SURFICIAL GEOLOGY AND AGGREGATE STUDIES IN THE BOREAL PLAINS OF NORTHEAST BRITISH COLUMBIA

Victor M. Levson[1], Travis Ferbey[1], Adrian Hickin[1], Jan Bednarski[2], Rod Smith[2], Tania Demchuk[1], Michelle Trommelen[1], Ben Kerr[1] and Amber Church[1]

ABSTRACT

This paper summarizes the results of several studies conducted as part of the northeast British Columbia surficial geology and aggregate mapping program. The detailed results of some of these studies are discussed in a number of articles within this volume, following this introductory paper. Much of the work has focused on the identification of aggregate deposits in the region which are typically rare and difficult to identify with traditional mapping methods. The rarity of aggregate deposits has resulted in excessively high road construction, improvement and maintenance costs. To address these problems, the program has applied a number of innovative techniques such as high resolution airborne electromagnetic surveys, LiDAR data analysis and interpretation, and digital compilation of large volumes of subsurface borehole and geophysical data.

The results of this work to date have led to the discovery of eight new major aggregate deposits, 25 new prospects and a large number of showings. Eleven of these new prospects have an estimated value of $120 million in direct royalty revenue to the province. Six of the new prospects were identified in a successful winter drilling program in 2005. More than half of the new deposits have been developed into aggregate operations. In addition to two new mines opened in 2004, three of the deposits were developed into gravel operations in the winter of 2005. These are the first significant aggregate mining operations that have been developed in the study region in over 15 years. Gravel from these mines has been used extensively on a number of provincially supported road initiatives.

Victor M. Levson, Travis Ferbey, Adrian Hickin, Jan Bednarski, Rod Smith, Tania Demchuk, Michelle Trommelen, Ben Kerr and Amber Church., Surficial Geology and Aggregate Studies in the Boreal Plains of Northeast British Columbia in Summary of Activities 2005, *BC Ministry of Energy and Mines, pages 42-50.*

[1] Resource Development and Geoscience Branch, BC Ministry of Energy and Mines, PO Box 9323, Victoria, BC, V8W 9N3
[2] Geological Survey of Canada, Terrain Sciences Division

Keywords: Quaternary Geology, Aggregate Resources, Surficial Geology Mapping, Shallow Gas, Quaternary Gas, Diamonds, Northeast British Columbia

INTRODUCTION

In this paper we provide an overview of ongoing Quaternary geology studies being conducted in northeast British Columbia (Figure 1), an area of active oil and gas exploration and development, by the Resource Development and Geoscience Branch of the Ministry of Energy and Mines (MEM). A number of papers follow that provide details on some of the components of this project. The project has involved collaboration with the Terrain Science Division of the Geological Survey of Canada (GSC), the Alberta Geological Survey, the BC Ministry of Transportation, Land and Water BC Inc. and various oil and gas companies.

Applications of Quaternary geology data to the oil and gas industry include: identification of aggregate resources for petroleum development road (PDR) construction, provision of a stratigraphic framework for the Quaternary/Tertiary gas exploration play, and the identification of areas of thick Quaternary deposits and permafrost for engineering purposes. Recent well blow-outs and serious drilling problems associated with shallow gas and artesian aquifers have further highlighted the importance of Quaternary geology studies in the region. Surficial geology map data, such as drift thickness information, also have applications in estimating drilling costs (*e.g.* casing depths), as well as in improving design of seismic surveys and interpretation of geophysical data. Another application of Quaternary geology studies in the region relates to the evaluation of diamond potential which is becoming of increasing importance in northern Canada.

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 the Ft. St. John region to the Northwest Territories. The main areas of focus for the 2003 and 2004 field seasons (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). Work in the 2005 field season is also planned for the Dawson Creek area (NTS 93 P).

