Geological Survey of Canada

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2006-A11

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2006

Natural Resources Canada | Ressources naturelles Canada

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CURRENT RESEARCH

ISSN 1701-4387
Catalogue No. M44-2006/A11E-PDF
ISBN 0-662-43579-6

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Publication approved by GSC Calgary

Original manuscript submitted: 2006-03-28
Final version approved for publication: 2006-04-06

Correction date:

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Huntley, D., Duk-Rodkin, A., Couch, A., and Sidwell, C., 2006: Terrain inventory and geomorphic history of the south-central Mackenzie River valley region, Northwest Territories; Geological Survey of Canada, Current Research 2006-A11, 8 p.

Abstract: As part of the Northern Energy Development Mackenzie Valley Project, an inventory of terrain, landforms, and geomorphic processes is currently being compiled for the Camsell Bend (NTS 95 J), Root River (NTS 95 K), Dahadinni River (NTS 95 N), and Wrigley (NTS 95-O) 1:250 000 scale map sheets. This work aims to provide government agencies, industry, and the public access to secure and reliable geoscience information. The regional surficial geology is being examined to improve understanding of the limits to glaciation, subglacial processes, meltwater-drainage patterns, glacial-lake history, landslide hazards, and aggregate and groundwater resources. Outputs from this study can be used in environmental risk and impact assessments, and will provide calibration for future predictive mapping and hazard analyses in the Mackenzie River valley transportation corridor. Other possible outcomes include the attraction of new investment and reduction of risks for exploration and development of aggregate, groundwater, and mineral resources.

Résumé : Dans le cadre du projet de la vallée du Mackenzie visant le développement de l'énergie dans le Nord, nous procédons actuellement à la compilation d'un inventaire du terrain, des formes de relief et des processus géomorphologiques dans les régions visées par les cartes suivantes à l'échelle du 1/250 000 : Camsell Bend (SNRC 95 J), Root River (SNRC 95 K), Dahadinni River (SNRC 95 N) et Wrigley (SNRC 95-O). Ces travaux ont pour objet de fournir des données géoscientifiques sûres et fiables aux organismes gouvernementaux, au secteur privé et au grand public. Nous examinons actuellement la géologie de surface régionale afin de mieux comprendre les limites de la glaciation, les processus sous-glaciaires, le tracé du réseau des eaux de fonte, l'évolution des lacs glaciaires, les risques de glissement de terrain, ainsi que les ressources en granulats et en eaux souterraines. Les résultats de cette étude pourront servir aux évaluations des risques environnementaux et aux études d'impact et permettront de mieux cibler les futurs travaux de cartographie prédictive et d'analyse des risques dans la voie de communication de la vallée du Mackenzie. Ils pourront également susciter l'intérêt de nouveaux investisseurs et réduire les risques liés à l'exploration et à l'exploitation des ressources en granulats, en eaux souterraines et en minéraux.

INTRODUCTION

As part of the Northern Energy Development Mackenzie Valley Project, the Geological Survey of Canada (GSC) is working to improve understanding of the geology and geomorphology of the Mackenzie River valley transportation corridor (Couture et al., 2005; Huntley and Duk-Rodkin, 2005; Smith et al., 2005; Sidwell et al., 2005; Fig. 1). Together with legacy data (e.g. Aylsworth et al., 2000a, b; Dyke, 2000; Heginbottom, 2000; Aylsworth and Traynor, 2001; Duk-Rodkin and Hood, 2004), new geoscience information provided by this study will be essential for effective land-management decisions regarding pipeline, highway, and settlement construction; extraction of aggregate and groundwater; and assessment of ecological sensitivity in Mackenzie River valley region (DiLabio, 2005). The 2005 field season focused on the Camsell Bend (NTS 95 J), Root River (NTS 95 K), Dahadinni River (NTS 92 N), and Wrigley (NTS 92-O) 1:250 000 scale map sheets (Fig. 1).

TERRAIN INVENTORY

Earth materials observed during the 2005 field season include cemented deposits, possibly of Late Pliocene to Middle Pleistocene age (ca. 3 Ma to 120 ka BP); till, glaciofluvial outwash, and lake sediments deposited during the Late Pleistocene (>30 to 10 ka BP); and postglacial colluvial, eolian, organic, and alluvial deposits of Holocene age (10 ka BP to present).

