Targeted Energy-Resource Studies in the Bowser and Sustut Interior Basins of British Columbia[1]

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INTRODUCTION

The Bowser and Sustut basins are interior basins of Jurassic and Cretaceous age in north-central British Columbia (Fig. 1). They have been underexplored in terms of hydrocarbon resources because of widespread misperceptions of their prospectivity, largely due to the reconnaissance nature of all geoscience work carried out there until recently. This two-year project focuses on specific, *detailed*, energy-resource studies complementary to an ongoing *regional* project that has been a collaboration between the Geological Survey of Canada (GSC) and the BC Ministry of Energy, Mines and Petroleum Resources (BCMEMPR; Evenchick *et al.*, 2005). The project includes three elements of research and compilation: apatite fission-track thermochronology (AFTT) of the southern basins; detailed study of the early history and structural development of the Bowser Basin; and data management, integration and digital publication. The sample analysis and interpretation of AFTT data are critical to understanding petroleum systems in sedimentary basins, which is an essential element of a geoscience-resource framework on which to base sound exploration decisions. Mapping in targeted areas will provide detailed field data on the important early history and geometry of the basin. Data management, integration and publication are critical because *communication* of data and interpretations are essential to attracting investment to the region. This paper outlines the three elements of this project, describing the nature of the work and its relationship to the broader GSC project. It also presents the status of the project. Details of work on the early Bowser Basin history are presented in a separate paper (Waldron et al., 2006).

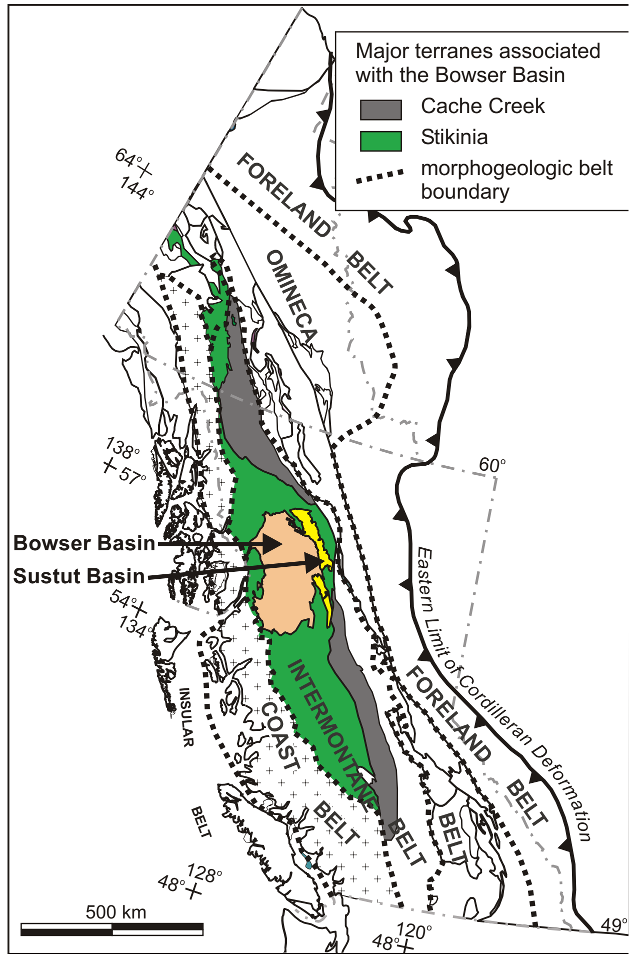

Figure 1. Location of the Bowser and Sustut basins (modified after Wheeler and McFeeley, 1991).

GEOLOGICAL AND HYDROCARBON-RESOURCE OVERVIEW OF THE BOWSER AND SUSTUT BASINS

The Bowser and Sustut basins underlie approximately 62 000 km^2 of north-central BC (Fig. 1) and are considered to be frontier hydrocarbon basins. Bowser Basin strata (the Bowser Lake Group) overlie volcanic and clastic rocks of the Early to early Middle Jurassic Hazelton Group. Bowser strata are late Middle Jurassic to mid-Cretaceous in age, and were deposited in a wide range of clastic sedimentary environments, from deep distal marine through slope, shelf, deltaic, fluvial and lacustrine (*e.g.*, Evenchick *et al.*, 2004). They contain minor carbonates and a huge volume

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This publication is also available, free of charge, as colour digital files in Adobe Acrobat PDF format from the BC Ministry of Energy, Mines and Petroleum Resources internet website at http://www.em.gov.bc.ca/Mining/Geolsurv/Publications/catalog/catfldwk.htm of dark grey siltstone and mudstone, all of which are potential source rocks. Bowser strata are overlain on the east by fluvial strata of the Upper Cretaceous Sustut Group. Most strata of the Bowser-Sustut region, except for parts of the northeastern margin of the Sustut Basin, were deformed by folds and thrust faults in the Cretaceous to form the thin-skinned Skeena fold belt (Evenchick, 1991). The style of deformation, which includes a classic triangle zone locally in the northeast, provides ample opportunities for structural traps of hydrocarbons.

