate the upper portion of this unit and vary in thickness from 20 cm in the bottom 2/3 of the unit to a 6 m thick bed at the top of the unit. The uppermost diamicton bed contains distinct horizontal to convoluted laminations and numerous isolated, matrix-supported, well-rounded, and less commonly, angular boulders.

Unit Ta is unconformably overlain by a 12 m thick stratified gravel unit (Tb, Fig. 5) with a 1.5 m thick boulder lag at its base. No imbrication was evident within this unit. The gravel clasts are well rounded or occasionally subrounded to angular, with a maximum long-axis length of 70 cm. Unit Tb contains lenses of tabular and trough cross-bedded sand, indicating paleocurrent directions averaging 252°. Small,

Fig. 3. Tahltan River section. A variety of laminated and poorly sorted sediment (units Ta–Td; see Fig. 2) is deposited beneath a Village Member basalt remnant dated at 330 ± 30 ka. The section rests on Triassic bedrock and is about 80 m high.

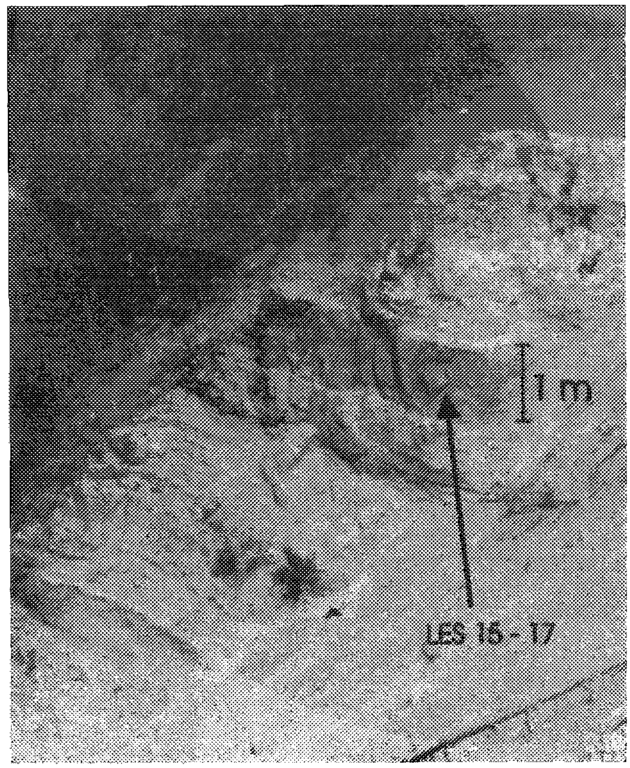


well-rounded, internally laminated silty clasts are common and are in clast contact with the coarser sediment.

Unit Tc (Fig. 3) is a faintly laminated, well-compacted, sand–silt-dominant diamicton that is 9 m thick. The contact with underlying Tb is sharp and erosional. Tc contains occasional angular and rounded, striated, gravel clasts and isolated coarse-grained lenses. Light-coloured strata in the uppermost 2 m of the unit are composed of undulating beds of diamicton with a silt–clay-dominant (rather than sand–silt) matrix. Gravel clasts are less common in the uppermost 2 m and are smaller than in the basal portion of the unit. The fine-grained nature and inaccessibility of this unit precluded fabric measurements.

Unit Td (Fig. 3) is 4 m thick, blue–grey in colour and contains laminated fine sand to clay-sized sediment. The beds are rhythmically deposited, with each bed consisting of a massive silt–sand bed (10–15 cm thick) capped by a horizontally laminated, 2 cm thick silt–clay laminae. Td contains occasional isolated angular gravel clasts, but does not contain diamicton units. The contact between Td and underlying Tc is abrupt.

Fig. 4. Tahltan Canyon section. Lower unit Ta is dominated by horizontally bedded cross-laminated and massive sediment with interspersed diamicton beds. Paleomagnetic samples (LES 15–17) were taken from clay laminae in the massive silty sand beds.



Unit Te (Fig. 2) is a 2 m thick, clast-supported, openwork, well-sorted gravel to boulder unit with some sand lenses. The gravel is not imbricated. The clasts are well rounded to very angular, heterogeneous in composition, and occasionally striated. The contact between Te and Td is strongly concave and erosional, with the largest and greatest concentration of angular clasts at the base of the unit.

Stikine Canyon section

This section is located on the east bank of the Stikine River about 2 km downstream from the mouth of the Tahltan River (Fig. 6). A Village Member basalt flow (VM2, Fig. 6) exhibits vertical columnar jointing and overlies stratified sediment. The basalt has been Ar–Ar dated at 300 ± 100 ka. The basal part of the basalt flow is fractured and intermixed with palagonite, indicating deposition in an aqueous environment or on ice. Four distinct stratigraphic units are present at the Stikine River section. Deformation (faulting, tilting, and some folding) is ubiquitous in the lower two units.

Unit Sa (Fig. 6A) is a deformed stratified deposit that overlies Triassic bedrock. This unit consists of thin diamicton beds interspersed with laminated and massive sand beds that are often truncated and deformed. The diamicton beds contain angular bedrock and clay–silt clasts (rip-ups) that are internally laminated. Folding and some thrust faulting are common within this unit and obscure the internal geometry of the laminated beds. Unit Sa is a minimum of 20 m thick. The basal contact is obscured by talus.

