SURFICIAL MAPPING AND GRANULAR AGGREGATE RESOURCE ASSESSMENT IN NORTHWEST ALBERTA

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ABSTRACT

This paper highlights results of the past two years' fieldwork and surficial geology mapping by the Geological Survey of Canada and Alberta Geological Survey in map sheets 84L and 84M, northwestern Alberta. Identification of granular aggregate resources has been a key objective of this work, and several new discoveries (including kames and eskers) have been made. Sedimentological investigations and aerial photograph interpretation have helped determine the nature and genesis of various glacial deposits that are exposed in existing or inactive gravel pits. Based on this work, it is now recognized that there is considerable granular aggregate potential in the Rainbow delta, the Chinchaga River valley glaciofluvial deposits, and the Elsa Hill ice-advance phase kame terrace and overlying deglacial, glaciofluvial gravel deposits. Moreover, evidence suggests that the Zama Beach gravel pit and another pit 2 km to the southwest may be stratigraphically linked as part of a larger subglacial channel system. This study has thus substantially increased the potential regional granular aggregate inventory, research that is seen as being of particular benefit to ongoing and future regional petroleum resource and infrastructure development.

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INTRODUCTION

Northwest Alberta has a long established history of oil and gas development, dating back to the initial 1965 Rainbow oilfield discovery in the Keg River Formation near Rainbow Lake. Subsequent discoveries of the Zama, Virgo and Shekilie oilfields (also within the Keg River Formation) were made between 1966-1969. Natural gas exploration and development began in earnest in the mid-1970's. This area remains an active site for exploration and development of conventional oil and gas deposits. New exploration and development activity is also focusing around unconventional shallow gas targets in the Sousa field, approximately 50 km east of the town of Rainbow Lake, where natural gas is trapped within unconsolidated sediments, infilling buried channel systems (Canadian Discovery Digest 2001; Pawlowicz *et al.* 2004a). Northwestern Alberta also serves as a major pipeline hub and includes the southern terminus of the Norman Wells pipeline, transporting oil from Norman Wells, NWT, to Zama City, AB. The proposed Mackenzie Valley gas pipeline will also terminate in northwestern Alberta, connecting with existing transmission systems west of Zama City.

With ongoing and proposed development there is a clear need by industry for an increased understanding of the regional surficial geology which serves to identify granular aggregate resources, areas underlain by permafrost, and mass wasting. In particular, the expeditious and economic development of road infrastructure networks is heavily dependent on acquiring substantial volumes of granular aggregate for projects such as the proposed Northern Link Road between the Sierra-Yoyo-Desan road, British Columbia, and Rainbow Lake, Alberta.

As part of a four-year, collaborative, multidisciplinary project initiated in 2003 under the Geological Survey of Canada's Northern Resource Development Program (NRD Project 4450), the Geological Survey of Canada (Natural Resources Canada), Alberta Geological Survey (Alberta Energy and Utilities Board), and Resource Development and Geoscience Branch (British Columbia Ministry of Energy and Mines) have undertaken extensive Quaternary geology studies in northwestern Alberta and northeastern British Columbia. Within Alberta, NTS map sheets 84L, M, N and K are systematically being studied (Figure 1); results from map areas 84L and M are reported here. Objectives of the project include: production of surficial geology maps at 1:100 000 scale, assessment of the nature and genesis of known aggregate deposits, and the identification and characterization of new and/or potential aggregate deposits.

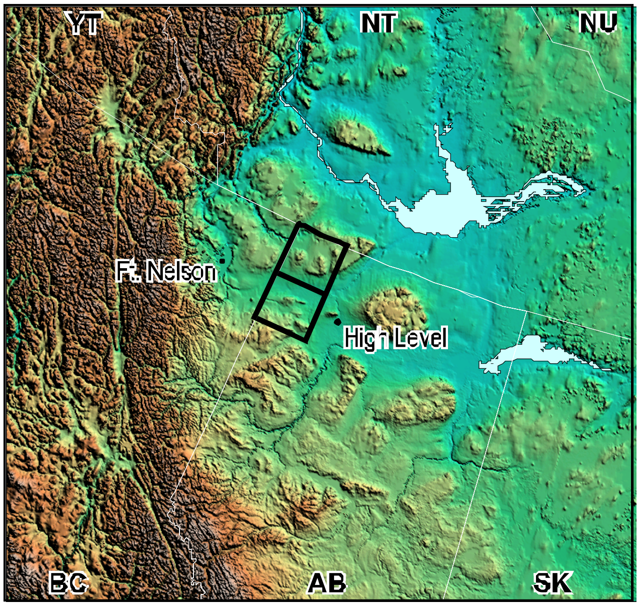

Figure 1. DEM image showing location of study area in northwestern Alberta. The two NTS map sheet areas, 84L (lower) and 84M (upper) that are the focus of this paper are highlighted.

Previous Studies

Few Quaternary geology studies have examined the northwestern Alberta region in detail. Reports containing information pertinent to the Late Wisconsinan glacial history include Bayrock in Lindsay *et al.* (1960), Taylor (1960), Green and Mellon (1962), Prest *et al.* (1968), Mathews (1980), EBA Engineering Consultants Ltd. (1984a), Fox *et al.* (1987a), Lemmen *et al.* (1994), Mandryk (1996) and Dyke (2004). Examination of granular aggregate resources in this area have also largely been conducted at the reconnaissance scale, various aspects of which are reported by Lindsay *et al.* (1960), EBA Engineering Consultants Ltd. (1984b), Richardson (1985a, b), Fox (1986), Fox *et al.* (1987b), and Edwards *et al.* (2004a, b). Borneuf and Pretula (1980), in a study of hydrogeology of the region, provided data on transmissivity within subsurface sand and gravel aquifers north of Hay-Zama lakes. Geotechnical research on surface sediments and permafrost has been conducted along the Norman Wells oil pipeline, which terminates at Zama City (Pilon *et al.* 1989; Geo-Engineering Ltd. 1992; Nixon and Burgess 1999). Zoltai (1993) examined the dynamics of peat and permafrost development in the region.

Study Area

Four 1:250 000 map sheets define the Alberta study area. The 2003 field season focused on the Zama Lake map area (NTS 84L), while the 2004 field season focused on the Bistcho Lake map area (NTS 84M; Figure 1). Subsequent fieldwork is planned for the Steen River (NTS 84N) and Mount Watt (NTS 84K) map sheets. The study area lies within the Fort Nelson Lowlands and Cameron Hills physiographic regions (Pettapiece 1986), and is blanketed by Boreal forest (white and black spruce, aspen, lodgepole pine) and extensive bogs and fens. Soils are generally poorly drained, commonly with shallow water tables, reflecting the high clay content of the tills (10-40 %) in which they have formed. In raised areas, where soil development is more advanced, gray luvisols predominate. Static and turbic cryosols are found in regions of sporadic discontinuous permafrost, and solonetzic soils are found in areas of thin drift overlying marine shale bedrock.

The southern quarter of the Zama Lake (84L) map area is characterized by upland regions (>600 m above sea level (asl); Figure 2) where rare outcrops of Cretaceous Dunvegan Formation sandstone are found. Dunvegan Formation is also found mantling the prominent, isolated hilltop south of Hay-Zama lakes, informally named Rainbow Ridge. Throughout the map area, outcrops of Cretaceous Shaftesbury Formation shale are found along modern stream channels and former glacial meltwater channels and canyons. The Hay River flows from the southeast, westward through a conspicuous canyon (incorporating Rainbow Lake), passing into British Columbia where it bends 180°, and then flows eastward through Hay-Zama lakes, eventually merging with the northward flowing Chinchaga and Meander rivers (Figure 2). The Chinchaga River flows northward along the eastern margin of the map and includes shallowly incised sections and areas of intense meandering (Figure 2). The latter occur within the Hay-Zama lowlands where a blanket of easily eroded glaciolacustrine silt and sand is found (Paulen *et al.* 2005a). Four 1:100 000 surficial geology maps are now available for the 84L map area, and readers are referred to these for additional information and greater detail than that which is discussed in this summary paper (Plouffe *et al.* 2004; Paulen *et al.* 2005a, b; Smith *et al.* 2005).