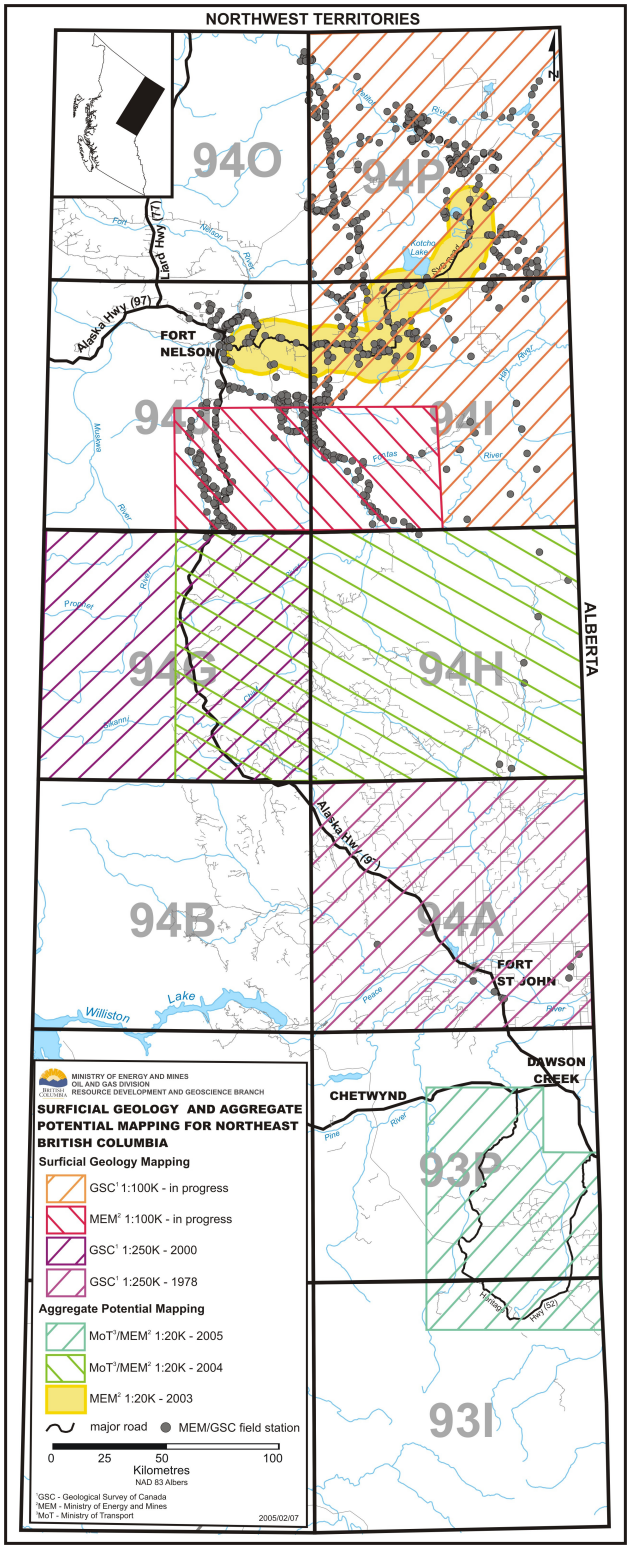

Figure 1. Location of study area and coverage of previous and current surficial geology and aggregate potential mapping programs. The SYD road is highlighted by a yellow 10 km buffer along which MEM reconnaissance mapping was conducted in 2003.

Previous Work

Previous geologic studies in the region northeast of Fort Nelson have been mainly regional in nature and have included soils, surficial geology, aggregate potential and bedrock geology mapping (*e.g.* Valentine, 1971; Thompson, 1977; Mathews, 1980; Stott, 1982; Mollard, 1984a, b). Surficial geology mapping farther south includes the work of Mathews (1978), Reimchen and Bouvier (1980) and Bednarski (2001). The Quaternary geology of the study area and a number of recent aggregate potential and surficial geology studies, conducted as part of this program, were summarized by Levson *et al.* (2004).

SURFICIAL GEOLOGY

The surficial geology of the study area is dominated by clay-rich tills and glaciolacustrine sediments. In places, these fine grained Pleistocene deposits completely cover glaciofluvial sands and gravels with aggregate potential. For example, a number of recently discovered gravel deposits, underlying clay-rich diamicton, are interpreted to be subglacial channel deposits overlain by meltout till. Poorly drained areas with thick organic deposits are also common in the region. Glaciofluvial deposits are relatively rare at surface and occur mainly within or near large meltwater channel systems.

The timing of glacial events in the Late Pleistocene is poorly constrained, but a few radiocarbon dates from sediments underlying till indicate that the last glaciation in the region was Late Wisconsinan. Fossiliferous organic sediments, of inferred Sangamonian age, underlying till have been discovered in the study area and indicate a paleoclimate somewhat similar to the present. Glaciers did not move into the region until after about 24 ka radiocarbon yeas BP and ice free conditions probably existed from then until well before 40 ka (Levson *et al.*, 2004).