Holocene

Alluvial deposits

Alluvial sediments include boulders, gravel, sand, and silt transported and deposited by rivers, streams, and creeks (Fig. 2). Deposits are confined to gullies, mountain fans, deltas, streambeds, point bars, and floodplains, all of which are subject to periodic flooding. Generally, alluvium is well sorted and stratified, greater than 2 m thick, and may contain interbedded debris flows and buried organic material (e.g. driftwood and anthropogenic material). Permafrost is absent on nonvegetated (i.e. active) parts of floodplains; elsewhere, segregated, interstitial, and/or cement ice may be present and thermokarst ponds are observed. Alluvial sediments are a potential source of aggregate. Gravel extraction, however, may produce significant changes in stream courses and downstream changes in patterns of stream sedimentation and erosion, and also have a detrimental impact on fish and wildlife resources.

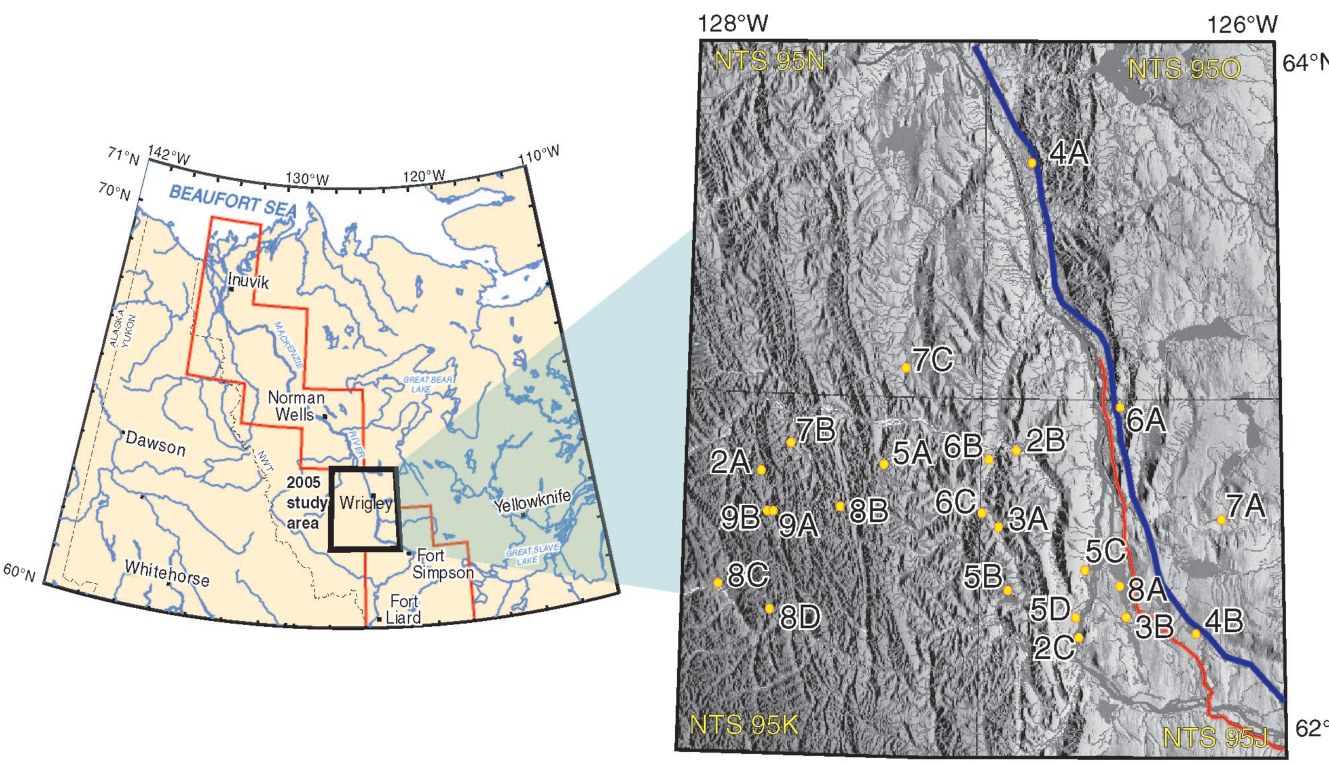

Figure 1. (Left) Limits of the Northern Energy Development Mackenzie Valley Project and location of the 2005 study area. (Right) Detail of study area, with locations of photographs in Figures 2 to 9.

