QUATERNARY GEOLOGY AND AGGREGATE MAPPING IN NORTHEAST BRITISH COLUMBIA: APPLICATIONS FOR OIL AND GAS EXPLORATION AND DEVELOPMENT

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INTRODUCTION

Rapidly expanding oil and gas development in northeast British Columbia has resulted in a dramatic increase in the need for new geoscientific data in the region. In the field of Quaternary geology, there are two main applications of these data: 1) the identification of aggregate resources for petroleum development roads, and 2) the provision of a stratigraphic framework for the "Quaternary gas" exploration play. A third application of Quaternary geology studies in the region relates to the evaluation of diamond potential. This latter component was included in this study because of the increasingly important significance of diamonds in the mineral exploration sector in northern Canada and because of the associated potential for development of new economic activity in the region.

Quaternary geology studies were initiated in northeastern most British Columbia (Figure 1) by the Ministry of Energy and Mines in 2002, primarily in response to the critical need for aggregate (sand and gravel) in the region. Access roads to new and rapidly developing gas fields require substantial volumes of aggregate for road construction, improvement and maintenance. Current infrastructure developments in the region include a major upgrade of the Sierra-Yoyo-Desan (SYD) Road, the construction of a bypass route to the Clarke Lake Road and a number of new petroleum development road proposals. The Quaternary geology mapping program is also intended to support future exploration and development within northeast British Columbia including construction of the proposed Northern Link Road (between SYD and Rainbow Lake, Alberta, Figure 1).

Objectives

The main objectives of this study are to:

- conduct regional geological inventories of aggregate resources in the vicinity of existing and planned resource roads in northeast British Columbia;
- conduct site specific investigations to define sand and gravel reserves along the SYD Road, the Clarke Lake Bypass and along new petroleum development roads;
- investigate the natural gas reservoir potential of Quaternary/Tertiary paleovalleys; and
- conduct reconnaissance-scale investigations of diamond potential in the region.

Previous Studies

Few Quaternary geology studies have been conducted previously in the region northeast of Fort Nelson. They have mainly included a regional investigation of ice retreat during the last glaciation (Mathews, 1980) and an unpublished airphoto interpretation study of terrain features and potential aggregate deposits by Mollard (1984a,b). The soils of the Fort Nelson area were mapped by Valentine (1971). The bedrock geology of northeastern most British Columbia was mapped by Thompson (1977) and Stott (1982).

Study area

The study area occurs within the Boreal plains region of northeast British Columbia and includes the area between the Alberta border and the Alaska highway, extending north from Ft. St. John to the Northwest Territories. The main areas of focus for the 2003 field season (Figure 1) were the Fontas River and Petitot River map areas (NTS 94 I and P, respectively) and the eastern half of the Fort Nelson map area (NTS 94 J). Results of some of the work conducted in the Fort Nelson area are proved elsewhere in this volume (see paper by Johnsen *et al.*)

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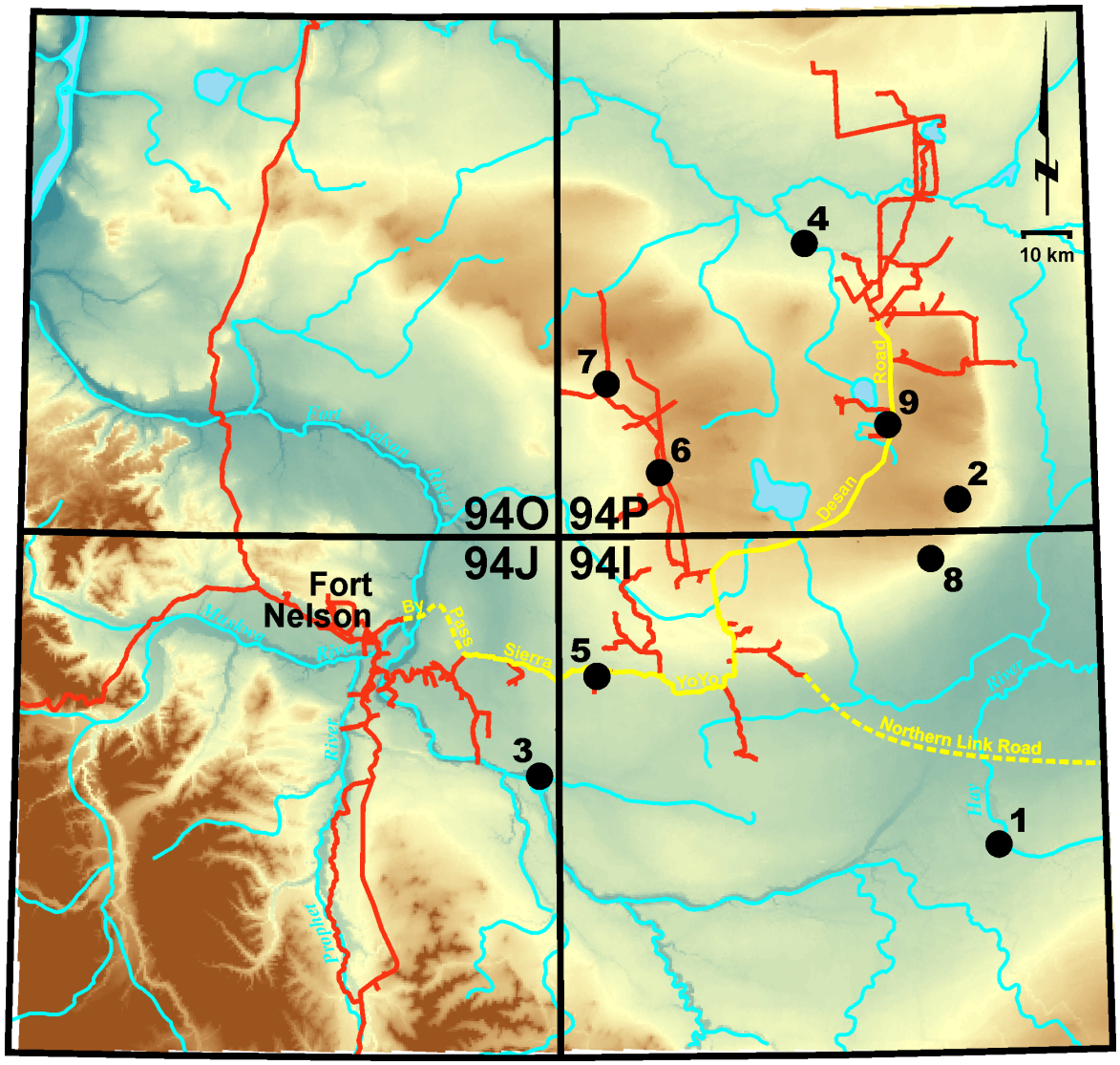

