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Highlights of recent research in the Bowser and Sustut basins project, British Columbia[1]

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Abstract: New research on energy resource potential of the Bowser and Sustut basins includes fieldwork in the central Bowser Basin, and a suite of energy-resource-related thematic studies. The new data and interpretations of thematic studies provide advances on a number of fronts. For example, new apatite fission-track thermochronology data are consistent with the regional levels of thermal maturation as defined by vitrinite-reflectance studies. The latter indicate highly variable thermal maturity. The northern Bowser Basin and western Sustut Basin are in the early oil to condensate-dry gas generation stage of thermal maturation, making these areas the most prospective for petroleum generation and preservation. New mapping in Bowser Lake area (NTS 104 A) significantly revises the distribution of lithofacies assemblages of the Bowser Lake Group strata, and has identified transitions between several units.

Résumé : De nouvelles recherches sur les ressources énergétiques potentielles dans les bassins de Bowser et de Sustut comprennent des travaux menés sur le terrain dans la partie centrale du bassin de Bowser et une série d'études thématiques sur les ressources énergétiques. Les nouvelles données et les interprétations issues des études thématiques permettent de réaliser des progrès dans un certain nombre de domaines. Par exemple, de nouvelles données de thermochronologie par traces de fission sur apatite sont compatibles avec les niveaux régionaux de maturation thermique établis lors d'études sur la réflectance de la vitrinite; ces niveaux indiquent une maturation thermique très variable. La partie nord du bassin de Bowser et la partie ouest du bassin de Sustut s'avèrent particulièrement propices à la formation et à la conservation du pétrole, car elles sont dans la phase précoce de génération de pétrole et de condensat-gaz sec de la maturation thermique. La nouvelle cartographie de la région du lac Bowser (SNRC 104 A) a permis de modifier de façon significative la répartition des assemblages de lithofaciès des strates du Groupe de Bowser Lake et de reconnaître des transitions entre plusieurs unités.

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[1] Contribution to the Northern Resources Development Program

INTRODUCTION

Project overview

The project 'Integrated Petroleum Resource Potential and Geoscience Studies of the Bowser and Sustut Basins' is a collaboration of the British Columbia Ministry of Energy and Mines (BCMEM) and the Geological Survey of Canada (GSC), Natural Resources Canada. The project addresses goals of the Northern Resources Development Program, Natural Resources Canada, by providing improved geoscience data and knowledge to spark new private-sector investment. Prior to this study many aspects of the geoscience framework of the basins relevant to resource potential were poorly known or unknown. It is essential to re-evaluate resource estimates (P. Hannigan, P.J. Lee, and K.G. Osadetz, internal report prepared for British Columbia Energy, Mines and Petroleum Resources, 1995) by determining if the physical environment and the temporal relationships among hydrocarbon generation, migration, entrapment, and preservation are conducive to the existence of a substantial petroleum resource. Integration of data and models of energy-resource studies with improved stratigraphic and structural frameworks provide more robust petroleum resource assessments. The degree to which new data can provide a leap in understanding is illustrated in a previous GSC-BCMEM collaboration (Evenchick et al., 2002) which demonstrated that, contrary to previous views, parts of the Bowser and Sustut basins, including the lowest stratigraphic levels, have sufficiently low organic maturity levels for the formation and preservation of a significant petroleum resource.

The project is multidisciplinary in scope and covers the extent of the Bowser and Sustut basins (Fig. 1). Primary activities include improving the geological framework (through a range of stratigraphic, structural, and thematic studies) and conducting energy-resource studies and resource assessment. This paper reports on new fieldwork in the central Bowser Basin and ongoing research. Ferri et al. (in press) and Smith and Mustard (in press) present results of new fieldwork in the south-central Bowser Basin. Overviews of the regional geological framework and context of the project are presented elsewhere (e.g. Evenchick et al., 2003; Evenchick and Thorkelson, 2005).

New research in 2004

The collection, management, interpretation, and dissemination of new, and greatly enlarged, data sets pertinent to energy resources are fundamental activities of this project. In 2004 these included: thermal maturity, organic petrography and diagenesis, characterization of effective petroleum systems, apatite fission-track thermochronology, paleomagnetism, lithogeochemistry, isotopic systems, rock magnetic susceptibility and density, seismic data, and paleontology. Preliminary results of many of these are presented below. New publications include the first pan-basin compilation map (Evenchick et al., 2004a), magnetic susceptibility and density data for Bowser Lake and Sustut Group rocks (Lowe et al., 2004), new thermal maturity data (Evenchick et al., 2004b), and reports on petroleum systems (Osadetz et al., 2004) and thermochronology (O'Sullivan et al., 2005).

New mapping focused on the central Bowser Basin. The previous geological map of Bowser Lake map area (NTS 104 A) was based on one month of fieldwork during the initial stages of understanding the stratigraphic framework (Evenchick et al., 2000). It has large areas of undivided Bowser Lake Group, and recent work in the map area to the east indicated that improvements could be made to its eastern boundary.