Organic deposits

Bogs and fens are formed by the accumulation of organic matter in depressions or level areas (Fig. 3). Typically, they are treeless or have scattered black spruce and tamarack, and have lichens covering commonly greater than 50% of the vegetated surface, resulting in high surface albedo. In vertical profile, organic deposits comprise sedge and woody sedge overlain by *Sphagnum* peat. The base of the active layer is observed at depths of approximately 0.5 m. Ice content is typically about 20%, but can locally be as high as 60%. Peat in wet depressions is thawed to depths greater than 1 m.

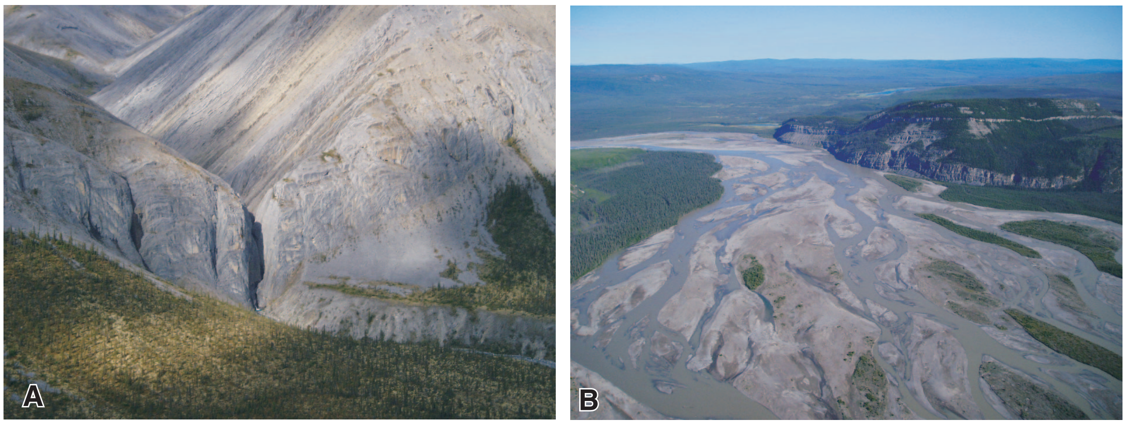

Figure 2. Alluvium in the south-central Mackenzie River drainage basin: **A)** Delorme Range (NTS 95 K): boulder and cobble-rich alluvial deposits in bedrock-bound channels, combined with colluvium derived from rockfall and debris fall. **B)** Root River breaching the Camsell Range (95 J): cobble- and sand-rich alluvial floodplain deposits with active braided channels incising relict glaciofluvial terraces. **C)** Mackenzie River and North Nahanni River at Camsell Bend (95 J): alluvial gravel and sand deposits forming active in-channel bars and a narrow floodplain flanking the main channel and terraced glaciofluvial outwash.

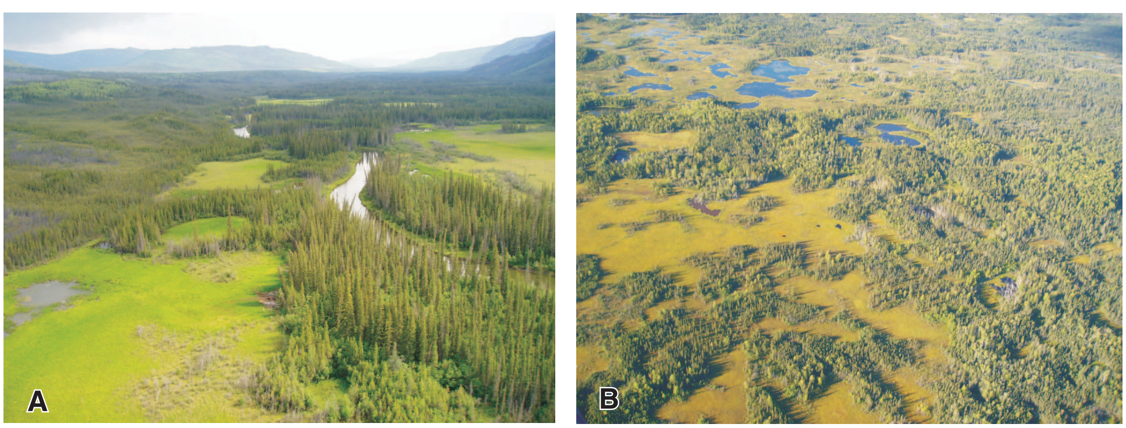

Figure 3. Organic deposits: **A)** Carlson Creek (NTS 95 J): bog-fen complex and alluvial floodplain; deposits are subject to thermokarst processes. **B)** Mackenzie Valley (NTS 95 J): bog, fen, and glaciolacustrine sediments; deposits are subject to thermokarst processes.