Figure 1. Location map of study area. Numbered sites are discussed in the text.

Low relief topography and clay-rich soils dominate the study region, resulting in poor drainage and a shallow water table in most areas. Lakes, marshes, fens and peat bogs with scattered black spruce are common. Areas that are elevated, even slightly, above the regional water table are largely forested with the dominant tree species being aspen, pine and white spruce.

PLEISTOCENE GEOLOGY

During the Pleistocene, glaciers advanced westward up the regional slope into northeastern British Columbia and dammed rivers draining eastward off the Rocky Mountains. This resulted in the widespread deposition of glacial lake sediments over pre-existing Quaternary deposits and hence the dominance of clay-rich soils. In addition, the local bedrock is dominated by shales and other fine textured rocks and, consequently, the derived glacial sediments are rich in clay. These fine grained Pleistocene deposits are common at the surface and are one reason why shallow aggregate deposits are relatively rare in the region.

The dominant surficial materials in the study area are organic deposits and clay tills. Elevated areas that support a tree cover are invariably underlain by morainal deposits whereas organic materials and glaciolacustrine sediments dominate lower, more poorly drained areas. Morainal landforms include low relief till plains, rolling moraines, crevasse-fill ridges, flute ridges, recessional moraines and interlobate moraines. Glaciofluvial landforms are relatively uncommon and include eskers, kames, fans, deltas and terraces. The latter occur mainly within the Kimea Creek – Petitot River meltwater channel system.

During deglaciation, numerous meltwater channels were incised by streams generally flowing westerly from the retreating Laurentide ice sheet. Sands and gravels were locally deposited in association with meltwater channels but many appear to be entirely erosional and

may have formed subglacially. Some recently discovered aggregate deposits, underlying stony diamicton along channel flanks, are interpreted to be subglacial channel deposits overlain by meltout till (Figure 2). Although, large surficial deposits of aggregate are rare, one exceptionally large glaciofluvial fan-delta (Figure 3; see Site 1, Figure 1 for location) was discovered on the east side of the Fontas River map area (NTS 94 I). This feature covers an area of approximately 100 km^2 and is likely the single largest sand and gravel deposit in northeast British Columbia. An indication of the enormous size of the fan is that it was first noticed on a satellite image. A measured section in the fan showed 7 m of well rounded, quartzite-rich gravels overlain by 5 m of well sorted sands. The thick sand cap has been largely removed in many areas by erosion of the Hay River which dissects the fan. The best target areas for coarse aggregate are thus along lower terraces of the river where it cuts the fan. These sands and gravels overlie approximately 5 m of clay-rich diamicton, interpreted to be basal till.

Dating of Pleistocene sediments in the area has been facilitated by the discovery of an interglacial peat underlying a thin till and oxidized sandy unit in the Spruce Road area (Site 2, Figure 1). The peat contains abundant plant matter including many wood fragments, as well as numerous pelecypod and gastropod fossils. Radiocarbon analyses on two wood pieces yielded dates of >38 690 BP (Beta 183832) >40 590 BP (Beta 183831) radiocarbon years. Another fragment of wood recovered from gravels stratigraphically underlying till in the Elleh Creek area (Site 3, Figure 1) was dated at 24 400 +/- 150 radiocarbon years BP (Beta 183598). Collectively, these dates and the associated stratigraphy provide new constraints on the Pleistocene history of the region and indicate that ice free conditions probably existed from before 40 ka until after about 24 ka BP.

AGGREGATE STUDIES

Aggregate resources in northeast British Columbia are relatively rare outside of major river valleys. Existing deposits in many areas of active petroleum road development have been largely depleted (Thurber Engineering, 2001, 2002) while demand is increasing. The region northeast of Fort Nelson is an area of

Figure 2. Sands and gravels in the Nogah Road area, interpreted to be subglacial channel deposits, underlying thin, stony, meltout till. The gravels overlie thick, clay-rich, basal till at most locations.