PRELIMINARY RESULTS OF NEW MAPPING IN THE CENTRAL BOWSER BASIN–BOWSER LAKE MAP AREA (NTS 104 A)

The Bowser Lake Group is the sedimentary fill of the Bowser Basin. It ranges from late Middle Jurassic to Early Cretaceous and includes strata deposited in distal submarine fan, slope, shallow-marine shelf, deltaic, fluvial, and lacustrine environments (e.g. Evenchick et al., 2001, and references therein). Strata are divided into lithofacies assemblages based on groups of criteria such as nature of cyclicity, types of fossils (not ages), and suites of sedimentary structures (e.g. Evenchick and Thorkelson, 2005). With the reconnaissance map as a guide, goals of new fieldwork were to determine the lithofacies assemblage for areas of undivided Bowser Lake Group and to identify and follow contacts between assemblages.

Major changes to the reconnaissance map

Figure 2 is a preliminary compilation of new fieldwork. Large-scale features of the map that have not changed with new work include the wide belt of Ritchie-Alger assemblage on the west side of the Bowser Basin, the large belt of Muskaboo Creek assemblage farther east of this that thins northward, and the presence of Groundhog-Gunanoot assemblage in the northeast (Fig. 2). Significant changes are: the addition of a belt of Ritchie-Alger assemblage continuous with the unit mapped in McConnell Creek area (Evenchick et al., 2003), addition of Jenkins Creek assemblage between Nass River and Muskaboo Creek, and broader distribution of the Groundhog-Gunanoot assemblage.

An important advance was the recognition of transitions between units. The boundary between Muskaboo Creek and Ritchie-Alger assemblages, where observed, appears to be a section dominated by massive to poorly stratified siltstone. Although only observed on a few ridges, this new (unnamed) unit appears to be transitional from the shallow-marine sandstone-dominated Muskaboo Creek assemblage (with common sedimentary structures indicating wave reworking of sands) to deeper marine, submarine-fan turbidite sandstone and siltstone units of typical Ritchie-Alger assemblage. This transition appears to be tens of metres to at most a few hundreds of metres thick and most commonly comprises massive to poorly laminated siltstone containing less than 10% fine- to very fine-grained sandstone laminations or thin beds.

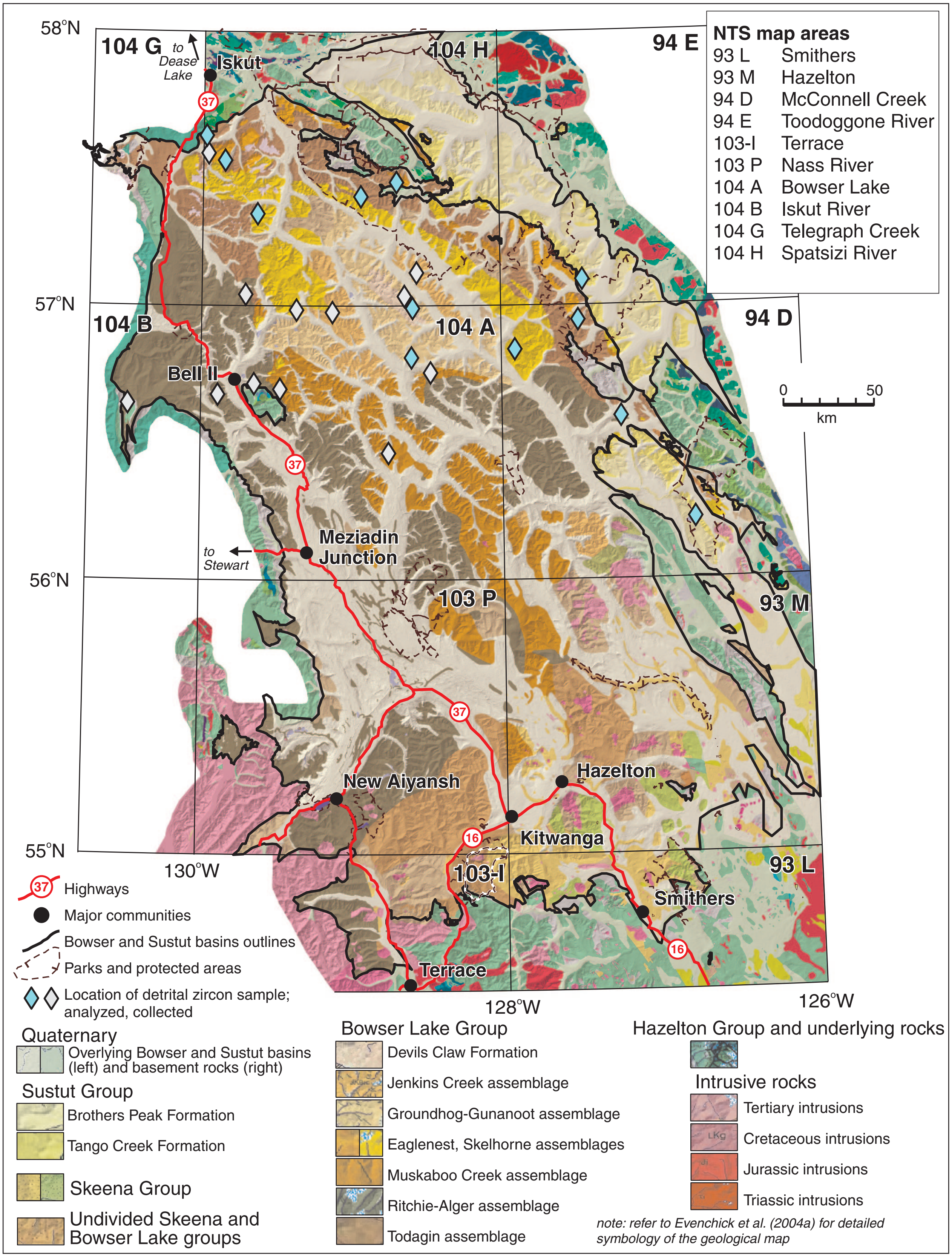

*Figure 1. Geological compilation of the Bowser and Sustut basins on shaded relief map (*modified from *Evenchick et al., 2004a), with locations of detrital zircon samples.*