The regional Bowser-Sustut project aims to provide basic regional geological and resource framework data and interpretations upon which to base more informed exploration decisions. Overviews of the regional geological framework and context of the project are presented elsewhere (*e.g.*, Evenchick *et al.*, 2003; Evenchick and Thorkelson, 2005). Fieldwork over the past three field seasons has contributed to significant refinements of the distribution of map units across the central and southern basin. Early results of regional energy-resource studies show that the basin is not entirely overmature (Evenchick *et al.*, 2002) and that there are at least three effective petroleum systems that at some point have generated, expelled and accumulated crude oil (Osadetz *et al.*, 2004). Hydrocarbon source rocks identified are a sub-Hazelton carbonate, upper Hazelton or lower Bowser marine strata and Mesozoic lacustrine strata. Recent results (Stasiuk *et al.*, 2005) indicate that the most prospective parts of the basins (in the early oil to condensate – dry gas generation stage of thermal maturation) are in the northwestern Bowser Basin and an elongate belt in the east, overlapping the Sustut Basin and eastern Bowser Basin. Energy-resource studies now need to focus on specifics of timing of petroleum generation and migration, and peak temperatures. The analytical parts of the current (Geoscience BC) project will address these through apatite fission-track thermochronology. Following up on the 2004 regional mapping, one element of this work is a detailed field examination of the early history of the Bowser Basin, which includes an interval known locally to include organic-rich shale (Thomson *et al.*, 1986).

REGIONAL BOWSER-SUSTUT PROJECT — CONTEXT FOR THE COMPLEMENTARY TARGETED ENERGY-RESOURCE STUDIES OF THIS PROJECT

The 'Integrated Petroleum Resource Potential and Geoscience Studies of the Bowser and Sustut Basins' project (referred to hereafter as the Bowser-Sustut project) is a project of the GSC's Northern Resources Development program. It started in 2003 as a collaboration between the GSC and BCMEMPR Oil and Gas Division. The primary goal of the four-year Bowser-Sustut project is to provide improved geoscience data and knowledge regarding energy resources of the Bowser and Sustut basins, in order to spark new private-sector investment. It is regional in scope, covering the breadth of the Bowser and Sustut basins. The final of many project deliverables (several of which are completed) will be a digital basin atlas, including resource assessment. The project has involved twenty-two GSC scientists and technicians; one BCMEMPR scientist (Fil Ferri); and one faculty member (Peter Mustard) and one graduate student from Simon Fraser University. This new targeted project includes one outside consultant (Paul O'Sullivan), and one faculty member (John Waldron) and two graduate students from the University of Alberta, following scoping of topics as part of the 2004 Bowser-Sustut field program. Geological Survey of Canada scientists involved in the project include specialists in a wide suite of geoscience and energy-resource studies that are all aimed at an integrated understanding of energy resources of the basins (*e.g.*, biostratigraphy, paleomagnetism, geophysics, geochronology, structural geology, basin stratigraphy, organic petrology, thermal maturity, petroleum systems, resource assessment). These are complemented by a small team dedicated to cartography, graphics, database management, information management, website creation and maintenance, development of tools for capturing field data digitally and integrating digital data for publication, and outreach. The latter group is highlighted because rapid and broad communication of results is essential in order to have the desired impacts; therefore, it is necessary to have staff dedicated to the manipulation and management of data and production of manuscripts and maps.

TARGETED ENERGY-RESOURCE STUDIES COMPLEMENTARY TO THE REGIONAL BOWSER-SUSTUT PROJECT

Apatite Fission-Track Thermochronology

The timing of hydrocarbon generation relative to the formation of structures affects petroleum-play and prospect-level 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 approximately >110°C to approximately <60°C. 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. Preliminary results of samples from parts of the northern Bowser and Sustut basins have indicated that 'pooled' AFTT ages range primarily between 45 and 35 Ma (O'Sullivan *et al.*, 2005). Results are interpreted to record rapid cooling (from temperatures greater than 100–110°C) at a time slightly before the value of the reported AFTT 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). Therefore, most of the samples appear to record a rapid regional event that postdates Skeena fold belt structures, highlighting the potential for structural traps in those areas.