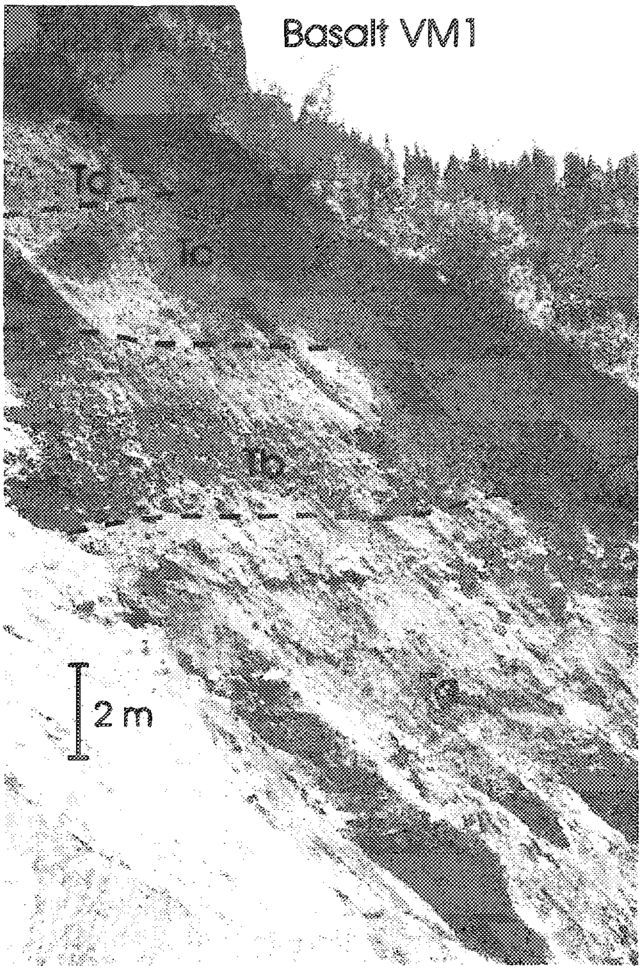


Fig. 5. Tahltan Canyon section. The upper portion of unit Ta consists primarily of coarse-grained diamictons separated by fine-grained facies. Unit Tb is 12 m thick and consists of stratified, poorly sorted, gravel-rich sediment. Discontinuous, tabular and trough cross-bedded sand lenses and isolated well-rounded clay clasts are common. Overlying unit Tc is a well-compacted silty diamicton.

Unit Sa is unconformably overlain by a poorly sorted, 12 m thick gravel deposit (unit Sb, Fig. 6A) that contains clay–silt clasts and, where not deformed, is stratified. Clasts are well rounded to subrounded with occasional angular clasts. Isolated pockets of sand and diamicton are present, but have limited lateral extent. Deformation has obscured laminations and possible imbrication and hence no paleocurrents were discernable within this unit.

Unit Sc is an 11 m thick, fine sand and silt-rich unit with occasional thin, matrix-supported gravel and diamicton beds at the base of the section. Individual beds average about 70 cm thick; clay laminae are common within the finer, massive silty sand beds. The contact between this unit and underlying unit Sb is gradational. Thrust faults (Figs. 6A, 6B) are common, with offsets commonly exceeding 1 m, but rarely greater than 2 m. Tabular and trough cross-lamination are present within the sand-rich beds and paleocurrent measurements averaged 270°. The silt-dominant beds are parallel-laminated with numerous gravel and cobble matrix-supported clasts; all clasts are well-rounded and were probably derived from underlying gravels.