AGGREGATE PROGRAM

In northeast British Columbia, aggregate typically accounts for 30 to 75% of the total cost of road building and maintenance projects. For example, a $111 million upgrade option on the Sierra-Yoyo-Desan Road (SYD) included $83 million in gravel costs (McElhanney, 2003a). A particularly critical shortage of aggregate in the Ft. Nelson region has resulted in high prices and, in a few projects, has necessitated shipping gravel by train from Ft. St. John at the expense of the provincial government. Prior to the beginning of this program, a study to evaluate the quantity of aggregate at ten gravel reserves along the SYD indicated that only three of the areas had more than 100,000 cubic metres (m^3) of gravel remaining, and most was available at only one location at the north end of the road (Thurber, 2001, 2002). Four of the reserves were completely depleted and two had less than 20,000 m^3 of gravel. Clearly the need to identify more local aggregate sources was required.

To meet this need, a program was initiated by MEM 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 oil and gas discoveries. This program was initiated as part of the British Columbia Oil and Gas Development Strategy (OGDS).

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 SYD road and construction of the new Clarke Lake Bypass at the start of the SYD in the Fort Nelson area, is expected to promote longer drilling seasons, accelerate exploration and production programs, and increase industry and provincial revenues.

HIGHLIGHTS

Aggregate discoveries

One of the main highlights of the northeast BC aggregate program has been the discovery of a number of new aggregate deposits leading to significant savings in road development programs in the region (Ferbey *et al.*, 2005). The results of this work to date have led to the discovery of eight new major aggregate deposits most of which have been developed into aggregate operations including two new mines opened in 2004 and three in 2005. Gravel from these mines has been used extensively on the SYD road, the new Clarke Lake Bypass and on a number of PDR's sponsored under the MEM Royalty Credit Road Program. The latter provides 50% provincial funding on approved projects via royalty credits on future production. Aggregate from the Kotcho East deposit (see below) was hauled out via winter road and stockpiled for use on the Spruce Road. The other two new mines in 2005, at the Courvoisier Ridge deposit and the South Gunnell-1 prospect (see Figure 1 in Ferbey *et al.*, 2005), were discovered the same winter. Gravel from these deposits was used on the Yoyo, Gunnell and Courvoisier Royalty Credit Roads within weeks of the first field exploratory excavations of the deposits.

To date, 25 new aggregate prospects have been identified as well as a large number of additional showings (Ferbey *et al.*, 2005). Six of the new prospects were identified in a winter field program in February and March of 2005. This winter program was exceptionally successful and a number of prospects were drilled with positive results (*i.e.* they contained coarse gravel greater than 4 m in thickness). The largest prospect found to date is the Hay River glaciofluvial fan-delta located on the east side of the Fontas River map area (NTS 94 I) in the vicinity of the proposed Northern Link Road (Levson *et al.*, 2004). This landform covers an area of about 100 km^2, similar in size to the Fraser River delta, and is likely the largest sand and gravel deposit in northeast British Columbia. It contains up to 25 m of sand and gravel overlying till. Gravels are exposed near the surface along low terraces of the Hay River which incised through the deposit and concentrated coarser materials in the terraces. Eleven of the largest of the new prospects have an estimated aereal extent of approximately 125 million square metres. Conservatively assuming that these prospects have an average thickness of three metres and if only 10% can be economically mined, they represent about 40 million cubic metres of aggregate. The value of this aggregate in direct revenue to the province, in royalties alone, is $120 million (at $3/$m^3$).

Cost savings as a result of this program are further exemplified by an engineering cost study conducted prior to the SYD upgrade (McElhanney, 2003a, b). Estimates of the quantity of gravel required for the upgrade varied from 1.8 to 2.7 million cubic metres. The estimated cost of hauling gravel by rail from the Teco pit south of Ft. St. John to Ft. Nelson was $34/$m^3$ (McElhanney, 2003b). An additional $19/$m^3$ would be required for the average haul along the SYD for a total of $53/$m^3$. The cost of the option of hauling gravel 180 km via winter road from the Ft. Nelson River pit at km 44 on Highway 77 was estimated at $40/$m^3$ plus $11/$m^3$ for average haul costs along SYD. In contrast, average costs for hauling from local sources along SYD, although limited in volume, varied from about $15 to $20/$m^3$ or 60-70% less. As McElhaney (2003b) reported, each dollar decrease in the unit price for gravel on the project would result in a cost savings of approximately $2 million.