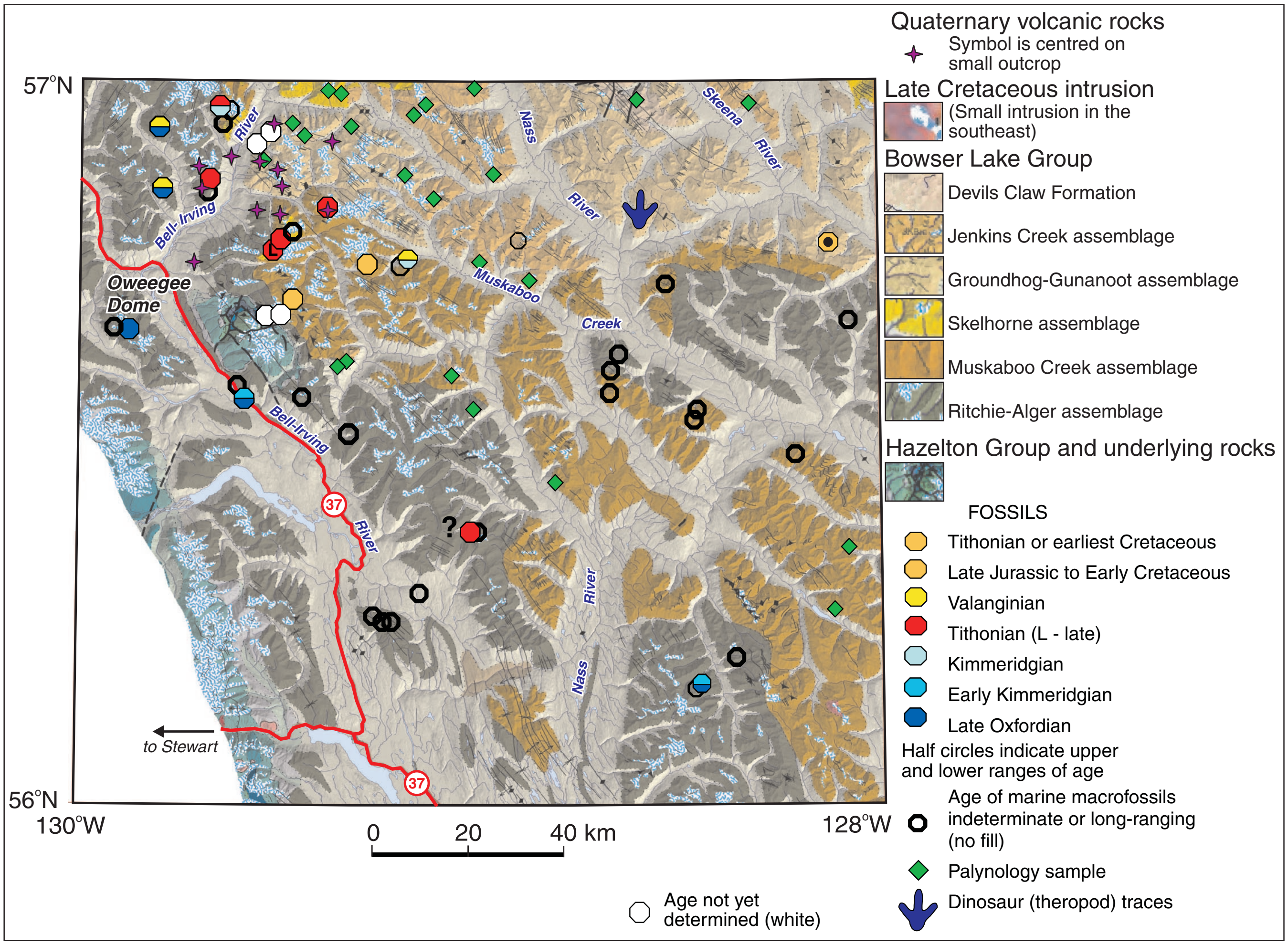

Figure 2. Preliminary compilation of the geology of NTS 104 A, with locations and ages of new fossil collections.

Sandstone rarely contains minor wave ripples or other evidence of slight current reworking. This appears to be a unit deposited in a deep (below storm-wavebase) outer shelf environment.

The transition between Skelhorne and Jenkins Creek assemblages was mapped near the north-central boundary of the map area. There, a well organized and repeated coarsening-upward succession tens of metres thick of mudstone (containing marine and trace fossils) to sandstone and minor conglomerate (both commonly containing planar and trough crossbedding) of typical Skelhorne assemblage deltaic lobes (Fig. 3) changes upward to increasing thick mudstone-siltstone successions with sandstone lenses (Fig. 4). The latter comprises minor fining-upward successions of sandstone that contain fluvial features (slightly erosive channellized bases, internal crossbedding, etc.) which fine up over a few metres to, and laterally are contained within, siltstone-mudstone facies. The latter contain common plant detritus and rare in situ rootlets, local carbonaceous mudstone, and rare orange-weathering paleosol horizons. The authors interpret this as a transition from river-dominated deltaic lobes (Skelhorne assemblage) to a nonmarine, upper delta-plain and fluvial floodplain (Jenkins Creek assemblage).