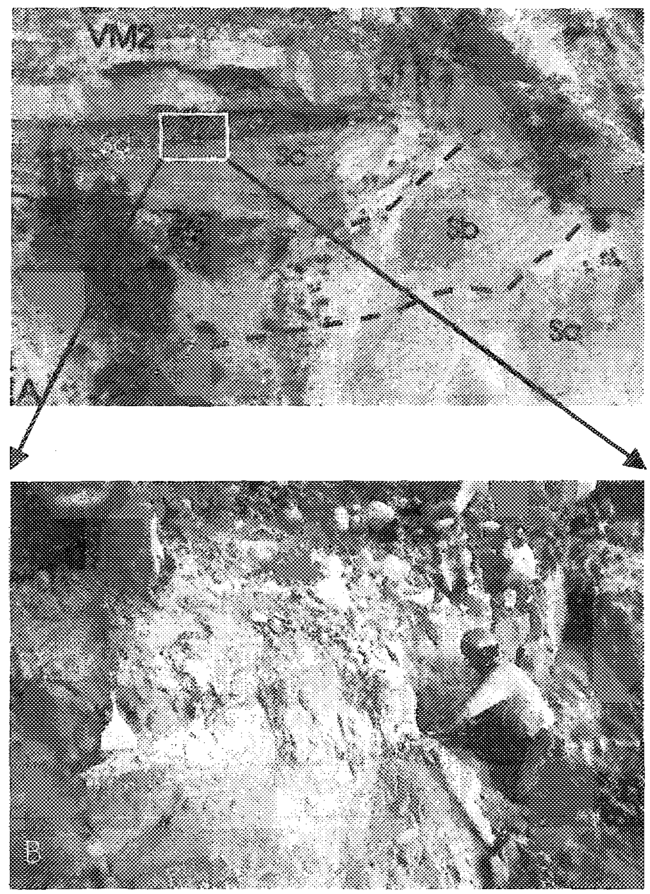


Fig. 6. (A) Stikine Canyon section. Village Member basalt remnant overlies three stratigraphic units (Sa, Sb, and Sc), which are the sedimentary record of regional ice advance and retreat. Unit Sd is a fluvial gravel deposited during initial reincision of the glacial sediment. (B) Detail of unit Sc, which is ice-proximal, glaciolacustrine sediment. The thrust fault was created by loading by the overlying basalt. Trowel is 15 cm high.

Unit Sd is a partially cemented, coarse sand to boulder deposit that is 7 m thick and is in angular–unconformable contact with unit Sc. The contact is concave upwards. Discontinuous lenses of trough cross-laminated sand are present as are pockets of openwork gravel. The gravel clasts are clast supported and well rounded to angular (some clasts with sharp edges).

Paleomagnetism

Samples for paleomagnetic analysis were oriented using sun and magnetic compasses (Table 1); all measurements agreed to within 0.5°. At the Tahltan site (LES 15), sedimentary paleomagnetic samples were taken from nondeformed clay laminae within unit Ta. At the Stikine Canyon site paleomagnetic samples (LES 10) were taken from a distinct, nondeformed clay–silt-rich layer within unit Sc.

The natural remanent magnetizations (NRM) were measured for all samples. Pilot specimens were chosen

Table 1. Paleomagnetic site results.

Site	Polarity[a]	Lat. (N)	Long. (W)	No. of cores	No. of specimens	M (A/m)	D (°)	I (°)	k	α_{95} (°)	Material
LES 10 (unit Sb)	N	58°0.2′	130°59′	23	23	0.1757	48.6	71.5	68	3.7	Clay–silt
LES 14 (unit R2)	N	58°0.2′	130°59′	6	10	3.101	13.7	82.6	198	3.4	Basalt
LES 15 (unit Ta)	N	58°0.9′	130°57′	18	18	0.0481	24.0	68.4	64	4.4	Silty sand
LES 19 (unit R1)	N	58°0.9′	130°57′	7	10	9.990	357.8	74.0	129	4.3	Basalt

Note: Sites are located by latitude, longitude, and map reference. M, mean intensity of magnetization of the specimens; D and I, declination and inclination, respectively, of the mean direction relative to the present horizontal; k, Fisher's estimate and precision; α_{95}, radius of the circle of 95% confidence.

[a]N, normal.

for alternating-field (AF) and thermal demagnetization. Thermal demagnetizations of basalt samples shows unblocking temperatures of 300–500°C (Fig. 7). Magnetizations past these temperatures became random. The decay of the intensity during Af demagnetization for the basalt and sediment samples from both sites was smooth and a substantial part remained after treatment at 100 mT. Orthogonal plots of AF-demagnetized samples (Fig. 8) displayed linear decay to the origin, with directions changing little throughout the treatment range; only a single component of magnetization is present.

All pilot specimens showed linear decay to the origin in the range 10–80 mT, and 20 mT was chosen as a suitable cleaning field sufficient to remove any recent overprints. This was sufficient for the determination of the polarity, which was the prime objective. All samples have normal polarity. The mean inclinations for the basalt samples at both sites is constant and the declination is northerly (Table 1). The sediment samples tend to have north-northeast declination (Fig. 9). This may be due to incomplete averaging of secular variation, an indication that the sediments may have been deposited over a relatively short period of time.

Interpretation

Although there is a possibility (from a paleomagnetic perspective) that these samples were deposited during earlier normal-polarity chrons, during treatment there was a conspicuous lack of evidence of overprints of either normal or reverse polarity. Therefore, the samples are interpreted as having been deposited during the Bruhnes normal polarity chron, which is within the last 780 ka (Shackleton et al. 1990; Cande and Kent 1992, 1995).

Stratigraphic interpretation

The sediments at the Tahltan Canyon and Stikine Canyon sections are thought to represent records of glacial advance, ice cover, and glacial retreat followed by fluvial aggradation and incision (Fig. 2). Glacial advance in the Coast Mountains impeded westward drainage and resulted in the deposition, within the preexisting Stikine and Tahltan river valleys, of a lacustrine sequence and intercalated debris-flow deposits (units Ta and Sa; Figs. 2, 10A). High sediment concentration coupled with fluctuating flow rates produced a variety of sedimentation styles. Massive beds are indicative of hyperconcentrated sediment loads and deposition out of suspension. Laminated beds are probably the product of underflows, whereas sporadic clay laminae are the product of occasional periods of quiescence (winter?), but do not occur rhythmically at either site. The diamicton beds interspersed throughout this unit are interpreted as lake-marginal subaqueous debris-flow deposits and are most likely a product of valley slope failure (Fig. 10A) (Broster and Hicock 1985). The upper 6 m of stratified diamicton may have been produced by the superimposition of several debris-flow layers and resembles glaciolacustrine diamictons described by Eyles and Clague (1991). The angular clay clasts are the transported remnants (rip-ups) of underlying beds. The debris flows that produced the distinct layering may have originated from subaqueous or subaerial slope failure in an ice-distal environment or, alternatively, may be the lacustrine sedimentary expression of debris-flow activity at the ice margin during regional ice advance.