Figure 4. Loess deposits (eolian silt and sand derived from deflation of glaciolacustrine and outwash in a proglacial environment): **A)** Eolian veneer overlying glaciolacustrine deposits northwest of Wrigley (NTS 95-O). **B)** Eolian dunes overlying glaciofluvial deposits southwest of Wrigley (NTS 95 J).

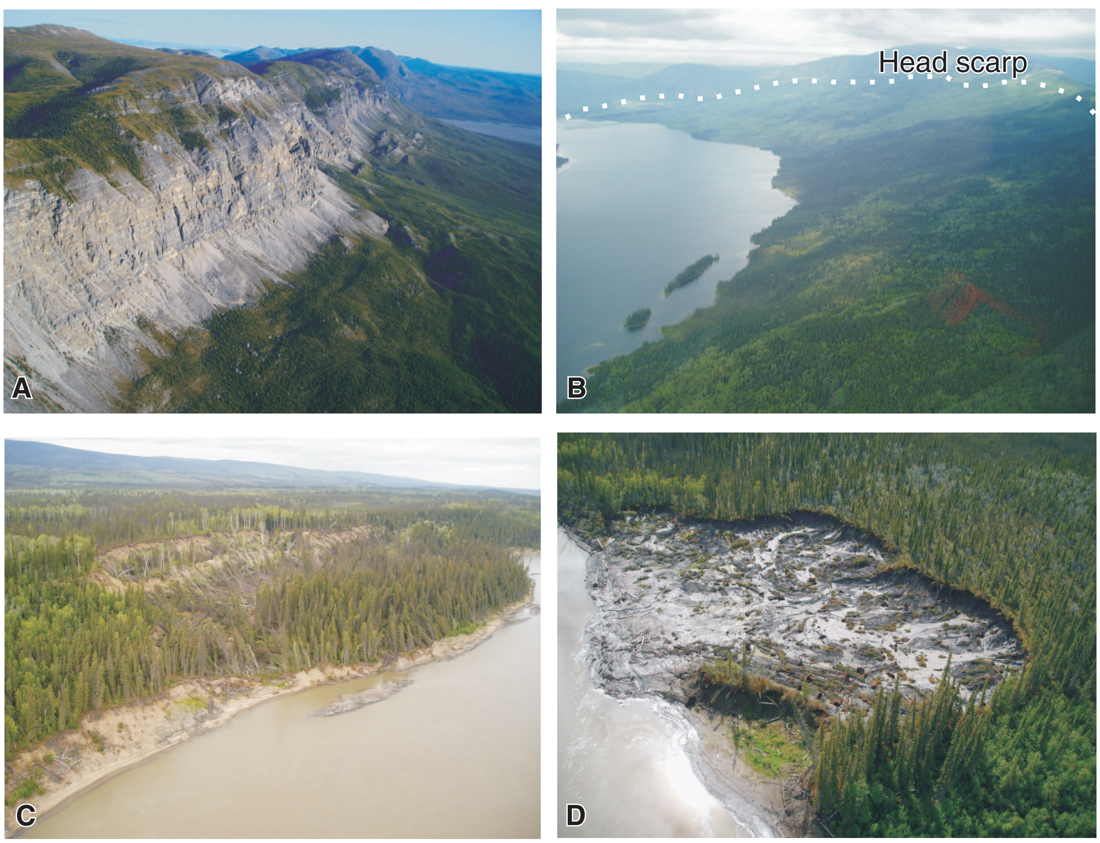

Figure 5. Colluvial deposits: **A)** Iverson Range (NTS 95 K): colluvial complex comprising inactive, large-scale, rapid (paraglacial) bedrock slides and active smaller rock falls, debris falls, and debris slides derived from the mountain front. **B)** Carlson Lake (NTS 95 J): active landslide comprising a large-volume (paraglacial) bedrock slide that is modified by smaller, active, slow-moving bedrock and debris slides; note head scarp. **C)** Mackenzie River (NTS 95 J): active, slow-moving debris slide remobilizing till, glaciolacustrine sediment, and glaciofluvial outwash. **D)** Mackenzie River (NTS 95 J): active retrogressive-thaw flow initiated by thermal and cutbank erosion of discontinuously frozen glaciolacustrine sediments.