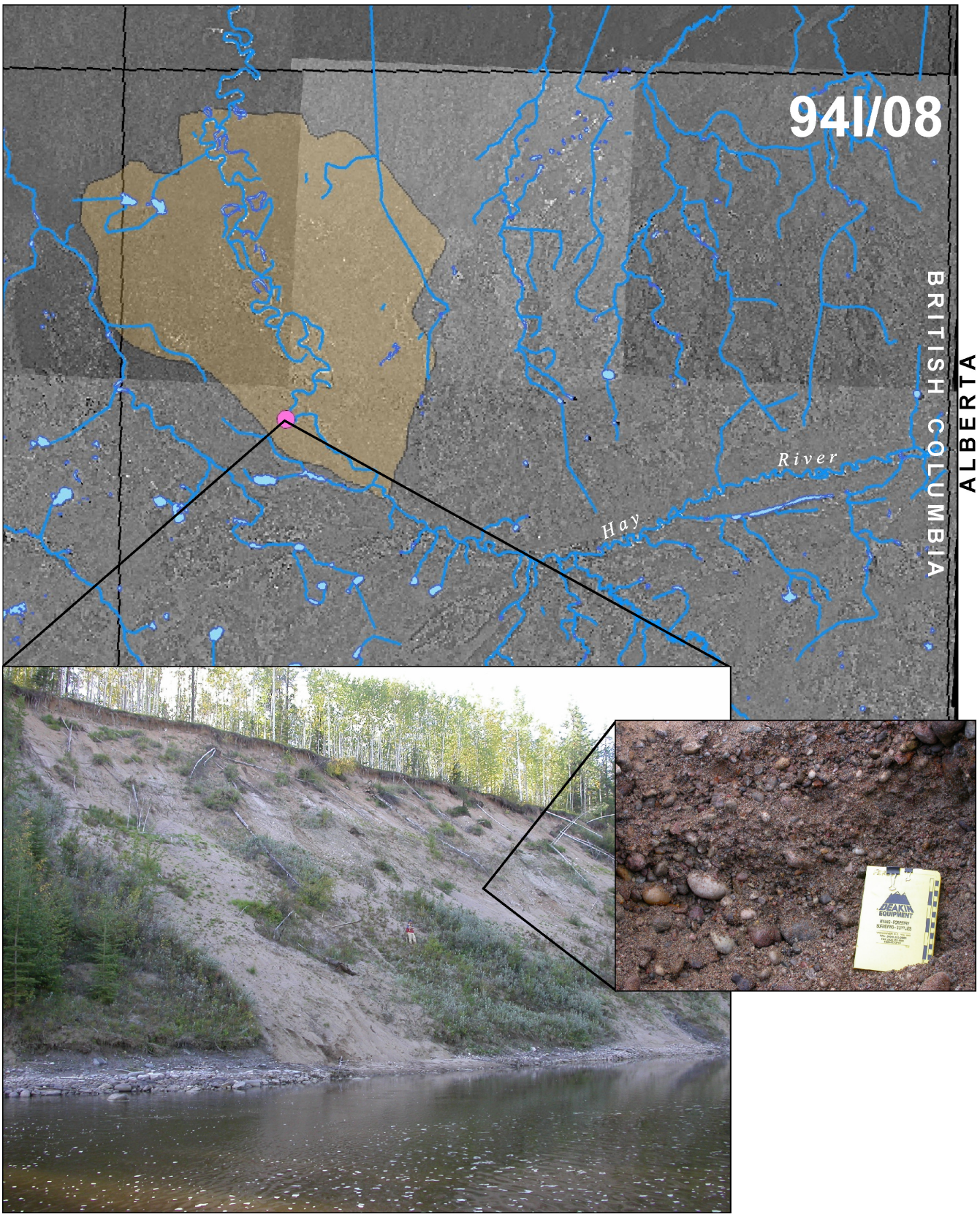

Figure 3. Large glaciofluvial fan-delta exposed along the Hay River. The orange polygon approximately delineates the extent of this fan. Inset photographs were taken at a section on Hay River where this fan-delta has been incised. Note person for scale.

particularly active exploration and development. For example, EnCana Corporation has described plans to drill about 100 new wells per year for the next several years on the Greater Sierra gas field which is nearly 300 km long (Daily Oil Bulletin, June 2002). Road improvements in this area would reduce the requirement to impose road bans in the spring, allowing for an extended drilling season. The chronic shortage of aggregate has resulted in high prices and even the need for shipping of gravel into the region by train from Ft. St. John.

To meet this need, a program was initiated as part of the British Columbia Oil and Gas Development Strategy (OGDS) to systematically explore for new, local aggregate sources in northeast British Columbia. The program includes both regional and site specific aggregate evaluations. The identification of regional sand and gravel resources will provide the necessary information for developing a long-term strategy to ensure that roads in the region are capable of supporting the future demands of industry. Improved access and transportation cost savings to resource companies will also enhance viability of projects and encourage exploration investment leading to new discoveries. The identification and evaluation of site-specific reserves will ensure an aggregate supply not only of adequate volume, but also of good quality. Sampling and laboratory testing will identify the areas of best aggregate quality for the various types of road improvement.

A key component of the OGDS is a comprehensive road infrastructure plan, aimed at promoting better access to resources through improved infrastructure. The completion of road improvements, such as the upgrade of the Sierra-Yoyo-Desan Road and construction of the Clarke Lake By-Pass Road in the Fort Nelson area, is expected to promote longer drilling seasons, accelerate exploration and production programs, and increase industry and provincial revenues.