Preliminary mapping by MEM in the fall of 2002 (Blyth *et al.*, 2003) resulted in the identification of nine targets that were followed up with test pit investigations in the winter of 2003 (Dewar and Polysou, 2003). The work was done under contract with oversight provided by MEM staff. Granular materials were encountered at eight of the sites in over 50% of the 458 test pits excavated. The results of the program were summarized by Levson *et al.* (2004). A total of more than five million cubic metres of gravel potential was identified at five locations in the region. One of these sites, in the Elleh Creek area, had a potential volume of well over one million cubic metres. This site was selected as a primary source of aggregate for the SYD upgrade and mining began there in the winter of 2004 (Figure 2). The Elleh deposit is interpreted to consist mainly of advance phase glaciofluvial deposits but also locally includes interstadial sands and gravels deeper in the deposit. Late glacial (retreat phase) gravels, that stratigraphically overlie till, also occur in the area at the surface (Levson *et al.*, 2004).

A second site referred to as the Kotcho East (Area 10a) deposit (NTS map area 93I/15), first identified from EnCana Corporation seismic shot hole data, was found to potentially contain approximately 450,000 m^3 of aggregate. The deposit is entirely buried and has virtually no surface expression (Levson *et al.*, 2004). It is overlain by one to five metres of clay-till and is interpreted as a subglacial stream deposit. It was further investigated with an airborne electromagnetic survey (see below) and in the winter of 2005 a new aggregate mine was opened at the

Figure 2. Active gravel mining operation during the winter of 2004 at the Elleh deposit. Aggregate from the operation was stock piled at various locations for use on the SYD and Clarke Lake Bypass roads. Gravels in the area are extensive and include mainly glaciofluvial gravels deposited during the last glaciation. (Photo provided by Quentin Huillery, Ledcor CMI Ltd.)

site by EnCana Corporation (Figure 3). The deposit is located 27 km south of the SYD and easily accessed via the Kotcho winter road or the Spruce PDR. The closest gravel pit to this deposit is more than 50 km away by air and more than 75 km by road. It is the only gravel pit in an area of more than 2500 km^2. The value of this deposit to the province is over $1.3 million in royalties alone. In addition, gravel removed by EnCana Corporation will be used on royalty credit roads resulting in a cost savings to the province of $0.50 for each dollar spent.

Surficial Geology and Aggregate Mapping

The northeast BC aggregate mapping project is part of a regional surficial geology cooperative mapping program involving researchers from the British Columbia, Alberta and Canadian governments. Current and previously completed mapping project areas are identified on Figure 1. The results of surficial geology mapping conducted in northwestern Alberta by the Geological Survey of Canada and the Alberta Geological Survey are presented by Smith *et al.* (2005). Two 1:50 000 scale surficial geology maps have recently been released by Bednarski (2005a, b) for key road development areas in the Petitot map area (NTS 94 P). Two 1:20 000 scale, airphoto aggregate potential mapping projects have been completed as part of this project in collaboration with the BC Ministry of Transportation and Land and Water BC Inc. (Savinkoff, 2004a, b).

Surficial geology mapping and Quaternary geology studies in the Fort Nelson (NTS 094J/SE) and Fontas River (NTS 094I/SW) 1:100 000 scale map areas (Figure 1) are provided by Trommelen *et al.* (2005). One highlight of this work was the discovery of a deep paleochannel of the Prophet River locally containing highly compressed peats of probable interglacial age (Sangamonian?).

Subdued topography and a widespread forest cover in the study area make the use of air photo interpretation of relatively little value in identifying subtle landforms in much of the region. The use of new geomatics technologies (Kerr *et al.*, 2005) and detailed application of LiDAR data (Demchuk *et al.*, 2005) have proven to be highly effective methods for the identification and mapping of surficial geology and aggregate deposits in this challenging area. A highlight of the LiDAR work has been the identification of a number of low relief landforms that are indiscernible on air photos. Many of these features are glaciofluvial in origin and have high aggregate potential. Detailed mapping of the landforms using LiDAR data is expected to greatly facilitate our understanding and use of these important deposits.