Late Pleistocene to Holocene

Eolian (loess) deposits

Eolian deposits range from discontinuous veneers to large dune fields of silt and sand transported and deposited by wind action, and derived from deflation of alluvium, glaciolacustrine sediments, and outwash (Fig. 4). Loess deposits are generally less than a metre in thickness; display crossbedding, ripple bedding, or massive bedding; and contain little to no ground ice.

Colluvial deposits

Colluvial deposits are a product of the weathering and downslope movement of earth materials by gravitational processes (mass wasting). Massive to stratified, clast-supported diamictons with highly variable ice content form a veneer or blanket on bedrock- and debris-covered slopes. Large, irregular ice bodies may be locally buried beneath landslide debris along mountain fronts. Mass-wasting processes include retrogressive-thaw flows and rotational slides in glaciolacustrine sediments and outwash in lowland valleys, and rock falls, rock slides, and debris flows in mountainous areas of shale, sandstone, and carbonate strata (Fig. 5). Slope instability presents major problems for construction.

Late Pleistocene

Glaciofluvial deposits

Glaciofluvial sediments include boulders, cobbles, pebble-gravel, sand, silt, and diamicton deposited by rivers and streams flowing from, or in contact with, glacial ice. Glaciofluvial deposits are generally massive to stratified and greater than 3 m thick, and currently have low ice content. Landforms include eskers, terraces, spillways, outwash plains, kames, and raised deltas (Fig. 6). Evidence for ice collapse, including slumping, kettles, and irregular topography, is also observed. Glaciofluvial sediments are a potential source of aggregate and groundwater when material is coarser than gravel.

Glaciolacustrine deposits

Glaciolacustrine deposits include massive or rhythmically interbedded silt and clay, with subordinate sand, gravel, and debris-flow diamicton. Sediments are deposited by subaqueous gravity flows, rainout of debris during thermal melting of icebergs and floating ice, and settling of suspended silt and clay in low-energy environments. Deposits may be reworked by wave action along shorelines adjacent to glaciers. Slump structures, irregular topography, and kettles indicative of collapse from melting of buried ice may be locally present. Glaciolacustrine deposits are generally thicker than a metre and ice content ranges from 10 to 25%,

Figure 6. Glaciofluvial deposits: **A)** Mackenzie River (NTS 95 J): esker ridge comprising sand and gravel deposited subglacially over drumlinized till. **B)** Carlson Creek (NTS 95 K): terraced glaciofluvial sand and gravel; deposit is gullied and remobilized on steep slopes by rapid debris flows. **C)** English Chief River (NTS 95 J): glaciofluvial deltaic sand with organic-rich clay rip-up clasts; deposit implies that part of the watershed was vegetated and subject to mass-wasting events during deglaciation (organic material has been submitted for radiocarbon dating).