All AFTT samples analyzed to date (O'Sullivan *et al.*, 2005) are from the northern two-thirds of the Bowser and Sustut basins (Fig. 2). These samples were collected and analyzed under a research agreement in 2002 between GSC and the BCMEMPR. New sampling in the southern basin, undertaken during this targeted project, was conducted in concert with mapping by the broader Bowser-Sustut project and addresses the following issues:

- A vertical profile in a high-relief Cretaceous intrusion will establish a well-constrained geothermal gradient for

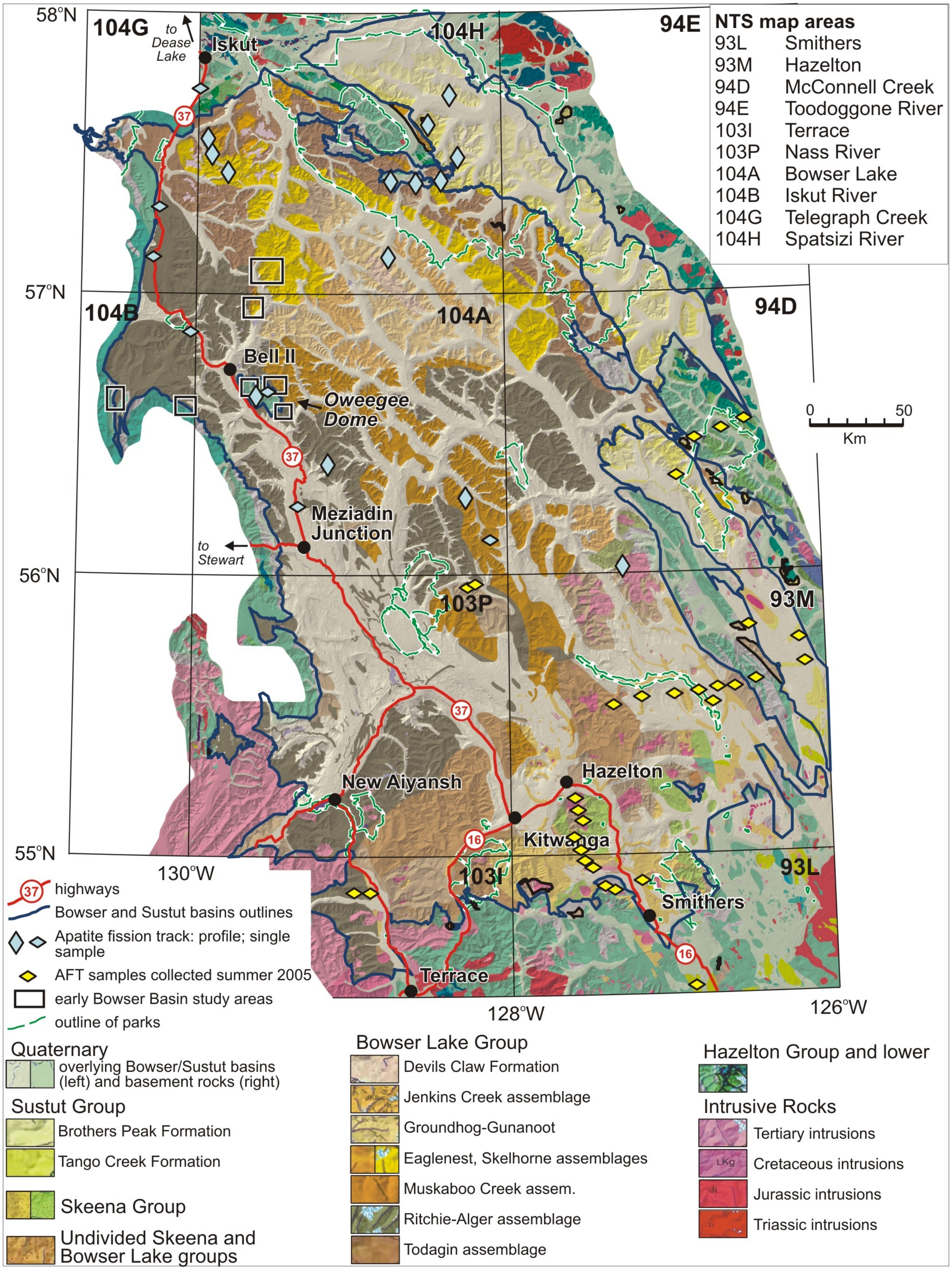

Figure 2. Geological compilation of the Bowser and Sustut basins on shaded-relief map (modified after Evenchick *et al.*, 2004), showing locations of detrital zircon samples collected in previous work and this work, and areas for field studies of the early history of the Bowser Basin.