Lacustrine conditions indicate blockage of the river valley downstream of the sites and arguably could have been created by a mass-movement event (of which no morphological evidence has been found) rather than an advance of ice in the Coast Mountains. The latter hypothesis appears most plausible, because the basal sedimentary sequence at both sites culminates in the deposition of poorly sorted gravels with clay interclasts (units Tb and Sb; Figs. 2, 10B), a deposit commonly associated with ice-marginal sedimentation (Shaw 1985). The preservation of silt–clay rip-ups within coarse gravels indicates short transport distances. This sediment may have been deposited in an ice-proximal glaciofluvial environment as glaciers advanced into the study area.

Possible evidence of subglacial deposition and local ice cover is present only at the Tahltan site (unit Tc; Figs. 2, 10C). The lack of sorted sediments, the sharp erosive basal contact, and the fine-grained, compact matrix of the diamicton indicate that it may have been deposited by subglacial processes (Levson and Rutter 1988). The upper 2 m of unit Tc is stratified, the strata being defined by varying matrix composition. Stratification of diamictons can be produced by debris stratification at the base of the glacier which is preserved during the melt-out process (Lawson 1979, 1981). Unit Tc is similar to sediment described by Huntley and Broster (1994) and Clague (1987) as a lodgement till, however, lack of fabric data in unit Tc makes this association tenuous. The absence of correlative sediment at the Stikine Canyon site may be a consequence of nondeposition, as the canyon may have remained a conduit for subglacial meltwater flow during regional glaciation. Under these conditions grounding of the ice sheet may not have taken place. Alternatively, it is possible that a thin till mantle, which is a common feature in montane valley-fill sequences (Clague

Fig. 7. Thermal demagnetization plots for basalt sample LES 142B (Stikine Canyon section). The declination for the sample was obtained from stepwise heating from 300 to 500°C. The unblocking temperature is between 500 and 600°C. The sample characteristic remanent magnetization (ChRM) is normal. NRM, natural remanent magnetization.

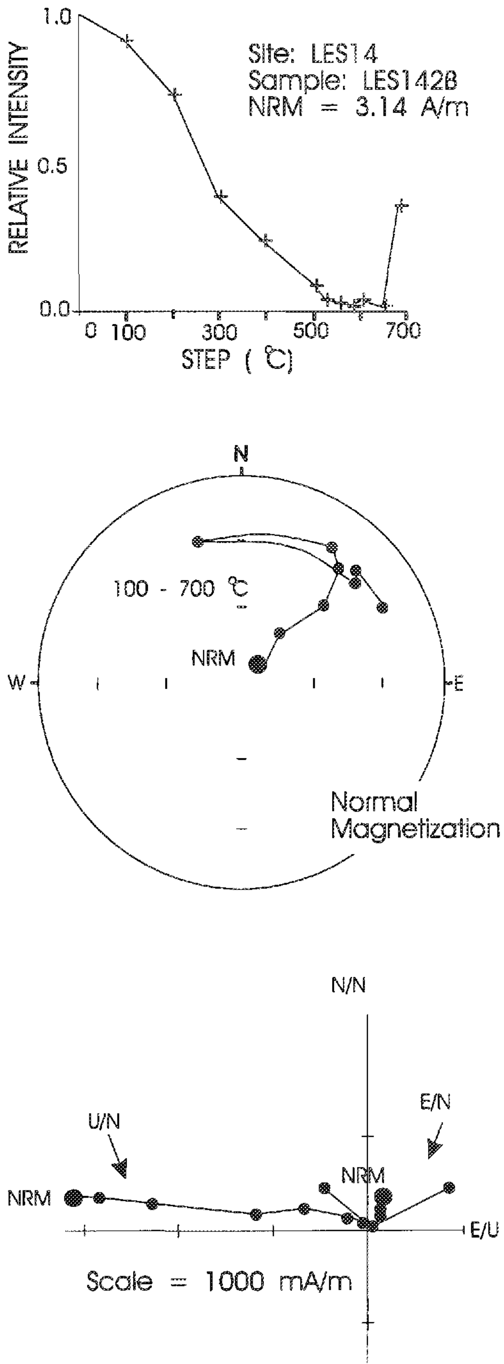
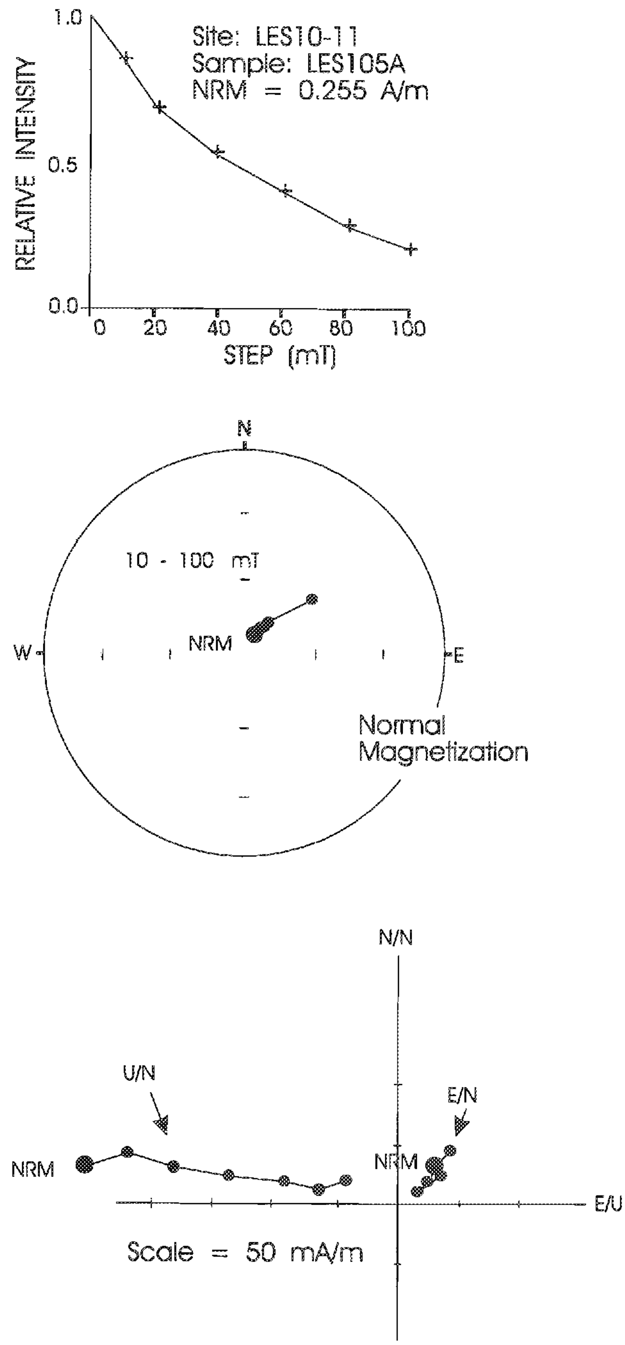