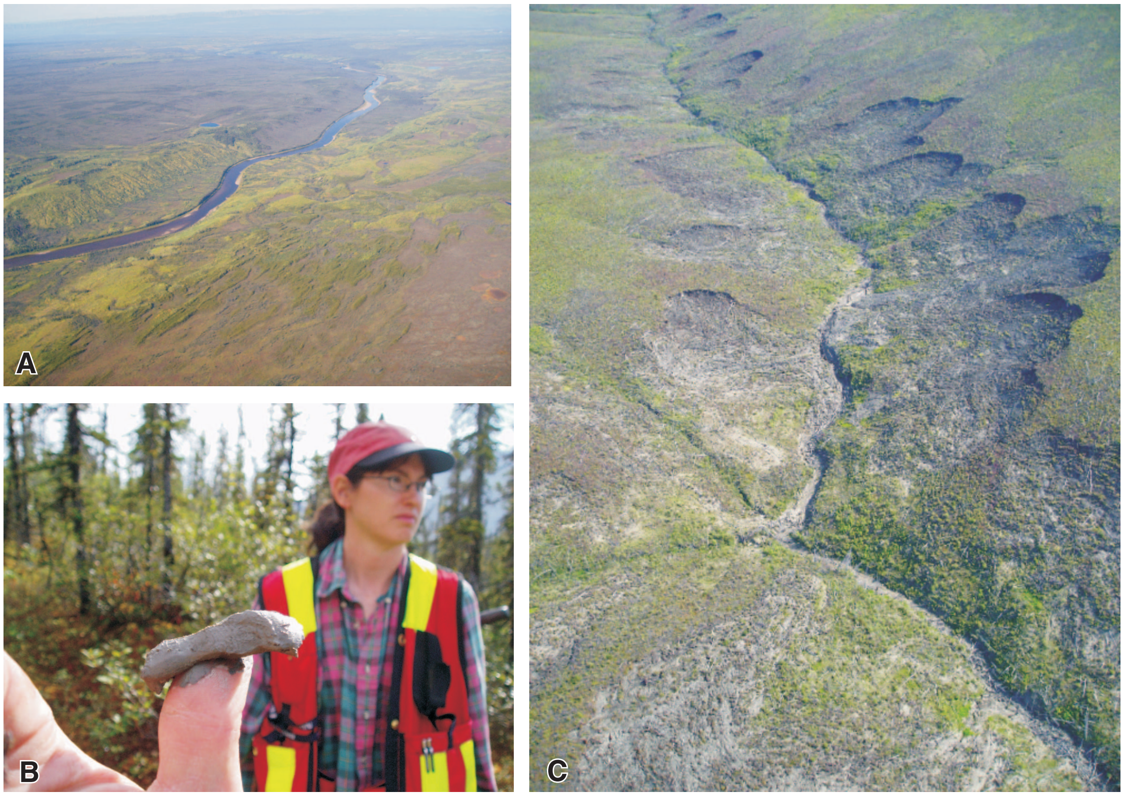

Figure 7. Glaciolacustrine deposits: **A)** Willowlake River (NTS 95 J): glaciolacustrine plain, comprising ice-proximal silt and clay draped over an extensive till blanket; treed ridges in the centre foreground are lake strandlines; during deglaciation, glaciolacustrine deposits and till were incised by meltwater channels; earth materials contain discontinuous permafrost. **B)** Landry Creek (NTS 95 K): detail of glaciolacustrine clay with massive structure and discontinuous permafrost. **C)** Root River (NTS 95 K): glaciolacustrine sediments draped over till; wildfires and stream erosion triggered active-layer detachments and retrogressive-thaw flows in deposits containing discontinuous permafrost.

but is often higher in areas undisturbed by recent wildfires. Where permafrost is present, glaciolacustrine deposits may be subject to thermokarst processes, including retrogressive-thaw flows, and even slopes less than 5° are potentially unstable (Fig. 7).

Till deposits

Deposits of massive, matrix-supported diamicton are interpreted as till formed directly by lodgment and melt-out processes. Till containing angular to subrounded granitic erratics derived from the Canadian Shield are interpreted as having been deposited by the Laurentide Ice Sheet (Fig. 8A, B). Montane tills contain locally derived, subangular to subrounded fragments of carbonate and clastic rocks in a sandy silt-rich matrix, deposited by valley glaciers from the southern Mackenzie Mountains (Fig. 8C, D). Landforms include end, lateral, and ground moraines; boulder lags; glacially sculpted bedrock; crag-and-tail features; drumlins; fluted ridges; and hummocky till with kettle depressions.

Pliocene to Middle Pleistocene

Undifferentiated valley fill

In the southern Mackenzie Mountains, carbonate-cemented debris flows, coarse alluvial channel-fill sequences, and laminated fine sand-silt couplets are locally preserved in valley floors beyond the western limit of the Laurentide Ice Sheet (Fig. 9). These deposits are interpreted as ice-proximal valley-fill sequences dating from Late Pliocene to Middle Pleistocene. Montane valleys have a modified V-shape, suggesting an inherited preglacial Paleogene (Tertiary) morphology and minimal modification during Neogene (Quaternary) glaciations. Although not deposited subglacially, they indicate that tectonic uplift and montane glaciers periodically altered drainage and influenced erosion and sedimentation rates in the southern Mackenzie Mountains prior to the Late Pleistocene.