Other changes in understanding of the units includes recognition of thick sections of Muskaboo Creek assemblage in the central part of the Bowser Lake map area. In this area it may be up to 2 km thick (although some structural repetition exists) and is dominated by well sorted, fine- to medium-grained sandstone that shows sedimentary structures typical of repeated successions of all shoreface environments, including common examples of hummocky, swaley, and trough cross-stratification (Fig. 5); many types of heterolithic bedding structures (with classic and well developed flaser and lenticular structures; Fig. 6); and several bivalve coquina beds up to 30 cm thick (both reworked and in situ examples). The thickness and extent of the shallow marine 'clean' sandstone of the Muskaboo Creek assemblage is encouraging in terms of reservoir potential.

A siltstone-mudstone-dominant subunit was recognized locally within and transitional to characteristic Ritchie-Alger assemblage. Where present this unit comprises more than 80% massive to faintly laminated silt-rich mudstone with less than 20% thin interbeds of fine- to very fine-grained sandstone. The latter appear to have originated as distal sand turbidite units (comprising Bouma DE, very rarely CDE intervals), suggesting that the succession represents the distal

Figure 3. Coarsening-upward cycles typical of the Skelhorne assemblage, west of Bell-Irving River. The most resistant sheets are conglomerate. Thickness of section is about 50 m.

Figure 4. Contact between the Skelhorne and Jenkins Creek assemblages. Upper Skelhorne assemblage is dominated by coarsening-upward siltstone to sandstone successions a few tens of metres thick capped by thick bedsets of crossbedded sandstone to pebbly sandstone. These transition upward to siltstone and sandstone of Jenkins Creek assemblage. The contact is at the top of the highest major coarsening-upward succession (at base of snowpatch in the centre of photograph). Thickness of resistant sheet below snowpatch is about 15 m.

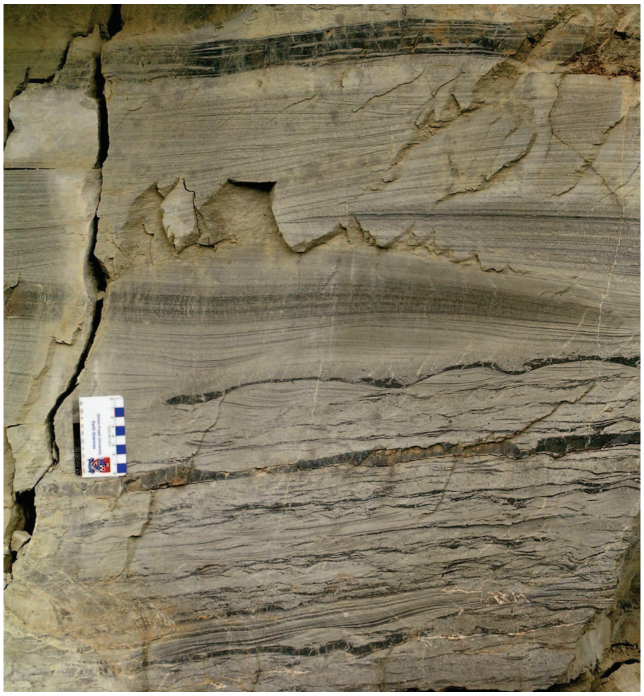

Figure 5. Muskaboo Creek assemblage sandstone and minor mudstone, displaying various heterolithic bedding-lamination structures in lower part (flaser bedding- and wavy bedding-dominated) changing upward to sandstone dominated by hummocky and swaley cross-stratification.

Figure 6. Rippled and lenticular stratification in the Muskaboo Creek assemblage, southeast NTS 104 A.

fan to off-fan depositional environments that change laterally and upward into more typical Ritchie-Alger assemblage, containing common (>50%) repeated sandstone beds spanning hundreds of metres (to a few thousand metres) of repeating successions and representing classical sand-rich turbidite deposits laid down in major overlapping fan complexes (e.g. Fig. 7).

Stratigraphic issues to resolve

The distribution of map units will be improved by resolving two issues. One is the affiliation of thick siltstone sections described above that have been included in the Ritchie-Alger assemblage or the Muskaboo Creek assemblage. Consideration of the sedimentary structures in each section will assist in assessing their regional extent and distinctiveness in order to determine whether they can be recognized as new map units or whether they should be regarded as local 'subunits' (the equivalent of members in formal lithostratigraphic hierarchy of formations). The second stratigraphic issue is how to treat sections with elements common amongst the Jenkins Creek, Groundhog-Gunanoot, and Skelhorne assemblages. It is increasingly apparent as lateral and vertical relationships are discovered that they are mutually transitional to each other and thus difficult to distinguish in transitional areas. They appear to represent slightly to significantly different types of river-dominated deltaic complexes (Skelhorne and parts of Groundhog-Gunaroot assemblages) with the Jenkins Creek assemblage as a common coastal floodplain–upper delta-plain succession. The difficulty of distinguishing parts of these units reflects the similarity of many aspects of their depositional environments. It remains a challenge to develop a set of criteria that will allow consistent classification of strata transitional between the 'classical' end members of the assemblages.