The Bistcho Lake (84M) map area is characterized by Cameron Hills in the northeast (maximum elevation 775 m asl) and two other broad uplands (Bootis Hill and Elsa Hill) in the central map area, which have similar upper elevations of approximately 775 m asl (Figure 2). The large Bistcho Lake (>45 km long) is found in the north-central part of the map, and the Hay-Zama lowlands (<450 m asl) stretch across the southern quarter of the map area. There is little fluvial dissection of the landscape, which is instead characterized by expansive fen and bog deposits. Highlands in the Bistcho Lake and Cameron Hills region are characterized by strongly fluted terrain, the surface expression of which is accentuated by bog development and surface drainage in the low-lying inter-flute regions (Figures 2 and 3A). An area of intensive ribbed-moraine mantles Bootis Hill and the lower-lying region to the west, marking the northward retreat of an ice lobe (Figure 3B). Prominent, discontinuous recessional moraines north of Bistcho Lake mark the northeastward retreat of ice across Cameron Hills (Figures 2 and 3C).

GLACIAL GEOLOGY

The southwest-advancing Laurentide Ice Sheet inundated northwest Alberta during the Late Wisconsinan

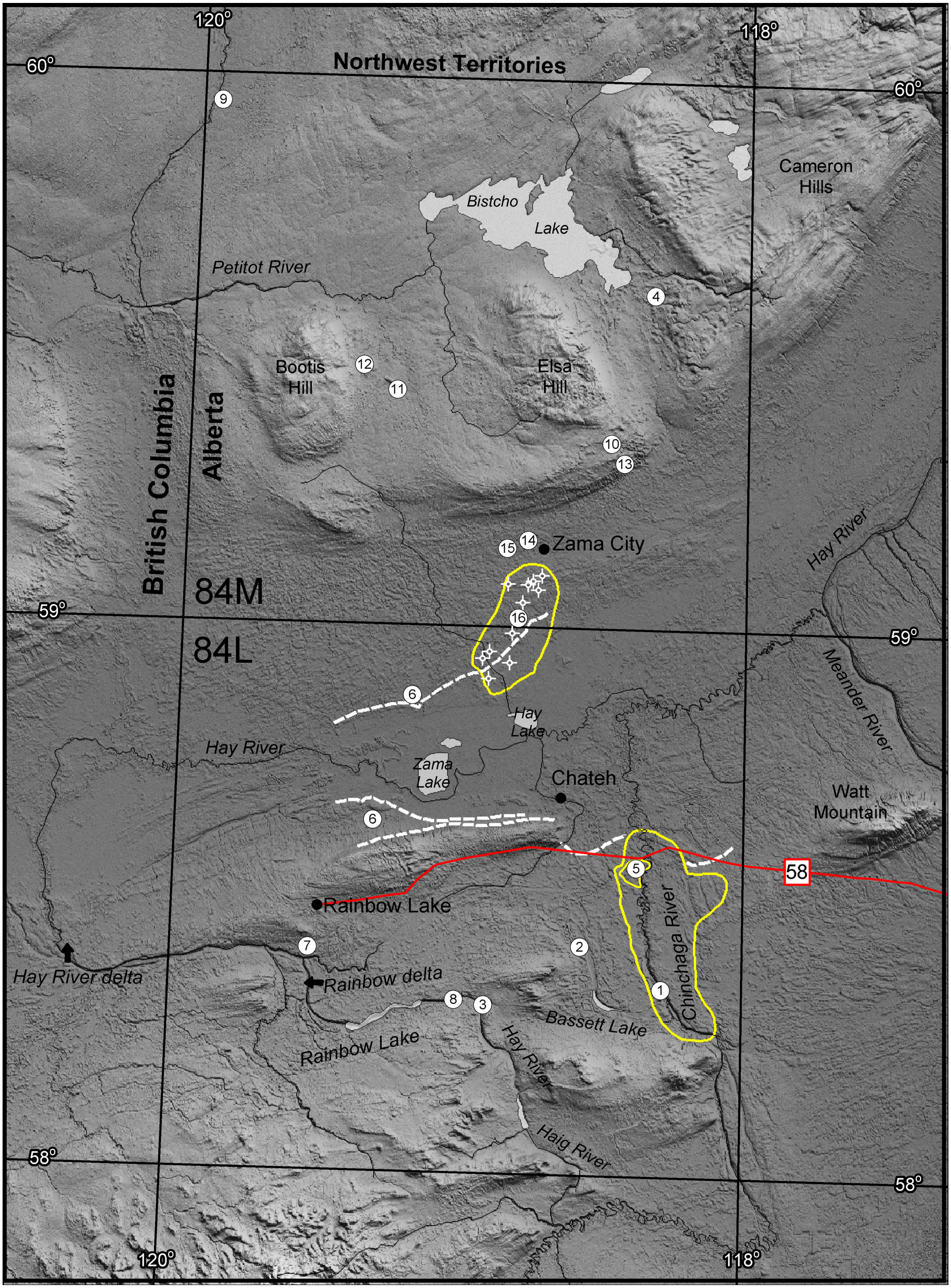

Figure 2. Space Shuttle radar (SRTM) generated digital elevation model (DEM) of map sheets 84 L, M, and surrounding region. Numbers and polygons refer to sites discussed within the text. Dashed lines correspond to raised shorelines of glacial Lake Hay