It has been estimated that the current upgrade of the SYD road will require two million cubic metres of aggregate for the initial road infrastructure improvement program. However, a study completed by Thurber Engineering (2002) indicated that existing aggregate resources along the SYD Road were largely depleted. Four of the ten reserves investigated were completely depleted and only three had more than 100 000 m^3 of aggregate remaining. To meet this need a program was initiated to systematically explore for new, local aggregate sources in the region.

Initial aggregate evaluations in the fall of 2002 focused on an airphoto study and brief field investigation of the SYD corridor (Blyth *et al.*, 2003). From this preliminary work, fourteen sites with aggregate potential were identified including sites in the Kimea Creek (Figure 4), Hoffard Creek, Courvoisier Creek, Komie Road (Figure 5), Kotcho East (Figure 6) and Sahdoanah Creek areas (Sites 4 to 9, respectively, Figure 1).

As a follow-up to the airphoto study, ground investigations were conducted in the winter of 2003 at nine sites (Dewar and Polysou, 2003a). A total of 458 test pits were excavated and granular materials were encountered in 235 of these pits at eight of the sites. Two additional areas, where bedrock was inferred to be shallow, were also investigated. Bedrock was encountered in all 15 test pits at the sites although the quality of the rock appeared to only be suitable for general borrow material. Detailed investigations conducted at four sites included field sampling and laboratory testing (124 sieve analyses, 10 sand equivalent tests and 10 degradation tests). Sieve tests were completed on an additional 47 samples from 3 other sites. The results of the sampling program and laboratory analyses are provided by Dewar and Polysou (2003b, c, d, e).

The four areas investigated in detail are referred to here as the Kimea, Kotcho East, Komie North and Elleh sites. These sites have a total inferred resource of approximately five million cubic metres of granular material: Komie North (>300 000 m^3), Kimea (>3 million m^3), Kotcho East (~450 000 m^3) and Elleh (>1 million m^3). The Kimea deposit is one of several prospective glaciofluvial terraces (Figure 4) within a large meltwater channel system extending along parts of Kimea Creek and Petitot River. The Komie North deposit is interpreted to be an-ice contact delta (Figure 5). The origin of the Kotcho East deposit (Figure 6) is enigmatic because it is entirely buried and has virtually no surface expression. It may be a raised delta or part of a proximal glaciofluvial stream deposit. The Elleh deposit is interpreted to consist mainly of advance phase glaciofluvial deposits but also locally includes interglacial sands and gravels deeper in the deposit, where the 24 ka BP radiocarbon age was obtained. Late glacial (retreat phase) gravels, that stratigraphically overlie till, also occur in the area at the surface.

Electromagnetic Surveys

Subdued topography, extensive muskeg, and a general scarcity of glaciofluvial landforms make the use of traditional aggregate mapping techniques such as aerial photograph interpretation relatively ineffective for locating new deposits in many parts of the study area. In addition, sand and gravel deposits in the area are commonly blanketed by glaciolacustrine and glacial sediments. As a result, new subsurface investigation and geophysical techniques are being tested and used to identify these buried aggregate deposits. Data sources include down hole geophysical logs, water well logs, seismic shot-hole data, and conductor pipe logs. Airborne aeromagnetic surveys, high resolution electromagnetic surveys, LIDAR and other remote sensing techniques are also being used in exploring for buried aggregate deposits. In this section we briefly report on the results of an high resolution airborne electromagnetic (EM) survey

Figure 4. Exposure of glaciofluvial terrace gravels in the Kimea Creek area. The deposit is within a large meltwater channel system extending along the Kimea Creek and Petitot River valleys. Note shovel in foreground for scale.

of a buried gravel deposit in the Kotcho East area (NTS map area 93I/15).

The survey was centered on a deposit originally discovered during a follow-up field investigation of buried gravels reported from seismic shot hole logs. Excavations in the vicinity of the reported occurrence show gravels underlying silt rich sediments (Figure 6). The buried sands and gravels were encountered in 10 test pits in an elongated, southwest-trending area, oblique to present surface stream channels. The sands and gravels occur along a gentle southeasterly slope with no obvious geomorphic indications of their presence. They are overlain by silts and clays generally 1-2 m thick, but locally up to 5 m thick. These sediments are interpreted to be glaciolacustrine in origin. In the inferred core of the paleochannel, the sands and gravels are at least 5 m thick and in 6 of the test holes the base of the channel was not encountered. Surprisingly, the water table was encountered in only one test hole at the southeastern most edge of the deposit.

An airborne EM survey was conducted over this area to evaluate the utility of the method for mapping shallow gravel deposits, to attempt to trace the extent of the Kotcho East gravel deposit beyond the field tested boundaries and to identify any new gravel targets in the region. To accomplish these goals a detailed survey with 100 m line spacing was flown over the Kotcho deposit and 200 m line spacing was flown over a larger area (~25 km^2) around the known deposit. The survey employed the helicopter RESOLVE multi-coil multi-frequency EM system supplemented by two high sensitivity cesium magnetometers and a GPS electronic navigation system. The EM system was located in a bird flown at an average height of 39 m above the ground. Apparent resistivity maps were produced from the 400, 1500, 6400, 25 000, and 115 000 Hz data.