Map pattern around Oweegee Dome

The reconnaissance map (Evenchick et al., 2000) showed that the Ritchie-Alger assemblage, up to 4 km thick and widespread in the western Bowser Basin, is very thin northeast of Oweegee Dome. New mapping (Fig. 2) suggests that the unit is probably even thinner than previously depicted, with Muskaboo Creek strata within a few hundred meters of upper Hazelton Group rocks. The latter shows indications of lateral facies variations, and includes local units of carbonate boundstone. This region may represent part of a paleoarch or horst, that existed during early stages of basin development.

Quaternary volcanic rocks

New outcrops of volcanic rocks overlying Bowser Lake Group are part of a cluster of erosional remnants previously assigned to the Pliocene Maitland Volcanics. (Fig. 2). Interpretation of outcrop features as subglacial in origin (B. Edwards, pers. comm., 2004) as well as a preliminary Ar-Ar age (V. McNicoll, unpub. data, 2005) are the basis for assigning them to the Pleistocene.

Structure

Strata of the Bowser Basin and underlying basement (Stikinia) are folded and thrust faulted. Structures define the Cretaceous (to (?) earliest Tertiary) Skeena Fold Belt (Evenchick, 1991). The dominant structures regionally are northeast-vergent, open to close folds of about 100–1000 m wavelengths. Larger wavelength folds are spatially associated with competent volcanic rocks of Stikinia and locally with competent, thick conglomerate sheets. Although the dominant fold trend is northwest, domains of northeast trends occur on the west side of the fold belt.

Bowser Lake Group in the study area is fold-dominated, with wavelengths typically less than 1 km. Longer wavelength folds occur in competent conglomerate of the Devils Claw Formation, above competent Lower Jurassic (and lower) rocks at Oweegee Dome, and in the Ritchie-Alger assemblage southeast of Oweegee Dome (Fig. 7). Most folds in the Bowser Lake Group are open to tight, upright to moderately inclined (Fig. 8), commonly conical, disharmonic, detachment or faulted detachment folds. Transported detachment

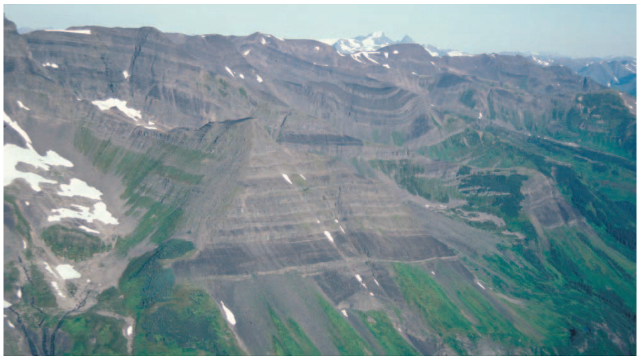

Figure 7. *View northwest to Ritchie-Alger assemblage on east limb of large, open fold southeast of Oweegee Dome. Light coloured intervals are dominated by medium-grained sandstone; dark intervals are dominated by very fine-grained sandstone and siltstone. Height of cliff in foreground is about 500 m.*

Figure 8. *View southeast to tight folds in Groundhog-Gunanoot assemblage near the head of Muskaboo Creek. Width of view is about 2 km.*

folds with high-angle hanging and footwall cutoffs are observed locally. Individual competent beds show no or minimal thickening in the hinge zones of even the tightest folds. Reverse faults have short strike length, small displacement, and many are related to faulted folds and disappear into bedding-parallel detachments or fault-propagation folds. Small displacement thrust faults may be associated with folds (e.g. Fig. 9), but those mappable at 1:50 000 scale are rare.

Northeast- and northwest-trending folds and faults occur in the northwest. Differing local relative timing relationships suggest these formed nearly synchronously. Cleavage is dominantly northwest- to north-trending. Northeast- to east-trending cleavage or crenulation cleavage occurs locally and indicates northwest as well as southwest compression. Constraints on the timing of deformation are rare. The post-tectonic Poison Pluton brackets compressive deformation in southeastern NTS 104 A to post-Jurassic and predating 84.1 ± 0.5 Ma (Evenchick and McNicoll, 1993).

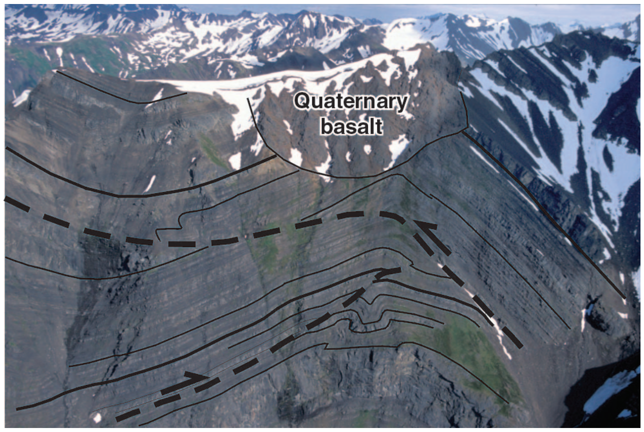

Figure 9. *View east-southeast to folds and related faults in fluvial strata north of Rochester Creek. Width of view is about 800 m.*

Figure 10. *Theropod track, Groundhog-Gunanoot assemblage.*

ONGOING THEMATIC STUDIES AND PRELIMINARY RESULTS OF SAMPLE SUITES COLLECTED IN 2004

Paleontology

The majority of preliminary ages of marine macrofossils collected in 2004 are Late Jurassic, or latest Jurassic to earliest Cretaceous (Fig. 2). These results are consistent with the previous distribution of ages (Evenchick et al., 2001), and add data to large gaps. Dinosaur traces (tracks) and two fossil turtles were found in the Groundhog-Gunanoot assemblage east of Nass River (Fig. 2, 10). These are the first tracks known within the Cordilleran Intermontane basins.