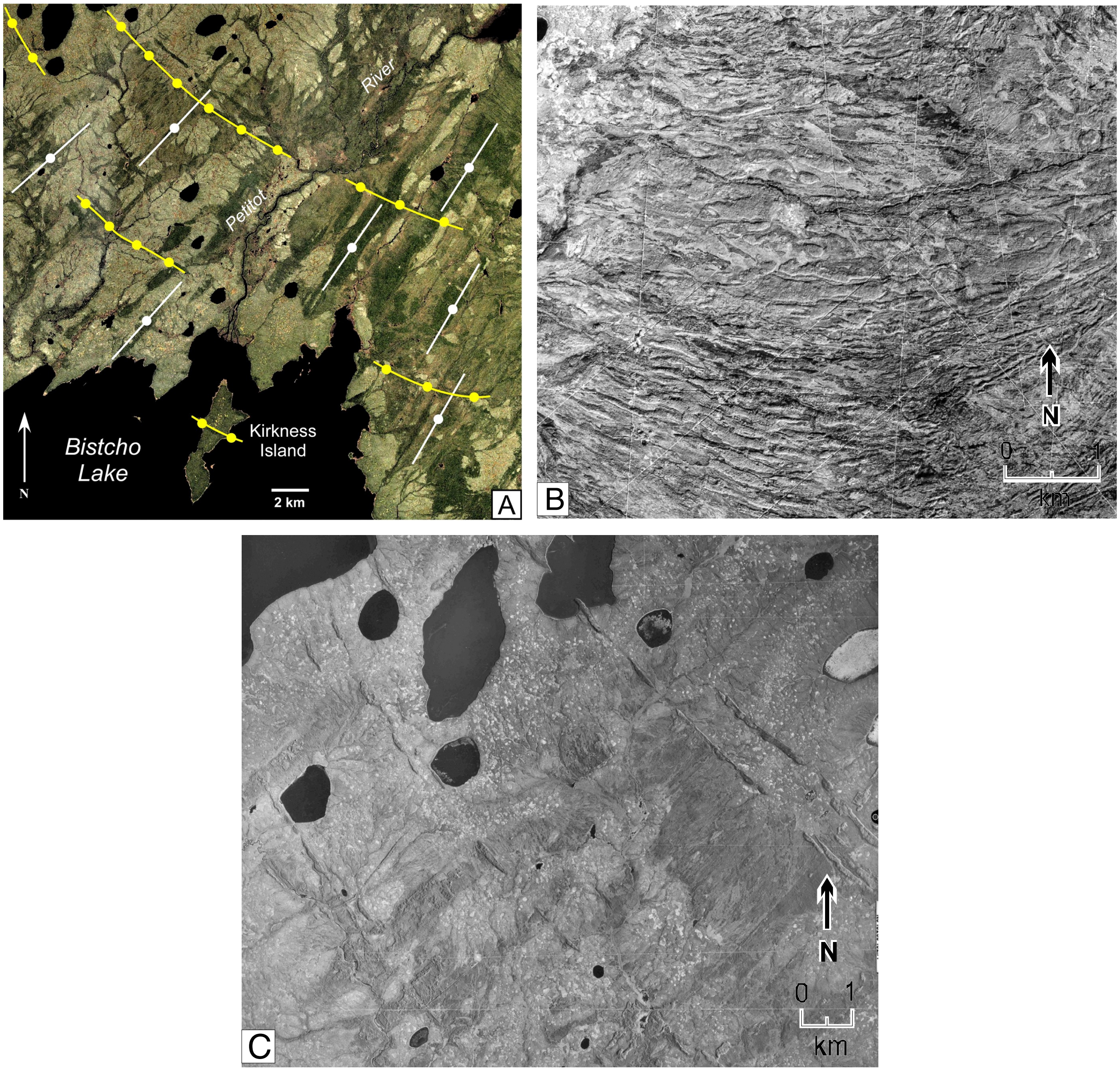

Figure 3. A) Landsat 7 image (courtesy of PhotoSat Information Ltd.) of large southwest-trending glacial flutings (white lines), draped by recessional moraines (yellow dotted lines), north of Bistcho Lake. B) Area of intensive ribbed moraines on Bootis Hill (59°26'N, 119°38'W). Moraines are 10's of metres wide, 10–15 m high and 100's of metres to kilometres in length; Airphoto 94–100 Line 23 AS4517-136, 1:60,000, ©Alberta Sustainable Resource Development. C) Prominent recessional moraines (aligned northwest-southeast) north of Bistcho Lake; Airphoto 94–100 Line 29 AS4519-207, 1:60 000, ©Alberta Sustainable Resource Development.

glaciation. Ice-flow direction is recorded by large southwest trending flutings across upland regions (Figure 2), as well as by a subsequent set of smaller, superimposed and cross-cutting flutings that trend south-southwest (Plouffe *et al.* 2004; Paulen *et al.* 2005a, b; Smith *et al.* 2005). Chronological constraint on the advance of ice is provided by a radiocarbon date of 24 400 ± 150 yr BP (Beta 183598) on wood recovered from gravel underlying Late Wisconsinan till in the adjacent region of northeastern British Columbia (Levson and Ferbey 2004; Levson *et al.* 2004). Retreat of ice from the area largely occurred between 11.5 and 11 ka BP (Lemmen *et al.* 1994; Dyke 2004).

During the ice advance phase, the eastward drainage of regional rivers would have been impounded, leading to development of large proglacial lakes. Progressively, these were displaced by ice which then deposited a blanket of distinctly clay-rich till (10-40%) across much of the region. The high clay content of this till reflects glacial erosion and entrainment of regional shale-rich bedrock and reworking of advance-phase glaciolacustrine sediment. This till is interpreted to have been largely deposited through basal lodgement processes.

Thicknesses in excess of 15 m have been observed in some areas. Clast content tends to be very low, generally between 1 and 10%, although in areas north of Bistcho Lake clast content tends to be higher (15-25%) reflecting the proximity of outcrops of Paleozoic carbonates and Canadian Shield igneous and metamorphic rocks. A second thinner and distinctly sandier till (30-45% sand in the <2 mm size fraction of the matrix) overlies this basal clay-rich till. Fabrics in the two tills tend to be very similar, and contacts between them are often diffuse suggesting that it is a second facies relating to deposition of a greater component of more far travelled (Canadian Shield-derived) coarser englacial sediment, rather than a different trajectory of ice.

During deglaciation, large proglacial lakes formed in lowland basins along the retreating margin (Mathews 1980; Lemmen *et al.* 1994; Dyke 2004). Extensive blankets of fine-grained glaciolacustrine sediment up to 3 m thick are found along the southern Hay River (Smith *et al.* 2005), while in the Hay-Zama lakes and Chinchaga River lowlands where glacial Lake Hay formed, glaciolacustrine blankets up to 10 m thick are found (Plouffe *et al.* 2004; Paulen *et al.* 2005a, b). Although glacial Lake Peace did not inundate the 84 L and M map areas, several of its outlets are inscribed upon the landscape. The uppermost Haig and Hay river channels in southeast 84L (hereafter referred to as the Hay River spillway) served as a major outlet of glacial Lake Peace (late Indian Creek stage - Mathews 1980), draining westward into a nascent phase of glacial Lake Hay and the Fontas–Nelson river system. As ice continued to retreat, outlets of glacial Lake Peace drained northwards along the ice margin, incising three prominent meltwater channels, including the present channel of the Chinchaga River (Figure 2; Keg River stage - Mathews 1980; Paulen *et al.* 2004b; Plouffe *et al.* 2004).

Two distinct strandlines of glacial Lake Hay are recognized at ~410 m asl and ~345 m asl (Paulen *et al.* 2005a, b). Fluted terraine along the northern edge of glacial Lake Hay indicates that sometime during its high water phase, ice surged southwest into the basin. Abundant iceberg scours (prow marks), preserved on the paleolake bed surface in the central and southern portions of the glacial lake basin, may reflect widespread calving during this period. Subsequent retreat of ice is associated with the lower glacial Lake Hay stage, the northward drainage of glacial Lake Peace through the Chinchaga River channels (Keg River stage) and the eventual drainage of glacial Lake Hay northwards along the present Hay River channel. Dense, deep-water (distal) silty-clay is sharply and conformably overlain by shallow-water sandy beds in the Chinchaga River valley which are interpreted to reflect a sudden drop in glacial Lake Hay water level. The Meander River spillway (confluent to the Hay River; Figure 2) marks the final northward drainage of glacial Lake Peace in the region (Mathews 1980).

GRANULAR AGGREGATE STUDIES

The methodologies used to assess granular aggregate resources in this study area included surficial geology mapping from 1:60 000 scale black and white aerial photographs, satellite imagery interpretation, ground truthing of sites accessible by truck, helicopter, all-terrain vehicles and boat, and the logging of sections within existing pits and naturally-occurring exposures. The locations of various granular aggregate resources discussed in the text are shown on Figure 2.

Till and Bedrock

Till, dug from borrow pits, is the most abundantly used form of aggregate in the study area and is employed to build well pads and most petroleum development and access roads (Figure 4). The high clay content of local tills presents both problems and advantages. When wet, roads constructed from till are treacherously slippery. Areas of high traffic and other roads of importance are top-dressed with gravel, providing an all weather surface. The high clay content of tills is an asset where roads traverse bogs and fens as it inhibits water infiltration upwards into the roadbed. This results in the reduction of frost heaving and formation of segregated ice, particularly in areas overlying permafrost. Roads constructed with less clay-rich material quickly become deformed and ridged, requiring constant upgrading. Pit excavators do not appear to distinguish between the clay-rich and sandier till facies, and the size and density of borrow pits appears to be largely a function of groundwater see page (rate of flooding) and logistics (relative travel time for hauling material versus establishing a new pit further down the road). Borrow pits are generally situated in direct proximity to roads being constructed and range in size from 50–150 m x 30–100 m, and 3–10 m deep.

Bogs and fens blanket much of the study area so immediate access to suitable borrow material is not always available. In these areas, till-cored ridges (easily distinguished because of their aspen forest cover) are opportunistically mined. Surficial geology mapping from this project has shown that many ridges in the area are morainal, formed by crevasse squeezing, or are glacial flutes, whereas elsewhere they constitute the general hummocky character of the till blanket (Plouffe *et al.*, 2004; Paulen *et al.*, 2005a, b; Smith *et al.*, 2005). North of Bistcho Lake there are numerous recessional moraines that extend discontinuously for several kilometres; their dimensions vary, but they average 20 m in width and can be over 5 m high. These moraines are much coarser than

Figure 4. Excavation of till from a borrow pit for construction of a well site access road. Photo R. Smith.

most material seen in the study area, containing abundant clasts and boulders (up to 25% by volume), which if necessitated, could be screened and crushed as a potential gravel resource.