Results (Figure 7) show that three main areas of high resistivity were identified in the survey on the high frequency data which best reflects the shallow geology. The northernmost area coincided remarkably well with the area of shallow buried gravels as mapped out by the field investigations. The southern two areas are much larger and will be the focus of future ground investigations. Preliminary testing indicates that these other areas of high resistivity are also sand and gravel deposits. The results of this work strongly indicate that

Figure 5. Planar cross-bedded gravels exposed in the Komie North deposit, interpreted to be deltaic forset gravels.

high resolution EM surveys can be an effective tool for mapping buried sand and gravel deposits in the study region. A more detailed discussion of the results of this survey is provided elsewhere in this volume (see paper by Best *et al*.).

PALEOCHANNEL MAPPING

Reconstructions of the three-dimensional architecture of thick Quaternary sequences in northeast British Columbia and northwest Alberta have recently become of interest for several reasons. First, natural gas exploration companies have been investigating shallow gas targets in the region (see below). Secondly, rapidly expanding oil and gas infrastructure has depleted local surface aggregate supplies and created a critical need for identification of subsurface gravel deposits. Thirdly, shallow groundwater aquifers are used for agricultural purposes, as drinking water sources, and, as possible discharge sites for waters extracted during coalbed methane operations. In addition, shallow aquifers are susceptible to contamination as development expands in the region. All of these applications have resulted in the need for an improved understanding of the Quaternary stratigraphy of the region. The main geological characteristic of shared importance to all these applications is the presence of relatively large bodies of granular sediment in a variety of paleochannel settings in the subsurface.

The depth and geometry of sand and gravel sequences, of either glaciofluvial or interglacial origin, in these paleovalleys is key to aquifer mapping and aggregate studies. Large, laterally continuous units can form significant aquifers at nearly any depth within the buried valleys. However, sand and gravel units must occur relatively close to surface and have a thin overburden to be of economic significance as aggregate resources. The greatest potential for shallow gravels is in smaller paleochannels that were tributary to the larger paleovalleys. Mapping these channel deposits is relatively difficult and often requires higher resolution geophysics or dense borehole data.

Preliminary reconstruction of the bedrock topography, the first step in identification and mapping of paleochannels, has been completed using water well logs and oil and gas well records (*e.g.* Figure 8). More detailed mapping of these buried features is being accomplished in

Figure 6. Test pit exposure of sands and gravels in the Kotcho East deposit buried by surficial silts. Test pit is approximately 1.5 m wide.

some areas by interpretation of geophysical data including high-resolution aeromagnetics, resistivity surveys, seismic profiling, and ground penetrating radar.

QUATERNARY/TERTIARY GAS

Interest in Quaternary gas was highlighted in the study region by development of the Sousa Quaternary gas field near High Level, Alberta. That field has successfully been producing gas since 1998 from paleochannel sediments underlying late Quaternary glacial deposits. The sands and gravels that form the reservoir are believed to be of early Quaternary age although a Late Tertiary age is also possible. The cap for the gas is thick clay-rich glacial tills and glaciolacustrine sediments. Numerous wells have been drilled into Quaternary sediments and completed at depths of less than 300 m. One field in Alberta has yielded more than 4 bcf of gas, with one well producing up to 4.4 mmcf/d (Canadian Discovery Digest, 2000).

Northeastern British Columbia has a similar geological and glacial history to northwest Alberta where these producing shallow gas fields have been developed and, as such, the region has similar potential to host Quaternary gas. In order to identify potential paleochannel areas, the British Columbia Ministry of Energy and Mines is currently mapping the regional bedrock topography of NTS map areas 94 I (Figure 9) and 94 P. To date, about 1000 wireline-geophysical logs have been used to map the surface of the bedrock (Upper Cretaceous, Dunvegan Formation conglomerates, sandstones and shales and Lower Cretaceous Fort St. John Group shales and sandstones). Where possible, lithologic and