Fig. 8. AF demagnetization plots for sediment sample LES 105A (Stikine Canyon section). The plots show a linear decay to the origin and indicate that both direction and polarity can be obtained from the sample. NRM, natural remanent magnetization.



1987; Huntley and Broster 1994), may have been eroded during deglaciation and the formation of the retreat-phase glacial lake.

Units Td and Sc are both interpreted as glaciolacustrine deposits. Unit Td (Figs. 2, 10D) is rhythmically bedded and contains low concentrations of sand, indicative of deposition in a distal, quiet-water environment. This sediment package is similar to sediments interpreted by Eyles and Clague (1991) as being deposited in a retreat-phase glacial lake. Unit Sc strongly resembles underlying unit Sa. Two interpretations of this unit are possible. Unit Sc could be the sedimentological expression of a return to advance-phase lacustrine conditions following local ice-margin fluctuations that deposited ice-marginal unit Sb. Alternatively, unit Sc could be retreat-phase glaciolacustrine sediment.

Units Te and Sd are sedimentologically equivalent and were likely deposited by a combination of fluvial and glaciofluvial processes (Fig. 10E). The preservation of striations on some clasts and the presence of numerous angular clasts may indicate that relatively little fluvial abrasion (transport) had taken place. These sediments are interpreted as river gravels deposited during aggradation following deglaciation.

Large-scale sediment deformation is most evident in the Stikine Canyon section and consists of reverse faulting, tilting, and some minor folding. The deformation occurs in sediments interpreted as advance-phase lacustrine, subglacial, and retreat-phase lacustrine and infers that the deformation is a syn- or post-retreat-phase depositional modification. Though normal faulting often occurs as a consequence of ice melt-out and dewatering of glacial sediment, thrust faulting is most commonly associated with loading by regional ice cover (Spooner 1988). The thrusting evident in the Stikine Canyon section occurs in retreat-phase lacustrine sediments (Fig. 6B) deposited during regional ice retreat. The deformation is interpreted as being a consequence of loading of the overlying basalt on saturated fine- to medium-grained retreat-phase sediments.

The Stikine and Tahltan canyon sections are interpreted to reflect the formation of an advance-phase glacial lake due to blockage of regional drainage by ice advance in the Coast Mountains followed by regional ice cover. The sediments and processes described have much in common with recent studies of valley-fill sedimentation in the narrow, incised river valleys of the British Columbia interior (Clague 1987; Eyles and Clague 1991; Huntley and Broster 1994). The lack of rhythmic sedimentation in advance-phase sediments is to be expected. Hsu and McKenzie (1985) and Eyles and Clague (1991) indicate that a seasonal cycle is suppressed as ice-contact lakes receive large volumes of coarse- and fine-grained sediment throughout the year, in contrast to ice (or moraine) dammed retreat-phase lakes, which have diminishing sediment inputs as the ice front retreats from the lake basin. The focusing of sediment input in narrow valleys (such as the Stikine and Tahltan river valleys) in conjunction with valley-side mass-movement processes are also important factors in suppressing the sedimentary expression of seasonality in advance-phase lakes.