Outcrops and shallowly buried Fort St. John Group (Shaftesbury Formation) shale along the north face of the upland Rainbow Ridge has also been used as an aggregate source for building roads and well pads. The shale is poorly indurated, making excavation easy, and has generally low slaking tendency and acceptable Atterberg limits (EBA Engineering Consultants Ltd. 1984b). Outcrops of shale are found elsewhere in the study area along former glacial meltwater channel margins, and may similarly be extracted as an aggregate base, although certainly in non-winter conditions, anything built with shale would require top-dressing with gravel to make it serviceable. Dunvegan Formation sandstone, which outcrops in the southern uplands of the 84L map area, could also be used although it is also poorly indurated, and in its lower reaches contains shale interbeds. Although regions of bedrock outcrop are not widespread in the study area, it should also be recognized that bedrock material may be easily accessed in regions identified as having only a thin cover of unconsolidated sediment, such as a till veneer (<2 m).

Glaciofluvial Channel Deposits

The winnowing of till by glacial meltwater streams is frequently associated with deposition of significant granular aggregate resources. In the present study area, such deposits are rare, likely reflecting the low clast content of the regional tills and the low-energy drainage systems that developed in the generally flat terrain. Exceptions exist with those channels relating to the drainage of glacial Lake Peace, and a deglacial meltwater system east of Bistcho Lake.

Glaciofluvial terraces and meltwater channels along and adjacent to the Chinchaga River valley (Figure 2, site 1) represent key targets for granular resources. Gravel pits within these terraces are found a few kilometres south of Highway 58, and there is high potential for more economic gravel deposits in terraces stretching at least 20 km further south, on both sides of the Chinchaga River valley (Fox *et al.* 1987; Edwards *et al.* 2004a; Plouffe *et al.* 2004). Gravel deposits along the Chinchaga River valley are 2–3 m thick and predominantly composed of pebbles and cobbles (70%) in a coarse to medium sand matrix (Figure 5). These deposits formed within meltwater channels draining northwards from glacial Lake Peace into glacial Lake Hay (Keg River stage), and include a range of glaciofluvial deposits including overbank sand and gravel, and aggradational terraces. The deposits are poorly to moderately sorted, with massive to crudely stratified planar beds. Clasts range up to 50 cm diameter, but most commonly are less than 5 cm diameter. Average clast size and content decreases from south to north (Edwards *et al.* 2004a), terminating in sandy deltaic and littoral deposits around Highway 58 that are interpreted to have been deposited in glacial Lake Hay. The contact between the Chinchaga River valley gravel deposits and the underlying till is sharp and undulating. Soft-sediment till clasts occur frequently in

Figure 5. Recent extraction of thin outwash sediments adjacent (east) of Chinchaga River, 8 km south of Highway 58. The dark material at the base of the pit is the underlying till unit. Photo R. Paulen.

the gravel, but rarely exceed 25 cm diameter. Using the extent of mapped glaciofluvial deposits along the Chinchaga River valley (Plouffe *et al.* 2004; Paulen *et al.* 2005a), and an estimated mean gravel thickness of 2 m, there are likely tens of millions of cubic metres of granular aggregate present in this region.

An earlier phase of northward drainage of glacial Lake Peace (Keg River stage) cut a meltwater channel west of the Chinchaga River valley (Figure 2). Aerial photograph interpretation has indicated an extensive cover of overbank gravel deposits adjacent to this meltwater channel (Figure 2, site 2). The presence of kettles and the general hummocky character of this deposit suggest that the gravel was deposited in an ice-contact position. The nature and extent of these deposits remain to be evaluated in the field.

Another significant glaciofluvial deposit is situated along the upper Hay River spillway (Figure 2, site 3). At this locality, there are several presently inactive gravel pits containing clean (<3% silt and clay) gravely sand (Edwards et al, 2004a). Field inspections reveal that the gravel is moderately to poorly sorted consisting of pebbles and cobbles with minor boulders, averages 3–4 m thick, and lithologically is dominated by Canadian Shield rocks with a lesser amount of quartzite and limestone (Figure 6). One exposure in an inactive pit indicates that the gravel was deposited by a northward paleocurrent, probably at a time when a glacial lake occupied the upper Hay River valley. It also appears that considerably more granular aggregate resources remain in this deposit than have already been extracted.

An extensive glaciofluvial meltwater channel complex extends from the edge of Cameron Hills to the eastern edge of Bistcho Lake (Figure 2, site 4). Several meltwater channels are incised into the till blanket and large deposits of sand and gravel occur on terraces within the former meandering deglacial meltwater system (Figure 7A). These deposits are less extensive than those of the Chinchaga River valley; the largest deposits are ~2.5 km^2, and rarely exceed 3 m thickness. Gravelly sand deposits in this system are moderately sorted with a modal clast size less than 10 cm diameter and occasional cobbles and rare boulders (Figure 7B). Overbank material

Figure 6. Inclined beds (20° dip to the north, 270-300° strike) of pebbly to bouldery-gravel in the upper Hay River valley (Figure 2, site 3) exposed in an inactive gravel pit (July 2003). Photo A. Plouffe.

Figure 7. A) At the edge of a meltwater channel (~150 m wide) east of Bistcho Lake and south of the Paramount Resources Ltd. gas plant. A bog has formed in the channel depression; a sand and gravel terrace occurs across the channel. Photo R. Paulen. B) A large gravel pit where the upper 2 metres of coarse glaciofluvial material was removed, screened, crushed and stockpiled adjacent to the winter road for ongoing and future local use. Photo R. Paulen

adjacent to these channels forms discontinuous ridges and hummocks of well-sorted medium sand. This favourable geology was one of the main reasons in locating the Paramount Resources Ltd. gas plant east of Bistcho Lake, allowing for the stable construction of a plant, camp and all-season runway in a region of sporadic discontinuous permafrost. Several pits were excavated to supply granular aggregate material during the initial construction phase of the plant and related infrastructure. Stockpiles from these pits continue to be used for ongoing gas well and pipeline development. Although noted as a potential aggregate resource by Edwards *et al.* (2004b), these sites are only accessible *via* the Bistcho Lake Paramount Resources Ltd. gas plant winter road.

Glaciolacustrine Deltaic and Shoreline Deposits

It is perhaps surprising that no significant deltas were formed along the retreating ice-dammed margin of glacial Lake Hay, suggesting that subglacial drainage was diverted elsewhere. In contrast, a prominent delta formed at the mouth of meltwater channels draining northward from glacial Lake Peace into glacial Lake Hay (Figure 2, site 5), and two very large delta systems formed along the southern Hay River spillway: the informally named Hay River delta (Levson *et al.* 2004) and Rainbow delta (Figure 2).

At the north end of the Chinchaga River valley gravel deposits, aggregate pits have been established in the larger deltaic deposits where 2–10 m thick, northward dipping, stratified and moderately sorted sand and gravel beds (Figure 8A) with a coarse cobbly-gravel topset lag are found. Trough-cross bedded gravels and gently dipping foresets of laminated pebbly sand occur at depth. At the north end of the deltaic deposits, the pits are comprised entirely of well-sorted, planar-bedded sand (Figure 8B), which likely represents subaqueous deposition at the delta margin. Deformed sand beds due to

Figure 8. A) Ongoing extraction of deltaic sediments west of Chinchaga River, 6 km south of Highway 58. Photo looks southward. Foreset beds dip gently towards the viewer, and are overlain by a coarser topset lag. Photo R. Paulen. B) Sand pit 3 km south of Highway 58, west of Chinchaga River. Here the sands were deposited subaqueously at the toe of the delta extending into glacial Lake Hay. Photo R. Paulen.

loading and dewatering are common in these northern sand pits. These pits are currently being mined and despite the long distance for hauling, the paved highway leading to Rainbow Lake allows these pits to economically supply granular aggregate material for the town of Rainbow Lake.