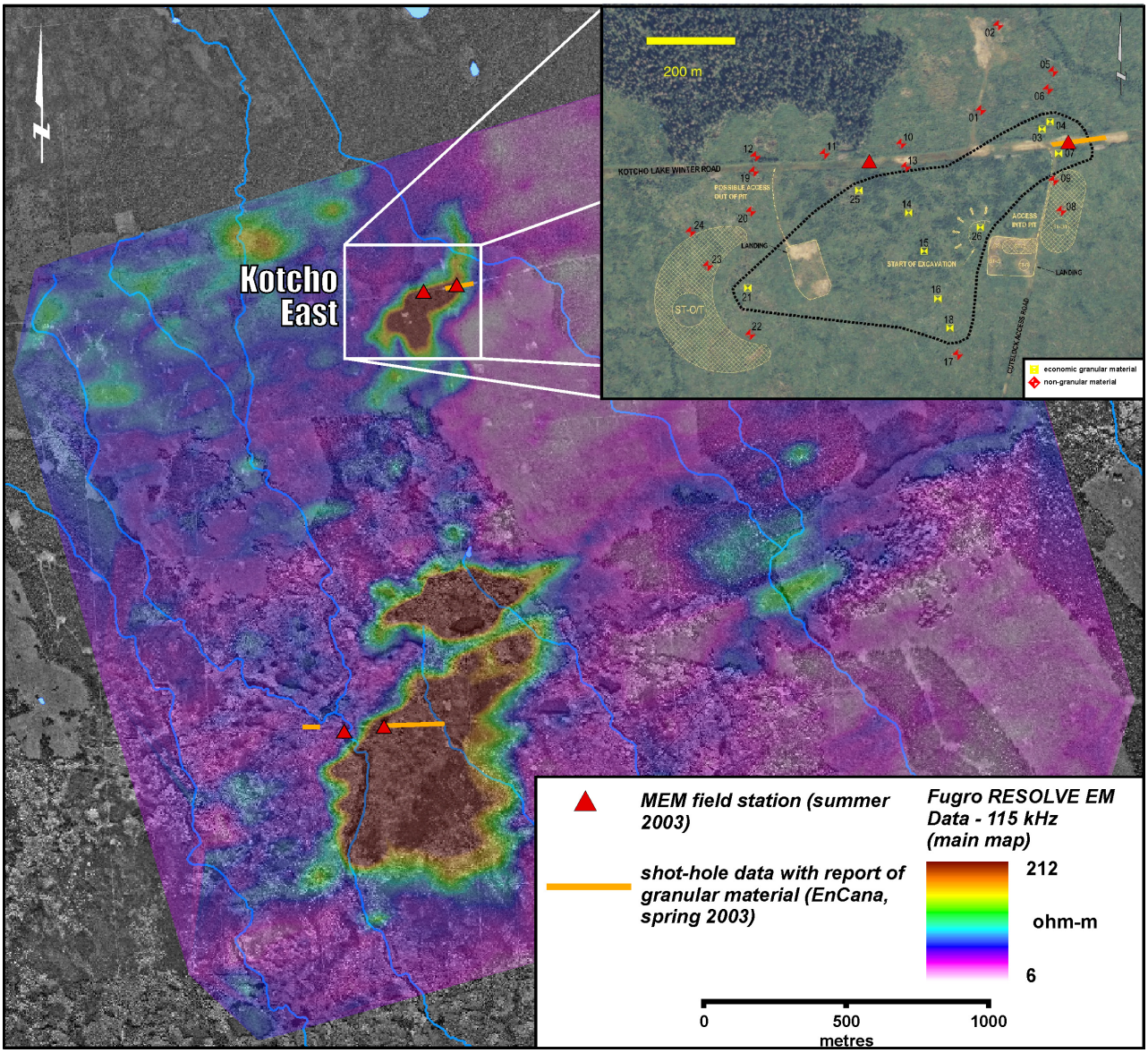

Figure 7. Results of an electromagnetic survey in the Kotcho East area. An area of high resistivity (in the north) corresponds closely with a known sand and gravel deposit (as determined by field investigations shown in the inset). Preliminary testing indicates that the large areas of high resistivity in the south are also sand and gravel deposits.

sedimentologic descriptions in nearby conductor pipe and water well logs have been used to verify bedrock picks (Figure 8). Drift thickness in these map sheets varies from a few metres to as much as 280 m. Bedrock valleys and areas with granular material overlying bedrock indicate the presence of Late Tertiary to Pleistocene paleochannels that could be suitable targets for gas exploration.

Quaternary/Tertiary gas occurrences appear to be mainly in areas distant from deeply incised, large modern valleys. The reservoir sediments are buried by thick sequences of Middle to Late Pleistocene deposits of relatively low permeability. The westward advance of Laurentide glaciers up the regional slope in successive Quaternary glaciations effectively dammed eastward draining rivers and deposited thick sequences of glaciolacustrine sediments and clay tills derived from local Mesozoic shales. Large paleovalleys in the Fort St. John area are up to a few hundred metres deep and a few kilometres wide and make significant exploration targets. Preliminary mapping indicates that a number of smaller buried paleovalleys in the Fontas River and Petitot River map areas are likely present (Figure 1). The proximity of these paleovalleys to producing Quaternary gas fields in Alberta, and the similar geological setting, suggests that this region has similar potential for new gas discoveries.

DIAMOND POTENTIAL

A secondary component of recent Quaternary geoscience studies in northeast British Columbia involves