Eyles and Clague (1991) reasoned that as ice in montane regions advances over intermontane areas, the advance-phase lakes (APL) grow in size and deepen, resulting in a general fining-upwards sedimentary sequence. They report the initial deposition of a boulder lag and planar and trough cross-bedded, pebble–cobble gravels and sand at the bottom of the APL sequence. Such material, thought to have been deposited as a response to increased sediment supply during glacial expansion, is not present in the Stikine and Tahltan canyon sections. However, these sections are located along the sides of the present river valleys, and any boulder lag and associated sediments would likely have been deposited in the paleochannel of the river. In the Stikine River valley, this sediment has been reincised; the sediment that was once deposited there has been eroded.

Age of sediments and pre-Fraser glaciation

Paleomagnetic analysis of the sediment samples taken from both sites strongly suggests that the sediments were deposited during the Bruhnes normal polarity chron (Present to 780 ka; Cande and Kent 1992). These data constrain the maximum age of the sediment succession to about 780 ka. The Tahltan Canyon basalt (VM1, Fig. 2) was dated at 330 ± 30 ka. The sample was fresh, contained no xenoliths, and was unaltered, suggesting that argon contamination (inherited or excess) had not affected the age of the sample. The Stikine Canyon basalt (VM2, Fig. 2) was dated at 300 ± 100 ka. This age is in general agreement with the date obtained for VM1; the lack of dating precision for this sample is due to large (>90%) atmospheric argon contamination. The K–Ar dates obtained

Fig. 9. ChRm (characteristic remanent magnetization) of all samples and site means. The mean declinations for the basalts (open symbols) approximate the geocentric axial dipole (GAD). The sediments (closed symbols) show an offset to the east. Deviations from the GAD may be due to the effects of the nondipole field.

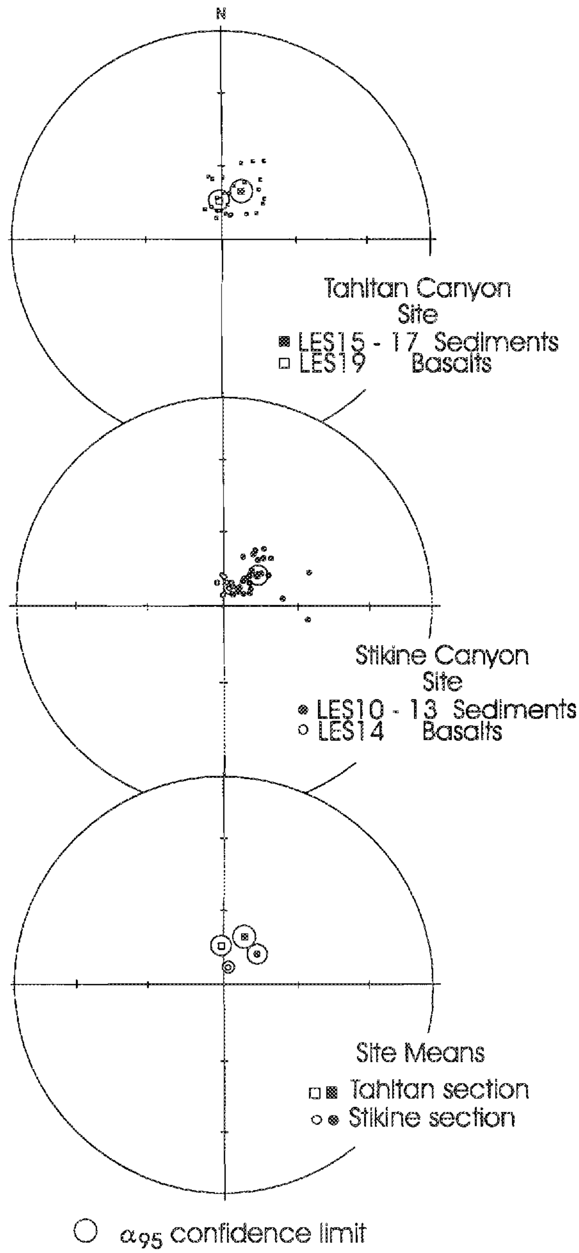
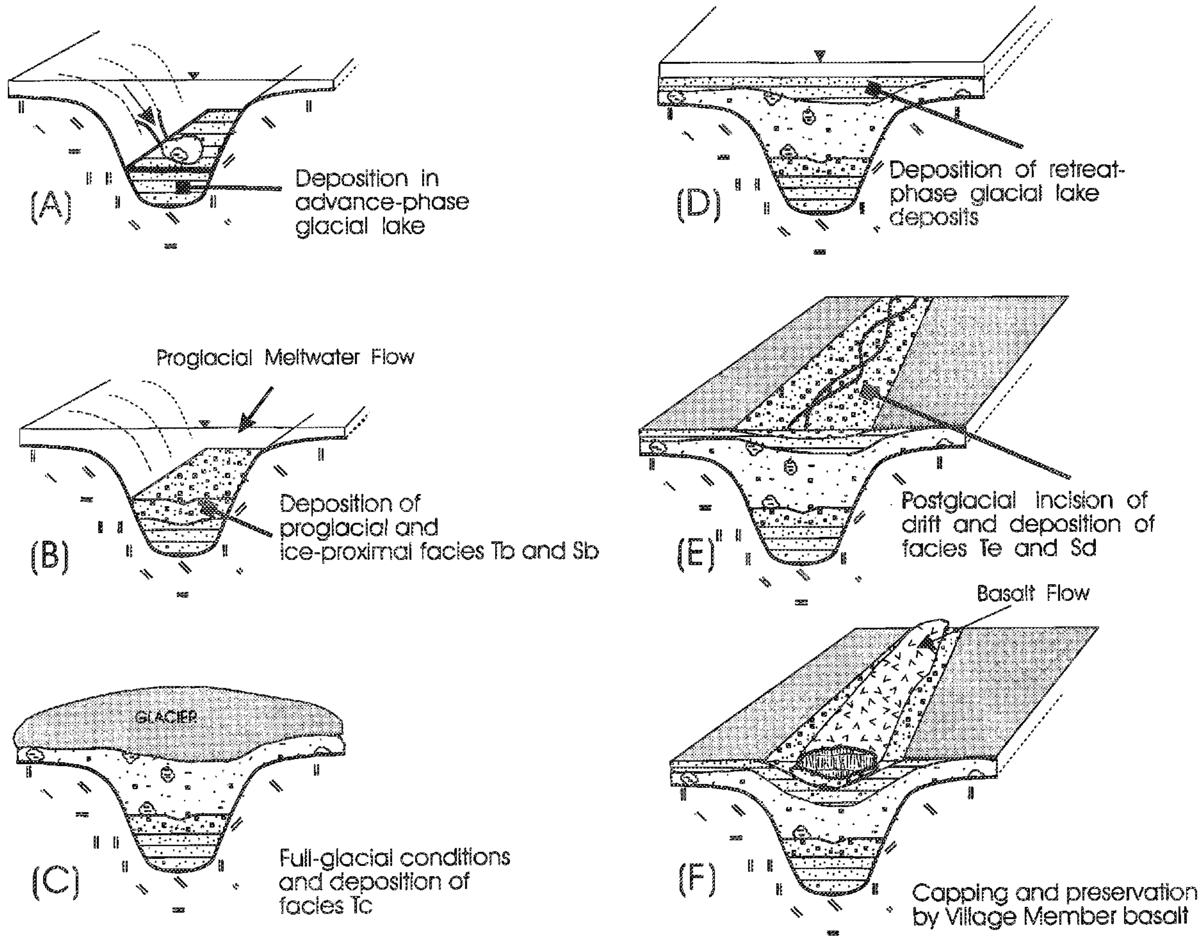