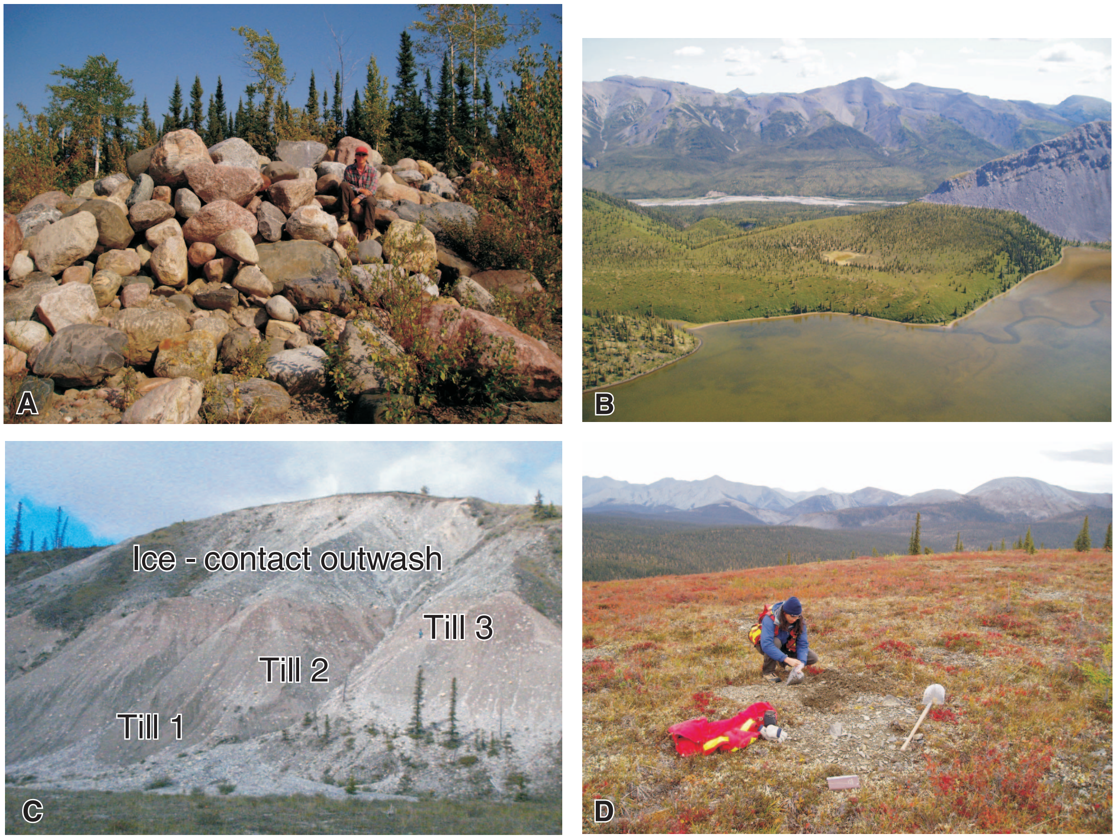

Figure 8. Laurentide and montane till deposits: **A)** Mackenzie Highway borrow pit (NTS 95 J): drumlinized till blanket exploited as an aggregate resource for highway construction and maintenance; till contains erratic granite boulders with Canadian Shield (i.e. continental) provenance. **B)** Mud Lake, Iverson Range (NTS 95 K): till ridge and ice-contact delta at the western terminus of the Laurentide Ice Sheet. **C)** North Nahanni River (NTS 95 K): multiple montane tills overlain by ice-contact outwash exposed in cutbank of glaciofluvial channel; till deposits are partly frozen. **D)** North Nahanni River (NTS 95 K): till veneer, locally remobilized by gelifluction near eastern limit of montane glaciation.