Provenance

An investigation of the provenance of Bowser and Sustut basin strata utilizing isotopic studies was initiated in 2003, and continued in 2004. The approach has been to analyze sandstone samples from strata the age of which is well constrained paleontologically, and from diverse geography, map units, and ages (Fig. 1). Preliminary conclusions, based on over 600 U-Pb SHRIMP analyses of detrital zircons from 12 sandstone samples of Bowser Lake and Sustut groups, show that Bowser Basin sources are distinct well into the Early Cretaceous from the younger Sustut Basin sources. This method provides an important new tool for constraining the ages of units that lack fossils in the area.

Thermal maturity

A subset of new outcrop samples for vitrinite- and bitumen-reflectance analysis (164 from NTS 104 A, 93 M, and adjacent areas) will supplement the maturity database (more than 1800 reflectance analyses from more than 900 samples; Stasiuk et al. (2005)).

Thermal maturity in the basins is highly variable, with random vitrinite reflectance in oil (%Ro_R) ranging from about 0.4 to more than 5.0. Middle and Late Jurassic Todagin and Skelhorne assemblages in the northern Bowser Basin and Late Cretaceous strata in a triangle zone in the western Sustut Basin, are dominated by values ranging from 0.6%Ro_R to 1.4%Ro_R. This is in the early oil to condensate–dry gas generation stage of thermal maturation, and these two regions are ranked as the most prospective for petroleum generation and preservation. Elsewhere, most Bowser Basin strata are within the dry-gas zone of petroleum generation and preservation, with the majority of the measurements between 1.6%Ro_R and 2.6%Ro_R. A broad area of the central and southern Bowser Basin is rated as having ‘low’ to ‘fair’ petroleum prospectivity (Stasiuk et al., 2005). Before a detailed interpretation of maturation patterns can be completed, greater integration with geology and other data are required as well as more research on the absolute timing of maturation and the burial and thermal history of the basin. Timing of petroleum generation in the basins is not presently known relative to structure-trap development, porosity development, and other critical elements. Constraints provided by vitrinite reflectance and organic petrology will contribute to an understanding of these issues.

Effective petroleum systems

A recent article on effective petroleum systems summarizes current knowledge (Osadetz et al., 2004). Crude oil occurrences are now known from wide geographic and geological settings in the Bowser and Sustut basins, and a biogenic methane gas seep is documented in the northwest. Crude oils extracted from Bowser Lake and Sustut Group rocks have molecular compositions indicative of at least three effective petroleum systems that have generated, expelled, and accumulated crude oil. One compositional family is inferred to be derived from carbonate source rocks in the succession below the Hazelton Group. A second family, with characteristics of normal Mesozoic marine sources is inferred to be derived from the upper Hazelton or lower Bowser Lake groups. A third oil family with Mesozoic lacustrine source characteristics is probably derived from nonmarine successions of the Bowser Lake Group.

Apatite fission-track thermochronology

The timing of hydrocarbon generation relative to the formation of structures affects petroleum play and prospect risks. Organic maturity provides a maximum recording geothermometer that indicates regions of probable petroleum generation, whereas apatite fission-track thermochronology (AFTT) provides an integrated thermal history for the period when samples last cooled from greater than about 110ºC to less than about 60ºC. Therefore AFTT provides potential constraints on the age of structures, at various scales that can be combined with petroleum system models to constrain play and prospect risks for petroleum accumulation. Thirty-one samples from the northeastern Bowser Basin and southwestern Sustut Basin have observed ‘pooled’ AFTT ages of between 51 Ma and 23 Ma, with most between 45 Ma and 35 Ma (O’Sullivan et al., 2005). Nine samples from a vertical profile through the Paleocene Motase Pluton, have ‘pooled’ ages between 44 Ma and 32 Ma. Six samples from the vicinity of the Groundhog-Klappan Coalfield have ‘pooled’ ages between 49 Ma and 35 Ma. These results are interpreted to record rapid cooling (from temperatures ≥100–110°C) at a time slightly before the value of the ‘pooled’ age beginning at various times in different parts of the basin. Rocks presently at the surface were within the zone of thermogenic petroleum generation until either Late Cretaceous (in the north and northeast) or at least Middle Eocene (the remainder of the region sampled) time. While some of the older AFTT ages in the northernmost basin and triangle zone may record the formation of Skeena Fold Belt structures, most of the samples appear to record a significant, rapid, regional epirogenic event that postdates Skeena Fold Belt structures.

Paleomagnetism

Paleomagnetic studies have been done on 55 sites within 30 km of Oweegee Dome, an area of relatively low thermal maturity with access to strata from Paleozoic units through the Late Jurassic (Bowser Lake Group). Polished thin-section observations reveal low-temperature (?<200°C), late diagenetic magnetite in most rocks, either along veins and shear lenses or as recrystallization of detrital grains. Paleomagnetism was used to date this diagenesis relative to tectonism, and absolutely by comparison to the apparent polar wander path.