RAINBOW DELTA

The Rainbow delta represents the largest known granular aggregate resource in the area, and is the primary aggregate source for the town of Rainbow Lake. It is a complex landform assemblage that includes an expansive ice-contact glaciolacustrine delta (Gdt) capped by a blanket of glaciolacustrine silt (Lb). The delta was dissected by meltwater channels leaving behind a series of glaciofluvial terraces (Gt), and two relatively deeply incised canyons along its western and eastern lateral margins in which the modern, under-fit Hay River (and its tributaries) now flow (Figure 9). Realizing that glaciolacustrine sediment may have levelled out some of the terrain, there is a trend in surface elevation from ~476 m at the proximal delta (south) to ~473 m in the central delta region to ~468 m in the distal delta margins (north; Figure 9). Five terrace levels mark glaciofluvial incision accordant with eastward retreat of the Laurentide Ice

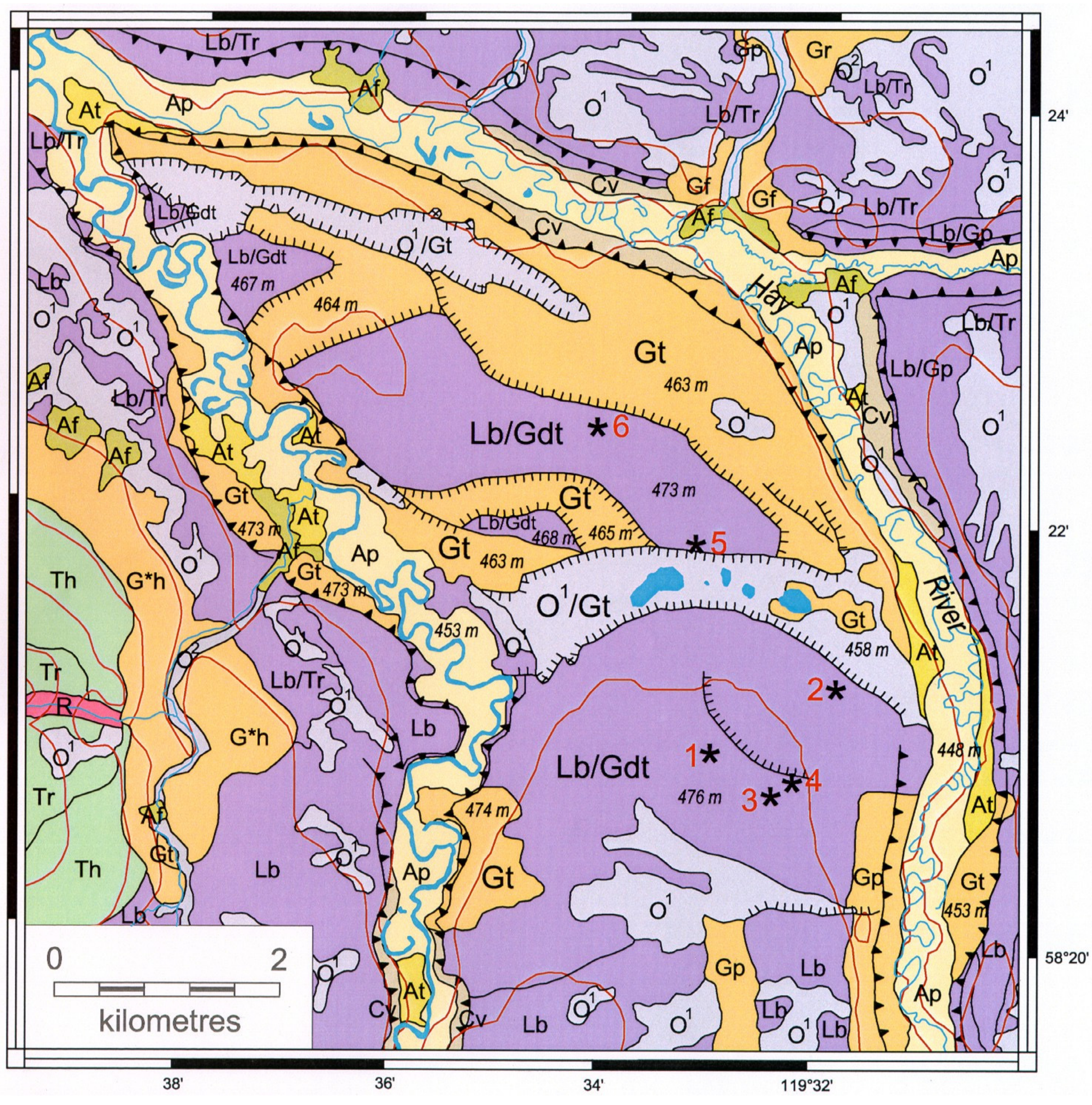

Figure 9. A portion of Smith et al.'s (2005) 84L/sw surficial geology map showing the Rainbow delta complex. Surficial geology units identified include: Gdt – glaciolacustrine delta, Gt – glaciofluvial terrace, Gp – glaciofluvial plain, G*h – kame terrace, Lb – lacustrine blanket, Tr – ridged till blanket; O1- bog, Ap – alluvial plain, At – alluvial terrace. Glaciofluvial terraces are bounded by hachured lines, while incised meltwater canyons are indicated by triangle-adorned lines. Where surficial materials overlie potentially important granular aggregate resources, polygons are labelled in the following manner: Lb/Gdt. Numbered stars identify gravel pits discussed in the text. Elevations interpreted from Shuttle Radar SRTM imagery are provided for key sites.

Sheet, and drainage of the proglacial lake in which the delta formed: i) 473 m, ii) 465 m, iii) 463 m, iv) 458, and v) 454 m (Figure 9; elevations are interpreted from Space Shuttle SRTM imagery).

Six active and former gravel pits are situated in the Rainbow delta complex, two of which exceed 1 km^2 in operational area (Figure 9, sites 1 and 2). The area containing pits 1–4 is considered the proximal delta front, and has the coarsest deposits. Total depth of material excavated ranges from 4 to 14 m. In pit #1 (Figure 9), the largest active pit, deposits are characterized as stratified, closed-work bouldery-gravel beds, and trough-cross and planar laminated, sandy-gravel (Figure 10A). Three metre thick foreset beds of coarse sand and finer gravel directly underlie 2 m of glaciolacustrine silt at the distal (west) end of pit #2. Isolated, climbing ripple and trough-cross laminated sand bodies are also present in this pit. Gravel (>2 mm) content is estimated to exceed 60%, while fines (silt and clay; <0.063 mm) are estimated to be <5%. Clasts (up to 60 cm diameter) are predominantly Canadian Shield-derived granites and gneisses (70% by volume), while the remaining 30% comprises limestones, dolomites, quartzites, sandstones and minor shale (Figure 10B). Paleocurrents at depth are generally west, shifting to progressively more northwest in the upper sections, a trend visible in channel scour patterns on aerial photographs. As expected, deposits fine in a down-flow direction and in pit #6 (Figure 9), there is 14 m of very well sorted, trough-cross and planar laminated, fining-upward, coarse to medium sand, with occasional gravel turbidite beds and dropstones (Figure 10C). Pit #5 (Figure 9) is predominantly sand, with <30 % gravel, although isolated gravel-rich beds are present. This pit is currently inactive, as is pit #2.

The proximal delta deposit represents the greatest aggregate potential and, as seen on Figure 9, occupies the entire southern Lb/Gdt polygon where pits 1–4 are located. Excluding the northwestern and southwestern extents of this area, where the stratigraphic relationship is uncertain, this is an area of approximately 7 km^2. If a conservative deposit depth of 5 m is applied, this would equate to a total potential gravel-rich resource of approximately 35 000 000 m^3. Estimates of largely well-sorted sand and minor gravel deposits in the central delta deposit (~4 km^2), using an arbitrary deposit depth of 10 m, are approximately 40 000 000 m^3. Field investigations and reports by EBA Engineering Consultants Ltd. (1984b) and Edwards *et al.* (2004a) have also shown that the upper glaciofluvial terraces in the central and western regions of the Rainbow delta complex contain gravelly-sand at surface. Inspection of shallow pipeline trenching activity across the glaciofluvial terrace immediately north of pit 6 (Figure 9) revealed a coarse boulder lag at surface, and gravelly-sand below. The absence of other surface exposures or exploratory drilling makes resource assessment in these areas uncertain, but clearly further study is warranted as this could expand the aggregate resource inventory immensely.