Bedrock Topography and Drift Thickness Mapping

Another component of this project has involved the mapping of the subsurface bedrock topography. There are

Figure 3. February 2005 exposure in the southwest corner of the Kotcho East gravel pit, operated by EnCana Corporation. Buried gravels in the area are up to several metres thick and the overlying clay-rich sediments are typically 1-2 m, but up to 5 m, thick. The upper part of the overburden has been stripped here and the base of the gravel is below the base of the exposure.

a number of applications of this work including shallow gas exploration, identification of subsurface gravel deposits, mapping shallow groundwater aquifers, identification of thick low velocity surficial zones for seismic interpretation, and identification of artesian aquifers and potentially over-pressurized shallow gas zones. The importance of the latter has been recently highlighted by blow-outs in northeast BC and northwest Alberta in the winter of 2005. One blow-out resulted tragically in the loss of life. All of these applications have emphasized the need for an improved understanding of the bedrock topography and drift thickness of the study region.

Preliminary bedrock topography map data for NTS map areas 94 I and P were initially compiled from water well logs, wireline-geophysical logs, and other oil and gas well records (Levson *et al.*, 2004). The data revealed drift thicknesses in the area of up to 280 m and indicated that a number of possible paleochannels existed in the region. Just across the Alberta border from this area, a number of wells have been drilled into Quaternary sediments and completed at depths of less than 300 m. One field has yielded more than 4 bcf of gas, with one well producing up to 4.4 mmcf/d (Canadian Discovery Digest, 2001). More detailed mapping of the bedrock topography is now being accomplished by the use and interpretation of other data sources such as chip samples from oil and gas wells and various types of geophysical data (Hickin and Kerr, 2005).

Mapping buried gravels with high resolution airborne electromagnetics – Kotcho East Deposit

Due to the difficulties associated with identifying buried aggregate deposits in the region, new subsurface investigation and geophysical techniques are being tested and used during this program. One of the most successful of these techniques is an airborne, high resolution, electromagnetic (EM) survey. The results of a pilot EM survey of a buried gravel deposit in the Kotcho East area were summarized by Levson *et al.* (2004). Excavations in the vicinity of the deposit show gravels underlying one to five metres of clay rich till (Figure 3). The EM survey was flown with 100 m line spacing over the Kotcho East deposit and 200 m spacing over a larger area (25 km^2). The helicopter-borne RESOLVE multi-frequency EM system was used (Cain, 2004). The flat, till covered, deposit, which was originally detected only in seismic shot hole logs, was mapped remarkably well with the high

frequency (115 kHz) data, which best reflects the shallow geology (Best *et al.*, 2004). Gravels in the region have high resistivity values (>50 ohm-m) and show a marked contrast with the adjacent fine-grained glacial sediments which exhibit low resistivity values (<15 ohm-m). This contrast in electromagnetic properties allows for relatively high resolution mapping using airborne EM.

All of the goals of the pilot EM survey were achieved including an attempt to evaluate the utility of the method for mapping shallow gravel deposits, 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. Recent results of this work have been described by Best *et al.* (in press) and show that three main areas of high resistivity were identified in the survey. The southern two areas are much larger than the Kotcho East deposit and were the focus of reconnaissance ground investigations that revealed the presence of sand and gravel deposits in these areas of high resistivity (Levson *et al.*, 2004; Best *et al.*, in press).

The Kotcho East deposit is characterized by crudely stratified, poorly sorted, large cobble to boulder-sized gravels interbedded with well stratified, moderately well sorted, sands and pebble-sized gravels (Figure 4). Contrasts in grain size and sorting from bed to bed are large and remarkably sharp. They are interpreted to reflect sudden changes in flow energy. Low angle, large-scale, trough cross-bedding, cut-and-fill structures, and large clast clusters reflect strongly channelized flows. The gravels are sharply overlain by a clay-rich diamicton (Figure 5) interpreted to be a meltout till. The diamicton is moderately dense, silty, matrix-supported, contains both local clasts and distally derived (Canadian Shield) erratics, and has thin laminae of sorted silts and very fine sands. The presence of angular, soft siltstone clasts that dip steeply and show little sign of shear precludes a lodgment till origin. The geometry of the Kotcho East deposit could not be determined from aerial photographic interpretation of geomorphic data due to the subdued relief created by the till blanket (Figure 6).

A new gravel pit was opened in this area in the winter of 2005 and the mine excavations to date have further confirmed the size and geometry of the deposit as predicted by the EM survey and as mapped out by the initial field investigations. The results of this work strongly indicate that high resolution EM surveys are an effective tool for mapping buried sand and gravel deposits in the study region.