Sites on Oweegee Dome and along Highway 37 consistently hold a magnetic remanence that fails the tilt test and was thus acquired after tectonic deformation. However, late tension veins containing randomly oriented wall-rock shards hold random magnetic remanence directions, proving that the magnetization predates this last tectonic event.

The mean direction ($D=285.1°$, $I=60.9°$, $k=38.6$, $\alpha_{95}=4.3°$, $N=30$ sites) has an exotic westerly declination, implying that the region rotated about 45° counter-clockwise following the acquisition of remanence. Inclinations are about 10° shallow compared to expected Tertiary directions or 20° shallow for expected Late Cretaceous directions. The Late Cretaceous age is preferred as it allows more time for the vertical axis rotation. An alternate, but less likely interpretation is that the region tilted about 25° westward.

North of Oweegee Dome, four sites from a syncline show syntilting magnetization. To the south, at Mount Ritchie, five sites from an anticline-syncline structure suggest that magnetic diagenesis occurred late during Skeena Fold Belt deformation. There is no evidence in this study of primary remanence. The remagnetizations are interpreted to be chemical remanent magnetizations that mark a pervasive Late Cretaceous (or (?) Early Tertiary) hydrothermal diagenesis that may record a period of hydrocarbon maturation and migration.

Lithogeochemistry and heavy-mineral studies

Major- and trace-element analysis has been carried out on 158 outcrop samples from the Bowser and Sustut basins with a view to characterizing and distinguishing map units, and interpreting sedimentary provenance. Heavy-mineral analysis was done on 30 sandstone samples. The samples were chosen from GSC collections; data and initial interpretations of results by Chemostrat Inc. were provided to the GSC by EnCana Corporation. First-order interpretations are that the Bowser Lake and Sustut groups are clearly distinct, consistent with hand specimen observation, petrographic examination, and isotopic studies. Chemical differences between assemblages of the Bowser Lake Group are more subtle.

Potential fields

Moderate- to high-intensity magnetic anomalies dominate east-central and northeastern NTS 104 A, whereas small-scale, high-intensity anomalies are common in the southwest, northwest, and southeast parts (Fig. 11). Small-scale magnetic

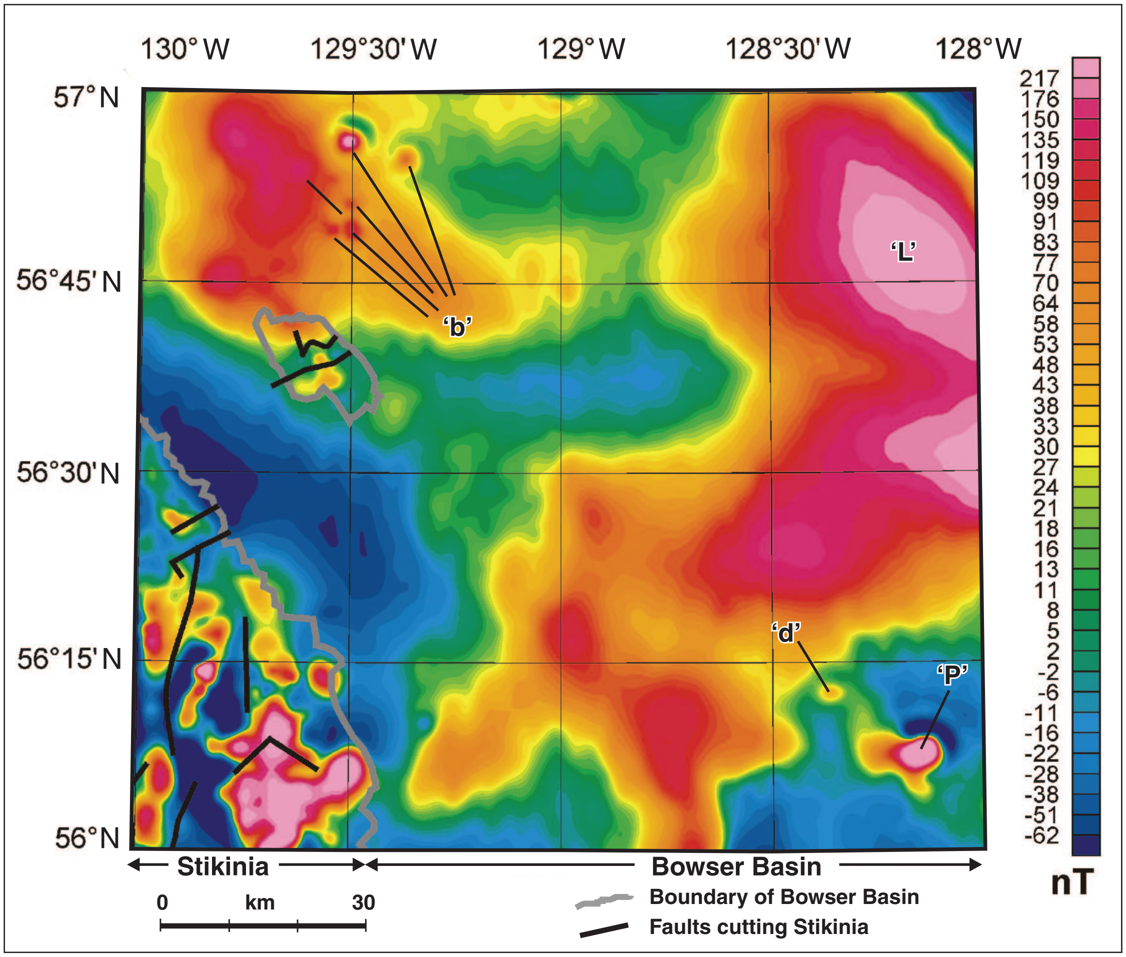

Figure 11. *Magnetic anomaly data (source: Natural Resources Canada). Anomalies 'b', 'd', 'P', and 'L' are discussed in the text.*