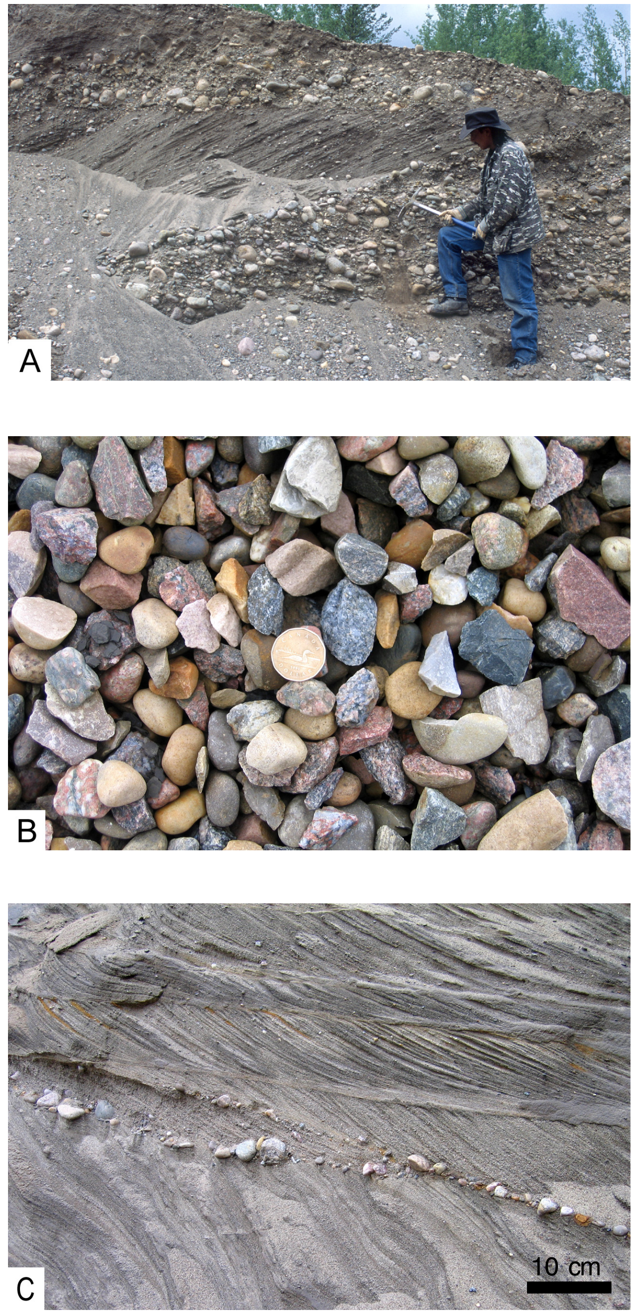

Figure 10. A) Open and closed work cobble-gravel beds and sandy fine-gravel inclined planar beds, proximal Rainbow delta pit #1 (Figure 9). Photo R. Smith. B) Crushed gravel (loonie for scale) from Rainbow pit #1 showing Canadian Shield-dominated lithologies. Photo R. Smith. C) Planar laminated and trough-cross bedded sand with gravel turbidite beds and dropstones in the distal Rainbow delta facies. Photo R. Smith.

GLACIAL LAKE HAY SHORELINES

Prominent raised shorelines, left behind from glacial Lake Hay, could potentially be exploited as a local source of sand and pebbly-sand granular aggregate (Figure 2, site 6 (dashed lines)). These beach deposits are narrow, often less than 5 m wide, and occur as small ridges <2 m above the surrounding glaciolacustrine and till plains. The matrix texture of the beach ridges varies from coarse to fine, well-sorted sand. Clast content ranges from <5 to 25%, but commonly a thin gravel lag (<0.5 m thick) mantles the beach ridge. As some of the beaches extend several kilometres in length (Figure 11) they should be taken into consideration by future road alignment planning.

Figure 11. The fall colours of poplar trees highlight a former shoreline of glacial Lake Hay that occupied the Hay-Zama lowland (at left). Photo R. Paulen.

Other Ice-contact Deposits

Eskers represent another potential granular aggregate resource. Only a few small eskers have been found within the study area (Plouffe *et al.* 2004; Smith *et al.* 2005), however, each occurrence could be targeted for localized granular aggregate needs. Site 7 (Figure 2) is a small esker complex with a series of subparallel ridges, 4–5 m high and 3.6 km long. The esker is made up of gravelly-sand (gravel content estimated at <30%), with a modal clast size of 6 cm, and maximum clast size of 25 cm. It is capped by 0.5 m of coarse till. Site 8 (Figure 2), in the Hay River channel, corresponds to an esker complex consisting of three parallel ridges that converge westward into a single esker ridge (total length ~3 km). Poor road access and a dense forest cover that prevented any nearby helicopter landing resulted in an inability to evaluate the granular aggregate potential of this esker. In the northwest sector of the study area, another esker complex extends for 4 km north of Lake May (Figure 2, site 9). A small natural exposure in the northern reaches of the esker revealed a 1.5 m cap of till overlying 2 m of well-sorted medium to coarse sand. Larger exposures or drilling would be required to assess the absolute granular aggregate resource potential of this esker.

A large kame, >30 m high, with the steeper slope oriented in the direction of up-ice glacial retreat (Figure 12) occurs on the eastern flank of Elsa Hill (Figure 2, site 10). The deposit consists of a moderately sorted pebbly gravel and sand with a coarser cobble-gravel lag on the surface. Hummocked and kettled sandy outwash adjacent to the kame corroborates its ice-contact nature. This single landform represents a large potential local source of sand and minor gravel. At site 11 (Figure 2) a complex of raised mounds (average height of ~2.5 m) and interconnecting ridges, interpreted to represent kames or subaerial ice-contact fan deposits were found. They are comprised of fine gravel and coarse sand, and given their location proximal to an existing well access road, make an obvious choice for future exploration and development.

Kame terraces, formed by glaciofluvial processes and the impoundment of drainage between glaciers and topographic highs, sometimes yield suitable granular aggregate material. Three kame terraces, in close proximity, were found along the eastern flanks of Bootis Hill (Figure 2, site 12). Field inspection revealed a fine gravelly-sand composition in the upper metre of these deposits. Total thicknesses of these deposits are uncertain, but they nonetheless represent significant potential granular aggregate sources, particularly in areas of otherwise extensive bog and fen.

Subtill Aggregate Deposits

Sorted sand and gravel deposits found below till have a number of possible geneses, including Tertiary fluvial deposition (Edwards and Scafe 1996), interglacial/preglacial fluvial deposition, ice advance phase glaciofluvial and glaciolacustrine deposition, intraglacial fluvial and lacustrine deposition (i.e., associated with an oscillating ice margin), and full-glacial subglacial channel or tunnel valley deposition. Several large subtill gravel deposits interpreted as preglacial and subglacial channel deposits have been found in northeastern British Columbia as part of activities of this project (Levson *et al.* 2004). Sand and gravel deposits have also been logged within buried channel systems in the northwest Alberta study area (Canadian Discovery Digest 2001; Hickin *et al.* 2004; Pawlowicz *et al.* 2004b), although these generally occur at such depths below surface that they are uneconomic to recover. Of all the known subtill aggregate deposits in the Alberta and British Columbia study areas, none can be said to have a

Figure 12. A large kame on Elsa Hill, adjacent to an oil pipeline. A small kettle lake lies at left. Cameron Hills can be seen in the distance. Photo R. Paulen.

surface expression of relief, drainage, or vegetation that could be used to predict their occurrence. As such, their "discovery" is often dependent on indirect, or unintended means, such as seismic shot hole operations (encountering gravel or "flowing" holes where there is an upward movement of groundwater), and geophysical logs from petroleum wells.

ELSA HILL

An active gravel pit on the southeastern flank of Elsa Hill currently supplies granular aggregate to the hamlet of Zama City as well as for local energy infrastructure demands (Figure 2, site 13). The gravel deposit accessed by this pit was recently discovered when well casing for a lease site was drilled through a 3 m thick till blanket and into several metres of cobble-gravel. Currently, the pit is small (<1 km^2) but will likely expand as the high quality granular material is extracted. The pit actually consists of two separate deposits of differing character and age. The northeast portion of this pit consists of steeply dipping and sheared sand and gravel beds several metres thick that underlie varying thicknesses of till and waterlain diamicton (Figure 13A). This material is interpreted to be proglacial outwash that was deposited proximal to the advancing Laurentide Ice Sheet. This ice-advance outwash exhibits massive to planar and trough cross-bedded, moderate- to well-sorted sandy-gravel (Figure 13B) that coarsen upwards until truncated by the sharp erosional contact of the overlying till. At depth, these sand and gravel beds dip steeply to the north, upslope to the current topography (Figure 13C). The fact that the bedding is not subparallel to topography suggests that glaciers already occupied the Hay-Zama lowland, and that these proglacial sediments were deposited as a kame terrace against the southeastern flank of Elsa Hill.