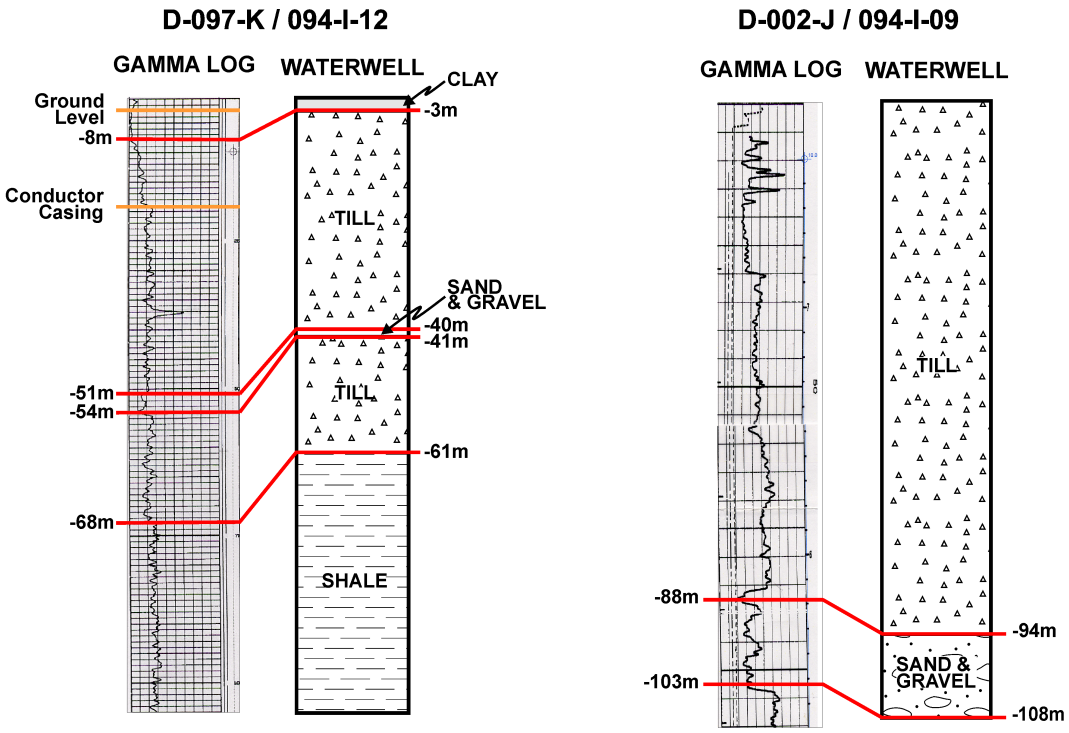

Figure 8. Examples of water well logs and nearby oil and gas well geophysical logs used in the identification and mapping of Quaternary stratigraphy, subsurface aggregates, bedrock topography and paleochannels.

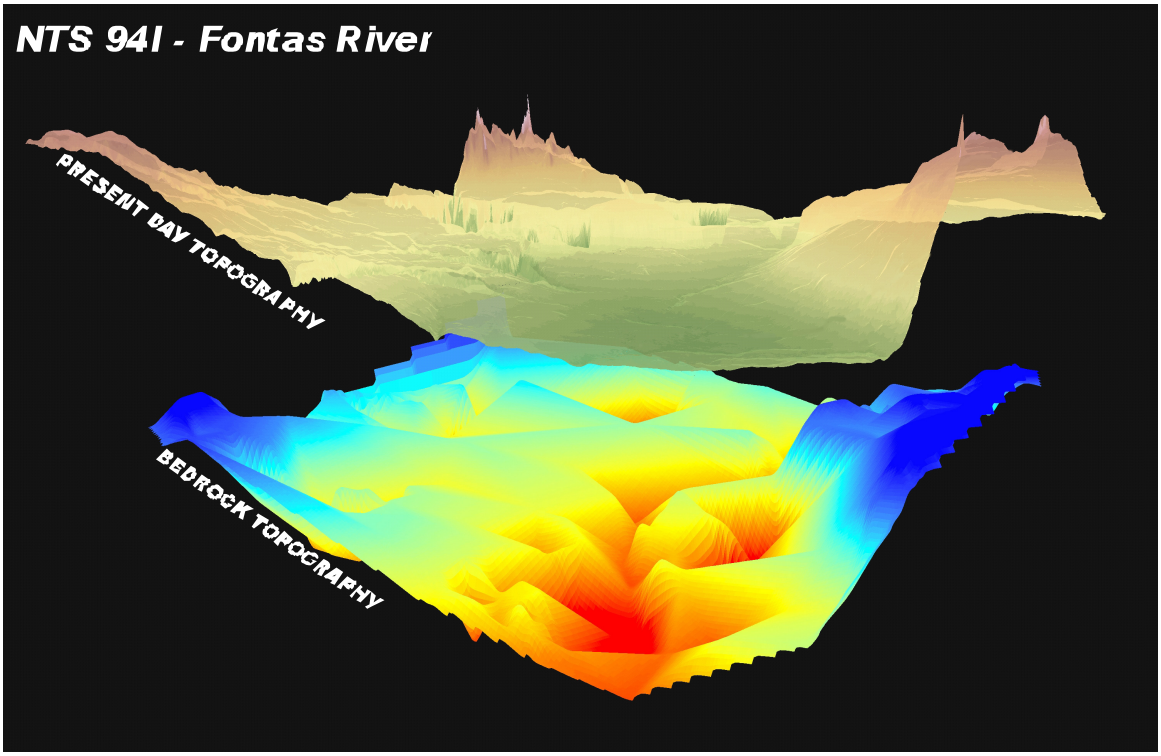

Figure 9. Preliminary reconstruction of the bedrock topography (lower panel) and surface relief (upper panel) of NTS map area 94 I based on data from about 400 wireline-geophysical logs. View is towards the southwest. Depth to bedrock varies from a few metres to as much as 280 m. Buried bedrock valleys are interpreted as Late Tertiary to Pleistocene paleochannels that are possible targets for gas exploration.

the evaluation of the regional diamond potential. Sedimentary rocks in the area are underlain by Precambrian basement with possible Slave craton equivalents, but the diamond potential of the region is largely unknown. As part of the 2003 Quaternary geology program, reconnaissance sampling of glaciofluvial deposits was conducted. Glaciofluvial sediments were selected as a sampling medium because of their potential to reflect relatively large drainage areas compared to modern fluvial deposits. Bulk samples were collected and concentrates were produced in the laboratory using heavy liquids. Kimberlite indicator minerals have been detected at a number of sites. Microprobe analyses are in progress to evaluate possible sources for the indicator minerals.