anomalies correlate well with the mapped bedrock geology. For example, six circular anomalies with diameters less than 6 km and peak magnetic intensities of 80–300 nT ('b' in Fig. 11) correspond with mapped Quaternary basalt. Magnetic susceptibility measurements confirm that the basalt samples have a substantially higher mean susceptibility than the Bowser Lake Group (Lowe et al., 2004). A similar anomaly ('d' in Fig. 10) is in an area with numerous felsic and mafic dykes.

A larger (12 km diameter), and higher intensity (573 nT), suboval magnetic anomaly ('P' in Fig. 11) correlates with the Cretaceous Poison Pluton. Magnetic susceptibility measurements on lithologically similar intrusions nearby yield a mean value more than three times higher than basalt (Lowe et al., 2004). The spatial extent of the anomaly indicates that the intrusion is considerably larger at depth than at surface and likely has lobes extending to the southeast and west.

Long-wavelength magnetic anomalies are underlain by the Bowser Lake Group and correlate poorly with bedrock geology. Although such anomalies may result from a shallowing of magnetic basement beneath the Bowser Lake Group (underlying rocks in Stikinia have significantly higher magnetic susceptibility; Lowe et al. (2004)), there is evidence that the large anomaly in the northeast ('L' in Fig. 11) may result from a large buried intrusion. The highest measured vitrinite-reflectance values of surface samples (Ro_{max} >5.5%) in Bowser Basin are restricted to the immediate vicinity of this anomaly (Evenchick et al., 2002). Forward magnetic modelling indicates that the observed anomaly is well matched assuming a highly magnetic source body (55 000 x 10^{-6} SI) that is about 52 km wide, up to 5.5 km thick, and has an upper surface approximately 4.5 km below surface. This scale of intrusion could account for the observed high coalification in the Groundhog Coalfield, and high vitrinite reflectance.

Interpretation of LITHOPROBE seismic data

In 1999 and 1997 seismic-reflection and -refraction surveys, respectively, were conducted along Highway 37 as part of the SNORCLE transect of the LITHOPROBE project. Data were collected and processed with the goal of imaging deep crustal structure. Line 2a of the seismic-reflection survey (Cook et al., 2004) and line 2 of the seismic-refraction survey (Hammer et al. 2000) transect the western Bowser Basin (Fig. 1, 2).

The long source-receiver offsets used in the SNORCLE surveys provide excellent opportunity for tomographic inversion for near-surface rock properties such as seismic wave speeds. The approximately 15 km offsets provide depth penetration of 1.5–2.5 km, depending on rock types, with resolution of about 100 m. Tomographic (wave-speed) velocity models were produced for the part of the SNORCLE line 2a in the current study area. The models show a distinctive increase in seismic velocity at the inferred contact between the turbidite units of the Ritchie-Alger assemblage and the underlying volcanic rocks of the Hazelton Group. Just south of Oweegee Dome, the Ritchie-Alger assemblage is especially thick and shows little internal structure on the velocity models. In the northwest part of the Bowser Basin, distinct, higher velocity layers are observed higher in the Bowser Basin sequence and may indicate variations in primary stratigraphy, later mafic intrusions, or structural imbrication.

Outreach activities

Outreach is focused on three related initiatives: an 'Earth Energy in Northern BC' educational program, a Geoscape highway map for northern British Columbia, and community guides. The Earth Energy Educational Program discusses hydrocarbon and coal resources in northern British Columbia through illustrations, classroom activities, and teacher resources. It is a partnership with The Exploration Place, a science centre in Prince George, and targets Grade 5 teachers and students, as well as other grades. Two teacher workshops have been held in Prince George to test the content.

The Geoscape highway map for northern British Columbia utilizes the *Geoscape Canada* map of Canada's earth materials in combination with photographs and illustrations of geological points of interest. The map combines bedrock and surficial geological units, defined on the basis of lithology. Its purpose is to highlight and provide explanation for a variety of important landscape features (e.g. mountains, lakes, glaciers, rivers, terraces), geological features (e.g. hotsprings, lava flows), and resources (e.g. mines, natural-gas plants, groundwater).

The third initiative is a series of community guidebooks and associated mini-posters that explore the dependence of communities on the land, using local examples. A prototype is being developed for Prince George, with guides planned for Smithers, Terrace, Hazelton and New Hazelton, and possibly other First Nations communities. Guides answer questions such as "Where does our water come from?", "Where does our gasoline and natural gas come from?", and "Where does our sewage go?". The Prince George guide profiles local gravel quarries, asphalt and concrete plants, local groundwater aquifer, wastewater treatment plant, landfill, and oil refinery. The goal of the guides is to connect the public to their local geological landscape and to promote "best sustainable practices".

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