The southwest half of this gravel pit is stratigraphically younger, with coarse boulder and cobble-gravel interpreted as being deposited during glacial retreat. Approximately 7–8 m of coarse, poorly sorted, crudely stratified proglacial outwash sediment overlies the regional surface till unit. At this pit however, the deglacial gravel deposit has eroded the till, and thus directly overlies the advance-phase kame terrace deposits described above. Beds dip gently to the south-southwest, parallel to present day topography, with strong northeast imbrication of clasts (Figure 13D). Matrix-supported coarse sandy-gravel and clast-supported boulder-cobble-gravels define individual beds. Armoured till balls occur in the deglacial sediments, but rarely exceed 30 cm diameter. A topset unit contains the coarsest material, and small channels eroded into the topset beds contain only cobbles and boulders. Most boulders in this upper deposit do not exceed 1 metre diameter and many of the harder lithologies (Canadian Shield derived) still show faceted surfaces. Average clast content of this uppermost unit exceeds 50%. Current granular aggregate stockpiles in this pit comprise screened and crushed rock material.

ZAMA BEACH

The Zama Beach pit measures 1600 m x 500 m x 4 m and was inactive in the summer of 2004 (Figure 2, site 14). Bluff exposures at this site reveal a surficial cover of ~1 m stratified glaciolacustrine sediment, atop 1–2 m of clay-rich till, which unconformably overlies 2–3 m of moderately to well-sorted, interstratified sand and gravel (Figure 14A). Gravel constitutes up to 70% of the

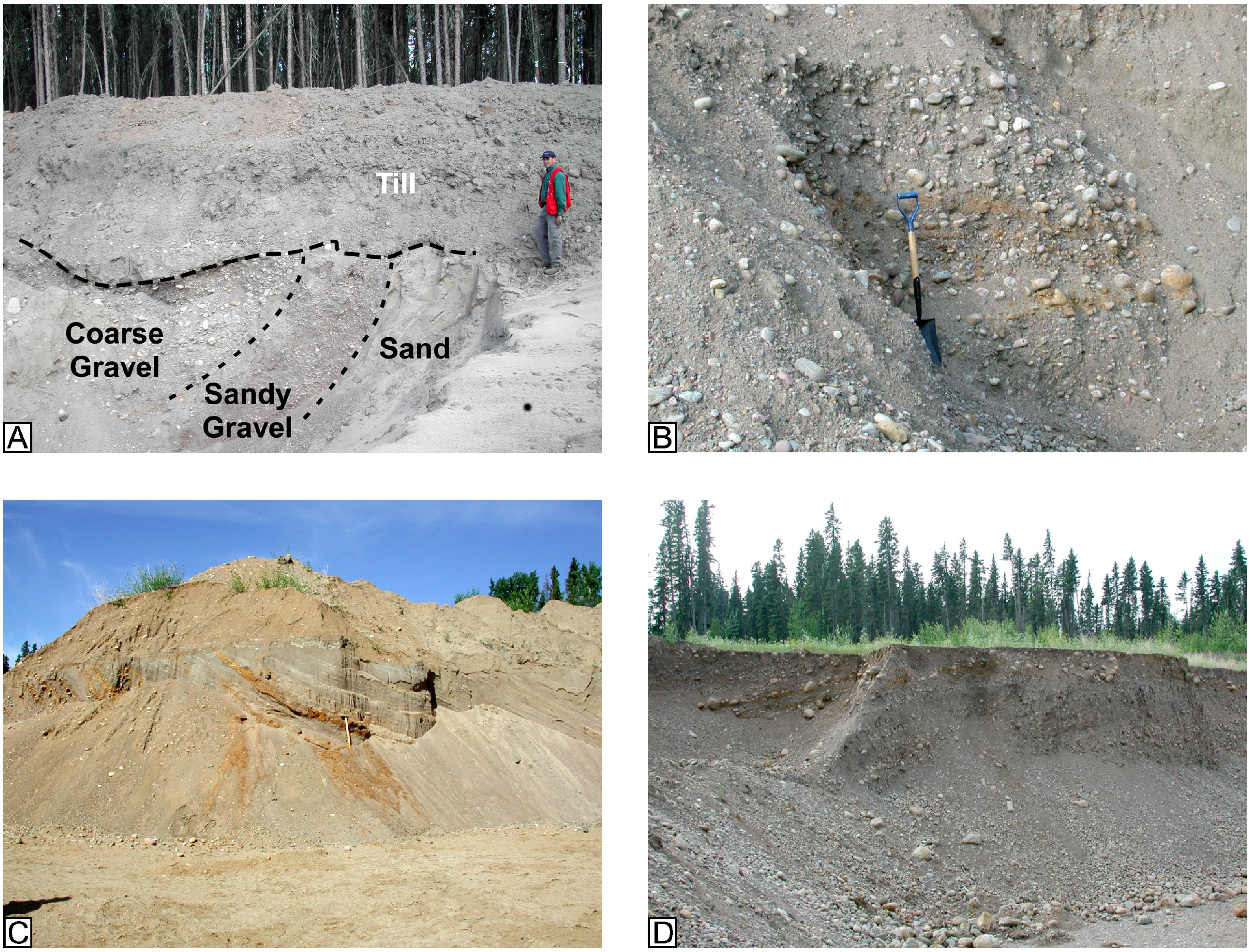

Figure 13. A) Sheared and rotated beds of a coarsening upwards ice-advance glaciofluvial deposit that was subsequently overridden by the Laurentide Ice Sheet. The clayey till at surface masks the underlying aggregate deposit. Photo R. Paulen. B) Typical coarse proximal glaciofluvial sediments that underlie the regional surface till. Photo R. Paulen. C) Lowermost gravel and sand beds dipping to the northeast. Photo R. Paulen. D) Coarse, poorly sorted proglacial outwash sediments deposited during glacial retreat. A coarse topset lag is seen with bouldery channel fills. Photo R. Paulen.

material, with few fines (silt and clay, <5%). Clasts are dominantly Shield-derived granites and gneisses, with a modal size of 5 cm, and a maximum size of 45 cm. Other clast lithologies include limestone, dolomite, quartzite and shale. Stratified beds 0.2 to 1.0 m thick generally comprise open-work cobbles, 1–3 clasts thick, overlain by normally graded pebbles and granules. Sand beds generally exhibit planar lower contacts, horizontal bedding, and have eroded upper contacts with overlying gravel beds.

A second presently active pit (200 m x 200 m x 5 m) is situated 2 km southwest of the Zama Beach pit (Figure 2, site 15). Up to 3 m of stratified sand and gravel underlies ~2 m of till; no glaciolacustrine cap was seen here. Just as in the Zama Beach pit, the contact between the gravel and overlying till is erosional. Here however, there are also pronounced shears, folds, and injections of sand penetrating up to 5 cm into the till at high angles. The sedimentology in this pit is broadly similar to that seen in the Zama Beach pit, including erosional upper contacts in sand beds (Figure 14B). There is however a higher amount of stratified sand beds, exhibiting large-scale trough cross stratification and climbing ripples (Figure 14C). A bed of fine-grained sand and dark coloured silt (0.4 m thick, 1.5 m long) was also observed at this site.

The amount of coarse-grained material and its sedimentological character at these two pits indicates a high-energy depositional environment. A subaerial glaciofluvial environment seems unlikely due to the lateral continuity of many of the beds and the regional context of glaciers advancing southwestward, up-drainage. It is instead interpreted to represent a subglacial channel fill, laid down under the advancing Laurentide Ice Sheet. The gravels were likely deposited rapidly and continuously, as laterally extensive fine-grained beds of silt and clay, representing periods of low energy are not found. Subsequent loading of the gravel deposit by ice during deposition of the overlying till is indicated by the abundance of fractured clasts in the underlying gravels and injection structures into the till.