Fig. 10. Sketch indicating the postulated sequence of events that resulted in the deposition of the Tahltan and Stikine canyon sections. Fluvial incision of the Village Member basalt (F) resulted in the exposure of both sections.



by Read and Psutka (1985) for Village Member basalts do not coincide with the date obtained for VM1. However, the Village Member basalt flows dated by Read and Psutka (1985) are not stratigraphically equivalent to either VM1 or VM2, because they do not overlie Pal sediment (as both the Tahltan Canyon and Stikine Canyon basalt flows do), but are found overlying other Village Member flows.

These constraints indicate that the age of the sediments at the Tahltan Canyon site is between 330 and 780 ka and hence they are of Middle Pleistocene age. A more specific age assignment can be made only by inference from the basalt–sediment contact.

Palagonite and quenched surfaces at the base of the Tahltan Canyon flow remnant (VM1) indicated that the base was in contact with water. The underlying sediment is fluvial, and these observations indicate that the basalt flow, upon entering the Tahltan River valley, occupied the valley low created by incision by meltwater streams. The sedimentary sequence is interpreted as having been deposited during the glacial interval that occurred immediately prior to the deposition of the basalt, because if a significant amount of time had passed between reincision of the Tahltan and Stikine rivers and the deposition of the basalt, the glacial sequence probably would not have been preserved. A section exposed at the confluence of the Stikine and Tahltan rivers serves to further illustrate this process. This section contains Late Wisconsinan Fraser Glaciation till that is preserved beneath Holocene Big Raven Formation basalts (Read and Psutka 1985; Spooner et al. 1993). Elsewhere, erosion of the Big Raven basalts has resulted in the complete removal of the underlying till. The sediments beneath the basalt flows were preserved only because the basalt shielded them from erosion. If an appreciable hiatus between sedimentation and volcanism had occurred, most sediment along the canyon walls would have been eroded during paraglacial conditions. It seems likely that the same set of conditions probably existed during the Middle Pleistocene.

The sediments at the Tahltan Canyon site are therefore interpreted to have been deposited during a glacial interval immediately prior to the deposition of the VM1 basalt remnant (330 ± 30 ka). Read and Psutka (1985) have indicated a similar age for Pal sediment. They have speculated that trachyte glass pebbles found within some Pal sediment sections are the product of tephra explosions during Kakkidi Formation eruptive activity on Mount Edziza (300 ± 70 ka; Souther 1992).