Diamond Potential Studies

As part of this program, reconnaissance sampling of glaciofluvial deposits was conducted as a first step in the evaluation of the diamond potential of the region. Prior to this program, there were no published reports of diamond indicator minerals in the area and little work had been done. Consequently, bulk sand samples were collected from glaciofluvial deposits at representative sites and concentrates were produced in the laboratory using heavy liquids. Kimberlite indicator minerals (KIMs) were detected at a number of sites and microprobe analyses were used to evaluate their chemistry and potential significance. These results led to the conclusion that the study area has some diamond potential and that further exploration is warranted (Levson *et al.*, 2004). The detailed results of the microprobe analyses of the KIMs were released in January 2005 (Simandl, 2005a, b) and immediately led to mineral staking in six different areas. This is the first diamond staking in the Western Canada Sedimentary Basin in northeast British Columbia.

CONCLUSIONS

A number of studies have been conducted as part of the northeast British Columbia aggregate program. This research has been carried out by the MEM Resource Development and Geoscience Branch in conjunction with industry, consultants, universities and other governments. The detailed results of some of these studies, discussed in a number of articles that follow this introductory paper, include research on the Quaternary geology of the region, surficial geology mapping programs and aggregate potential studies. Most of the work has focused on the identification of aggregate deposits, the general absence of which has resulted in excessively high road construction, improvement and maintenance costs. The rarity of aggregate deposits in the region is partially due to the fact that many are buried by a thick clay-rich till blanket and many have subtle surface expressions. In addition, ground based exploration techniques are costly in this vast area and the widespread forest cover and subdued topography make traditional geomorphological methods relatively ineffective. To address these problems, the program has applied a number of innovative techniques such as high resolution airborne electromagnetic surveys, LiDAR data analysis and interpretation, and digital compilation of large volumes of subsurface borehole and geophysical data.

The results of this work to date have led to the discovery of eight new major aggregate deposits, 25 new prospects and a large number of showings. Gravel from several of these deposits has been used extensively on a number of government supported road programs including construction of the new Clarke Lake Bypass Road, the SYD upgrade and on a number of PDR's within the MEM Royalty Credit Road Program including the Yoyo, Gunnell and Courvoisier roads.

Products from this program that were released in 2004/2005 include three papers in 2004 Summary of Activities and Geological Fieldwork and 14 posters and presentations at numerous conferences and meetings including the Canadian Society of Petroleum Geology, the Cordilleran Geology Round-up, the GeoTech Conference, and the Canadian Society of Unconventional Gas. In addition, the release of the details on the 2003/2004 KIM results led to diamond staking in six areas, the first such activity in northeast BC. A digital field station database, including data from over 1000 field sites, was also completed. Other products for the year include three new unpublished aggregate reports (for the Ft. Nelson Airport, Muskwa Heights, and Fontas Road discoveries), one new MOT-MEM aggregate potential evaluation (1:20 000 mapping for parts of 93 P and I), a completed digital reference library and a new aggregate web site

Figure 4. Close-up photo of the gravels and sands at the Kotcho East gravel pit. Note the crude bedding, large clast clusters, sharp changes in grain size distribution and localized oxidation. The gravels are interpreted to be a subglacial stream deposit (see text).

Figure 5. Close-up photo of the contact between gravels and the overlying diamict at the Kotcho East gravel pit. Note the white friable siltstone clast (about 5 cm long) in the diamict at right side of the photo. The diamict is interpreted as a basal meltout till (see text).

Figure 6. Overview of the landscape beside the Kotcho East gravel pit. The edge of the deposit as indicated by test pits and EM data approximately extends from left to right across the centre of the photo. Note the lack of topographic relief marking the edge of the buried deposit, even though the area has been cleared (seedlings are about a metre high). The dark area at right-centre is a soil stockpile.

(http://www.em.gov.bc.ca/subwebs/oilandgas/aggregates/aggregates.htm). Products expected in the 2005/2006 fiscal year include seven papers in the 2005 Summary of Activities (this volume), a paper in the Journal of Environmental and Engineering Geophysics, an interactive web based aggregate map, chip-sample logging for five 1:250,000 NTS sheets and a completed subsurface database containing over 8000 records.

ACKNOWLEDGMENTS

We acknowledge the contributions of numerous government agencies, private companies and universities that have participated in this collaborative program including: the Geological Survey of Canada, the Universities of Victoria and Simon Fraser, EnCana Corporation, Canadian Natural Resources Limited, Ledcor CMI Limited, the Alberta Geological Survey, Land and Water BC Inc., the BC ministries of Transportation and Forests, MEM Business Development Branch, Fugro Airborne Surveys and Bemex Consulting. A list of individual participants is provided by Ferbey *et al.* (2005, this volume).

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