CONCLUSIONS

Recent Quaternary geology investigations in the Boreal plains in northeastern most British Columbia have been initiated in response to the need for more information on the surficial geology of the region. The main demand has come from a rapidly expanding oil and gas road infrastructure and an accompanying critical need for the identification of aggregate deposits. Gravels close to surface with minimal overburden are preferred but such deposits are relatively rare in northeast British Columbia. In addition, techniques commonly used for identifying gravel deposits, such as geomorphological mapping, are relatively ineffective in the region due to the widespread forest cover and subdued topography. Additionally, ground based exploration techniques are too costly and time consuming for covering vast areas of investigation such as the plains region of northeast British Columbia. As a consequence, Quaternary mapping programs in the region have focused on the collection of subsurface borehole and geophysical data as well as airborne aeromagnetic, high resolution electromagnetic, and LIDAR survey data.

The result of this work has led to the discovery of several new aggregate occurrences in the region. To date, four main aggregate deposits have been investigated in detail within the study area, with a total resource of approximately five million cubic metres of granular material. One of these deposits was completely buried and could not be detected by traditional airphoto mapping techniques. It was initially discovered from seismic shot hole data and was subsequently mapped using an airborne high resolution electromagnetic survey. Several other occurrences have been investigated to various levels of detail. One of the most significant of these in terms of size, is a large fan-delta in the Hay River that covers an area of approximately 100 km^2 and contains a maximum known thickness of 22 m of sand and gravel.

Mapping of buried channels in northeast British Columbia has recently become of interest because of the discovery of natural gas in Quaternary paleochannel sediments in northwest Alberta. Sands and gravels, of probable Early Quaternary or Late Tertiary age, form the reservoirs which are capped by thick Pleistocene, glaciolacustrine deposits and clay-rich tills which act as cap 'rocks'. Preliminary bedrock topography mapping in the study area suggests that paleochannels with gas potential are present. Finally, the discovery of kimberlite indicator minerals at several sites in the study area suggests that northeast British Columbia has diamond potential and that further diamond exploration in the region is warranted.

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REFERENCES

Blyth, H., Levson, V. and Savinkoff, P. (2003): Sierra-Yoyo-Desan aggregate potential mapping; British Columbia Ministry of Energy and Mines, fourteen 1:50 000-scale map sheets.

Cain, M.J. (2004): RESOLVE survey for the British Columbia Geological Survey; *Fugro Airborne Surveys*, Report 3091, 22 pages.

Canadian Discovery Digest (2001): Sousa 111 2W6 Quaternary Gas; Exploration Review, Canadian Discovery Digest, January/February 2001 Report, pages 25-39.

Dewer, D. and Polysou, N. (2003a): Project overview report: Sierra-Yoyo-Desan Road area gravel investigation, Northeastern British Columbia; *AMEC Earth and Environmental Limited*, Report No. KX04335-KX04395, 14 pages.

Dewer, D. and Polysou, N. (2003b): Field and laboratory work-Summary Report (Areas 1,2,3,4,5,5A,7,7A): Sierra-Yoyo-Desan Road gravel investigation, Northeastern British Columbia; *AMEC Earth and Environmental Limited*, Report No. KX04335-KX04395, 19 pages.

Dewer, D. and Polysou, N. (2003c): Area 8 (Komie North) gravel investigation - Sierra-Yoyo-Desan Road area, Northeastern British Columbia; *AMEC Earth and Environmental Limited*, Report No. KX04335, 19 pages.

Dewer, D. and Polysou, N. (2003d): Area 9 (Kimea) gravel investigation - Sierra-Yoyo-Desan Road area, Northeastern British Columbia; *AMEC Earth and Environmental Limited*, Report No. KX04335, 25 pages.

Dewer, D. and Polysou, N. (2003e): Area 10 (Kotcho East) gravel investigation - Sierra-Yoyo-Desan Road area, Northeastern British Columbia; *AMEC Earth and Environmental Limited*, Report No. KX04335, 13 pages.

Mathews, W.H. (1980): Retreat of the last ice sheets in Northeastern British Columbia and adjacent Alberta; *Geological Survey of Canada*, Bulletin 331, 22 pages.

Mollard, D.G. (1984a): Office airphoto study for the mapping of sand/gravel prospects in Kotcho Lake area, Northeastern British Columbia; *JD Mollard and Associates Ltd.*, 9 pages.

Mollard, D.G. (1984b): Terrain and surface geology map; Kotcho Area, British Columbia; *JD Mollard and Associates Ltd.*, 9 pages.

Stott, D. F. (1982): Lower Cretaceous Fort St. John Group and Upper Cretaceous Dunvegan Formation of the foothills and plains of Alberta, British Columbia, District of MacKenzie and Yukon Territory, Geological Survey of Canada, Bulletin 328, 124 pages.

Thompson, R.I. (1977): Geology of Beatton River, Fontas River and Petitot River map areas, Northeastern British Columbia; *Geological Survey of Canada*, Paper 75-11, 8pp.

Thurber Engineering (2001): Sierra-Yoyo-Desan Road gravel inventory; report to British Columbia Ministry of Energy and Mines, Oil and Gas Initiative Branch, 14 pages.

Thurber Engineering (2002): Sierra-Yoyo-Desan Road gravel inventory; supplementary report to British Columbia Ministry of Energy and Mines, Oil and Gas Initiative Branch, 9 pages.

Valentine, K.W.G. (1971): Soils of the Fort Nelson Area of British Columbia; *British Columbia Soil Survey, Canada Department of Agriculture*, Report No. 12, 60 pages.