While the two pits and various sedimentary structures within appear to be aligned, the absence of any surface expression of the underlying gravels, and the inability to

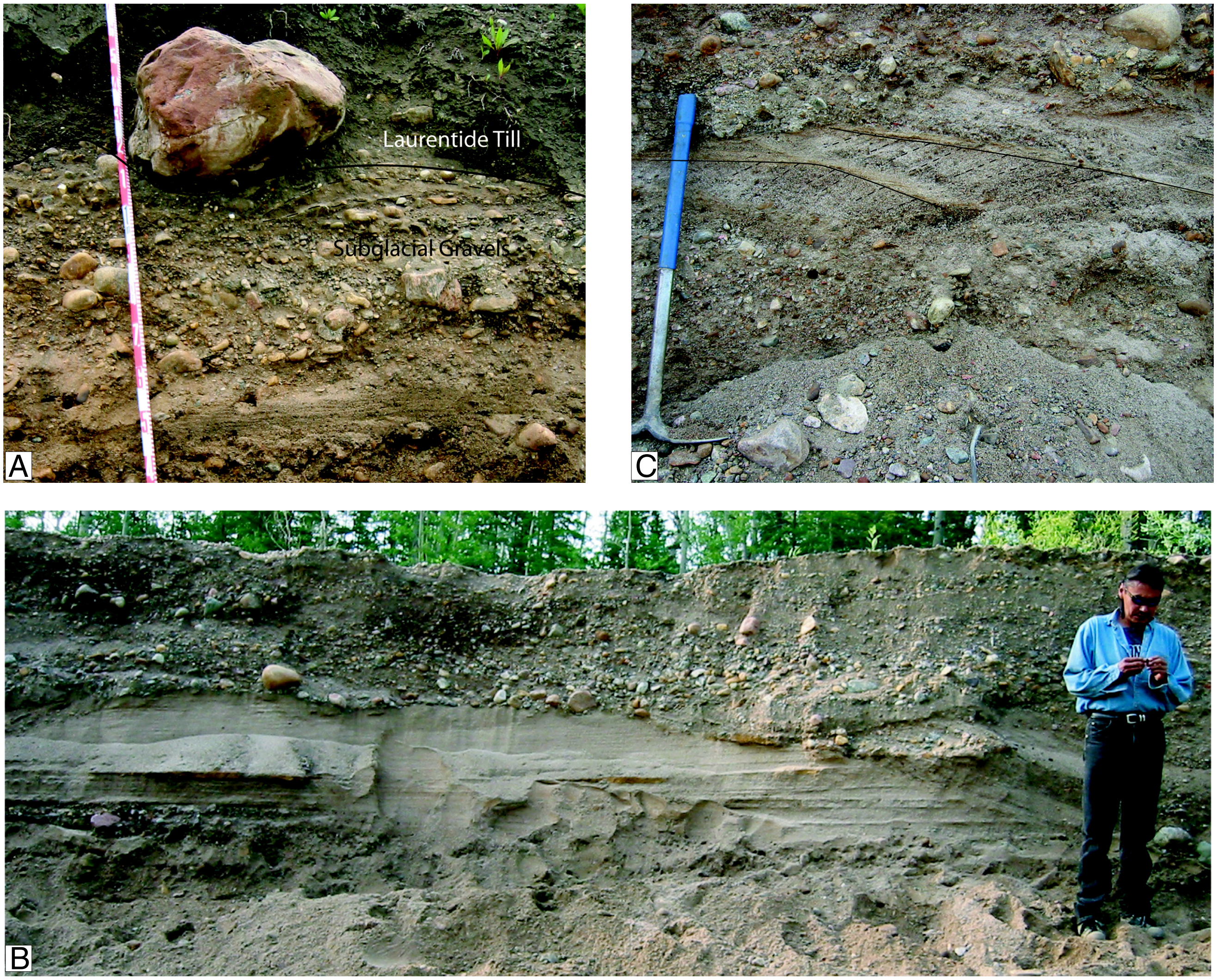

Figure 14. A) Contact between upper till and lower gravels at Zama Beach. Note shear structures at base of boulder. Visible portion of ruler is 130 cm. Photo C. Kowalchuk. B) Sand body within gravels at active pit. Sand is planar bedded with an erosional upper contact with overlying gravels. Photo C. Kowalchuk. C) Climbing ripples in coarse sand. Photo is toward southeast. Pick is 65 cm. Photo C. Kowalchuk.

easily probe through the regional overburden, makes delineation of potential aggregate resource in this area extremely difficult. Of relevance to the regional interpretation of these deposits is the report by Borneuf and Pretula (1980) on a number of sites north of Hay Lake where subsurface sand and gravel deposits, 5–23 m thick, were found (Figure 2, site 16 (polygon boundary)). These deposits represent an important aquifer, from which water is extracted and then injected down oil wells in secondary recovery operations (location of wells indicated by symbols on Figure 2). The extent and sedimentological characteristics of these deposits is intriguing, particularly when they are placed in context of being down ice flow of the two Zama Beach gravel pits. Although a stratigraphic linkage between these two areas is unknown, it could be conjectured that if the Zama Beach gravel pits represent subglacial channel deposits emanating from the westward advancing Laurentide Ice Sheet, then the thick subsurface sand and gravel deposits north of Hay Lake are deltaic deposits formed in an ice-dammed lake. Given the scarcity of aggregate resources in the Zama City area, it seems worthwhile to propose that a detailed study be conducted here, in order to better delineate potential aggregate deposits. A study could take three levels of inspection. The first could consist of a survey of regional seismic shot hole logs (generally drilled to a depth of 10–20 m) and petroleum well geophysical logs in order to see if any report encountering sand or gravel. A second study could employ a power auger to drill a network of test pits across a representative area. A final approach to be considered is that of high resolution electromagnetic (EM) surveying. This technique was used with a high degree of success in northeastern British Columbia to locate and delineate a large gravel resource that was initially identified from seismic shot hole logs (Best *et al.* 2004).

CONCLUSIONS

This study was initiated in response to a need by industry for an increased understanding of the regional surficial geology, including the assessment and expansion of the regional granular aggregate inventory. Field investigations over the past two summers have focused on two 1:250 000 map areas (NTS 84L and M), with subsequent fieldwork planned for NTS 84N and K. Four 1:100 000 maps covering the Zama Lake (84L) map area have been produced (Plouffe *et al.* 2004; Paulen *et al.* 2005a, b; Smith *et al.* 2005), and four 1:100 000 maps covering the Bistcho Lake (84M) area are in production. The new maps produced by this project will be of particular benefit to industries as they expand operations in the area by allowing them to orient roads or site potential borrow pits along identified raised terrain. In addition, many smaller potential granular aggregate sources, such as eskers, discontinuous glaciofluvial terraces, and glacial lake shorelines are identified on the maps, and with further exploration and study, these may prove to be potential economic resources for local operations.

Another contribution of this work is its assessment of gravel resources exposed in active and inactive pits within the study area. This work has led to the considerable expansion of the potential granular aggregate inventory. Several gravel deposits presently or formerly mined are now recognized to contain vastly more granular aggregate resources. The Chinchaga River valley gravels, presently being mined just south of Highway 58, have been shown to occur in glaciofluvial terraces on both sides of the Chinchaga River stretching south for over 20 km. With gravel deposit thicknesses of 2–3 m, this would equate to tens of millions of cubic metres of potential granular aggregate. The Rainbow delta complex is estimated to contain approximately 35 million cubic metres of coarse sandy-gravel deposits in the proximal delta facies, and considerably more well sorted sand and minor gravel material in the middle delta reaches and along incised glaciofluvial terraces. The Elsa Hill gravel deposits contain both ice-advance phase kame terrace deposits and 7–8 m of overlying deglacial, ice-contact outwash deposits. Opened only recently, this pit is likely to be increasingly important in the coming years as a primary aggregate source for Zama City and local infrastructure development. Also within the Zama City area, the Zama Beach and adjoining pit are interpreted to represent subglacial channel fills, possibly linked to extensive subsurface sand and minor gravel deposits previously identified to the south. If this interpretation is born out by further testing, then these same subglacial channel fills may extend laterally between these two pits, as well as up and down-flow of them.

The success of this study speaks volumes to the collaborative nature of its participants and reinforces the importance of conducting systematic and detailed field-based surficial geology operations to enhance the responsible and economical development of natural resources. It provides additional proof that even in largely flat-lying and boggy terrain, with seemingly low aggregate potential, suitable granular aggregate resources can often be identified.

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