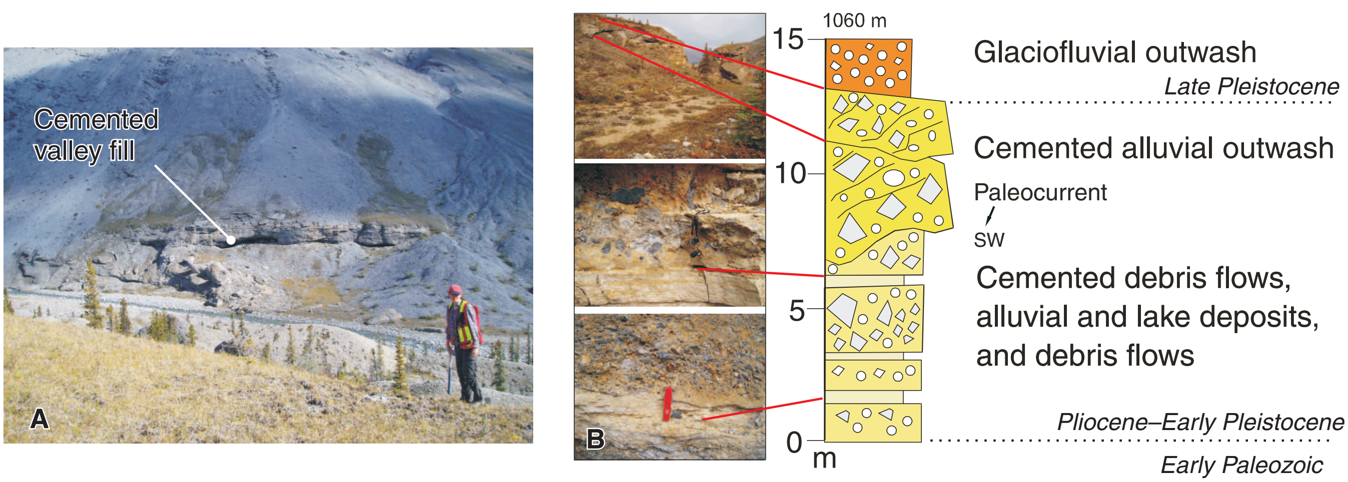

Figure 9. Undifferentiated earth material in the southern Mackenzie Mountains: **A)** Delorme Range (NTS 95 K): terraced glaciodeltaic sediments overlying carbonate-cemented alluvial outwash, lake deposits, and debris flows; incision by meltwater triggered rapid rotational slide involving earth materials. **B)** Composite log for A, showing tentative chronostratigraphic relationship of undifferentiated Pliocene to Late Pleistocene deposits and Late Pleistocene ice-contact glaciofluvial deposits.

TERRAIN ANALYSIS: GEOMORPHIC HISTORY

The study area has a complex geomorphic history, including being glaciated by ice from two different mountain sources in the west and an ice mass from the plains to the east. Stratigraphic and geomorphic evidence indicate that montane glaciers occupied the region at a slightly different time than did ice from eastern sources.

During the Late Pleistocene (>30 to 10 ka BP), a continental ice sheet (the Laurentide Ice Sheet) advanced westward over the foothills and up major valleys before montane valley glaciers reached their maximum extent. The advancing Laurentide Ice Sheet blocked the drainage of the east-flowing paleo-Redstone, paleo-Dahadinni, paleo-Root, and paleo–North Nahanni rivers, causing major changes to the landscape. Rivers were diverted northward, incising new channels through highly folded and faulted terrain. Rapid downcutting, together with seismic activity, triggered landslides that continue at present. At its maximum extent (ca. 22–18 ka BP), the Laurentide Ice Sheet flowed northwest across the lowlands and plain, eroding preglacial sediments and bedrock, and depositing a clay-rich, matrix-supported till containing granitic erratics from the Canadian Shield. Glaciolacustrine sediments and outwash are interbedded with Laurentide tills, indicating intervals of ice-sheet advance and retreat. In the Mackenzie Mountains, beyond the Laurentide limit, glaciers were confined to cirque basins and valleys.

As the ice sheet began to retreat, glaciers from montane sources locally extended as piedmont lobes over Laurentide sediments. Between ca. 18 and 10 ka BP, retreating montane glaciers, ice-sheet lobes, stagnant ice, and outwash blocked drainage, and an interconnected system of proglacial lakes formed in unglaciated valleys. Glaciolacustrine deposits in the Mackenzie River valley are incised by a spillway system that functioned as a northward meltwater drainage route for glacial Lake McConnell around 10 ka BP. This spillway evolved into the north-flowing Mackenzie River and captured east-flowing drainage out of the mountains. The modern landscape is an artifact of Quaternary glaciations, but has been modified by postglacial tectonism and climate-change, mass-wasting, permafrost, and fluvial processes, and to a lesser extent by wind action and human activities over the last 10 000 years.

ACKNOWLEDGMENTS

The authors would like to thank the following for their contribution to this project: GSC Calgary office staff and field crew, the Pehdzeh Ki Dene (Wrigley), and Great Slave Helicopters. The manuscript benefited greatly from reviews by Rod Smith (GSC Calgary) and Rudy Klassen (GSC Calgary).

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Geological Survey of Canada Project Y51-5001