Though the date obtained for the Stikine Canyon basalt (VM2) is not precise, we believe that it is correlative (within the margins of error) with the Tahltan Canyon basalt (VM1) based on stratigraphic, elevational, and paleomagnetic similarities between the two sections. However, Pearce element ratio analysis of whole-rock geochemistry indicated that there were significant differences in the geochemistry of the two basalts. Thus these remnants most likely did not originate from the same magma batch (Spooner 1994).

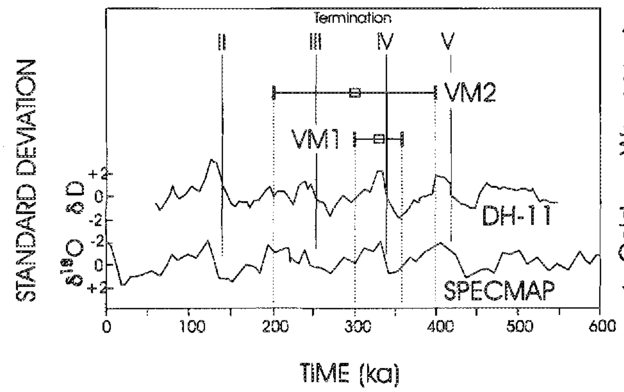
A tentative age can be assigned to the sediments by association of the estimated timing of regional ice cover with timing of global climate change indicated by the SPECMAP (Imbrie et al. 1984) and Devils Hole Core 11 (DH-11; Winograd et al. 1992) $\delta^{18}O$ records (Fig. 11). In the Devils Hole record, dates were obtained through detailed uranium-series dating rather than "tuning" to the Earth's orbital parameters (as was the case in the "tuned" SPECMAP record). In both of these proxy records, a glacial termination occurs at approximately 338 ka (termination IV; Broecker and Van Donk 1970), and peak cold conditions are indicated as having occurred at either 342 (SPECMAP) or 353 (DH-11) ka (Fig. 11). The 338 ka termination is bracketed by an earlier termination (V) at approximately 416 ka (DH-11) or 422 ka (SPECMAP) and a later termination (III) at 243 ka (SPECMAP) or 251 ka (DH-11). The older termination occurs at least 56 ka before the deposition of the Tahltan Canyon basalt (330 ± 30 ka), far too great a time span to permit the preservation of the glacial sequence. The younger termination (242 or 251 ka) occurs at least 49 ka after the deposition of the basalt, and the peak cold period indicated by both the Devils Hole and SPECMAP records occurs about 270 ka, 30 ka younger than the minimum age for the deposition of the basalt. Assuming that basalt and sediment deposition at the Tahltan Canyon site were indeed closely spaced in time, the 338 ka termination age is the most likely candidate for the sediments. Isotope stage 10 (about 338–367 ka; Shackleton and Opdyke 1973, 1976; Shackleton et al. 1990) is the glacial stage on the isotope scale which corresponds to age proposed for the sediment.

Middle Pleistocene glacial events are not well represented in the regional stratigraphic record. Ryder and Clague (1989) noted that exposures of Early and Middle Pleistocene glacial deposits outside of volcanic areas are rare. Older pre-Sangamonian glacial deposits in British Columbia, such as the Brown Drift (Fulton et al. 1992), the Westlyn Drift (Hicock and Armstrong 1983), and pre-Fraser tills recognized by Armstrong and Leaming (1968) and Ryder (1976), may be Middle Pleistocene in age but are poorly dated at present. The Klaza Glaciation deposits noted on the Yukon Plateau by Bostock (1966), pre-Reid glacial deposits as defined by Hughes et al. (1969), and pre-Reid till (till B) noted in the Liard Lowland by Klassen (1978, 1987) are also possibly Middle Pleistocene in age, but are not precisely dated.

Summary

The sediments at the Tahltan Canyon section were deposited after the Bruhnes–Matuyama reversal (about 780 ka) and prior to 330 ± 30 ka (the age of the capping basalt flow). They record a period of initial ice advance and river valley blockage in the Coast Mountains and formation of an advance-phase glacial lake, possible inundation of the study area by intermontane ice at the height of the glacial interval, and the formation of a retreat-phase glacial lake when blockage persisted in the Coast Mountains during regional deglaciation.

Fig. 11. A diagram of global warming and cooling trends from various sources. Within the age constraints of the capping basalt flow VM1 only one glacial termination took place (i.e., termination IV). As geomorphic evidence suggests that the sediment at both sections was deposited penecontemporaneously to the capping basalt flow, the sediment can be correlated to the termination (IV) and the preceding glaciation (isotope stage 10). Modified from Winograd et al. (1993).



The advance- and retreat-phase sediments were preserved beneath basalt flows that occupied depressions created by meltwater streams. Sediments at the Stikine Canyon section are interpreted as having been deposited under similar conditions at the same period in time.

The advance- and retreat-phase sediments at both sites are interpreted to have been deposited during the glacial interval immediately prior to the deposition of the basalt remnants. Through correlation to the SPECMAP (Imbrie et al. 1984) and Devils Hole (Winograd et al. 1992) climate records an estimate of their age is 330–360 ka, which corresponds to isotope stage 10.

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