- the southern basin region, which will enhance thermal history modelling of other samples.
- Current geological maps of the southeastern Bowser Basin (*e.g.*, Richards, 1990) display a rectilinear pattern of normal faults. This interpretation is based on the presence of young rocks in valleys and a model of Tertiary extension. However, the faults are poorly exposed and alternatives exist to explain the map pattern. Results from AFTT, when combined with mapping, can elucidate the nature and significance of the faults by placing constraints on their timing and magnitude of displacement. This is important for petroleum exploration because the map pattern could be interpreted as resulting from fold-and-thrust-belt structures similar to those farther north. The geometric difference between the two interpretations is fundamental to any attempt to extrapolate structures and units to depth. Therefore, the resolution of the dominant structural style is an issue critical for petroleum assessment and planning geophysical surveys or drill programs. Mapping in 2004 in the western part of NTS 093M (Hazelton map area; Ferri *et al.*, 2005) suggested that several faults shown on the previous map (Richards, 1990) are not required by the distribution of map units.
- AFTT results from Tertiary units will provide a thermal history for a younger period than existing samples, extending into the period of inferred rapid cooling for farther north.
- AFTT results from samples collected from the southern Sustut Basin will be used to compare and contrast with those previously collected from the northern basin, and to determine when rocks in the southern Sustut Basin were within the temperature range for generating petroleum.

After initial stages of data and information are released as they become available, a final report will integrate these new data with other pertinent datasets.

STATUS OF RESEARCH

During the 2005 field season, 29 samples were collected to cover the targeted issues listed above. The location of new samples is shown in Figure 2. The samples were shipped to the laboratory in September and will be processed and analyzed. Initial data release is anticipated for the spring 2006. Field observations indicate that fold-and-thrust-belt structures are common in the southeastern Bowser Basin and affect strata below the Bowser Lake Group, all units of the Bowser Lake Group, the Skeena Group and the Sustut Group. The degree to which the present structural relief is a result of normal faults rather than contractional structures will be addressed with further analysis of the field data, and its integration with apatite fission-track thermochronology.

Early Bowser Basin History and Structural Analysis

A field study led by John Waldron (University of Alberta) focuses on potential source rocks and structures in the transition from a volcanic-dominated rifted-arc environment (Hazelton Group) to a sedimentary basin (Bowser Lake Group). Reconnaissance in 2004 as part of the regional Bowser-Sustut project identified major lateral facies changes in this transition, in the northwestern part of the Bowser Basin (Oweegee Dome area; Fig. 2). In this area, volcanic and coarse volcaniclastic rocks of the lower Hazelton Group are separated by a conspicuous unconformity from laminated, thinly bedded siltstone of the upper Hazelton Group. The latter contain tuffaceous bands, occasional intercalations of bioclastic limestone and localized spectacular mound-facies limestone; it is unknown whether the mound-facies limestone represents *in situ* reefs or olistoliths that slid in from basin margins. The upper Hazelton rocks, including the limestone, are organic rich and may have acted as source rocks for petroleum during burial and deformation of the basin. To the east of Oweegee the Dome, work in 2004 under the regional Bowser-Sustut project demonstrated a shallowing in the lower Bowser Lake Group, with the deposition of bioturbated shelf clastic rocks. In contrast, other parts of the dome appear submerged in thick turbidite successions (Evenchick *et al.*, 2005). These observations indicate that Oweegee Dome may be founded on a primary feature of the basin floor, modified by later deformation.

Bowser strata around the Oweegee dome display a pattern of folding, locally with weak cleavage development, involving intersecting northwest and northeast-trending folds, producing structural domes and basins. Evenchick (2001) suggested that the transverse folds were related to strike-slip motion. Evidence for the relative timing of the two sets of folds is contradictory.

The objectives of the work are to,

- determine stratigraphic relationships in the Hazelton-Bowser transition, in order to understand the tectonic processes involved in the initiation of the basin and the role of the Upper Hazelton as a potential source rock; and
- determine the origin and relative timing of transverse structures responsible for domes and basins within the basin, with the aim of understanding their relationship to potential petroleum traps.

As an additional benefit, the work will provide an improved regional understanding of the stratigraphic interval that farther west is extensively mineralized and contains the Eskay Creek gold mine.

The work is being undertaken by two graduate students (W. Loogman and J.-F. Gagnon) under the supervision ofJohn Waldron. Gagnon is working on relationships in the Hazelton-Bowser transition, to define the rock types, lateral relationships and tectonic setting of the sedimentary rocks. Loogman is focusing on transverse structures and folds in the Bowser Lake Group. The work is field based and initially (summer of 2005) focused in the Oweegee area in the northwest Bowser Basin (Fig. 2). Work was also undertaken to determine target areas for 2006 fieldwork.

STATUS OF RESEARCH

Field work was completed successfully and is reported in a separate paper (Waldron *et al.*, 2006)

Digital Aspects of the Field-to-Publication Process

Critical links in the path from field observation to communication and publication of the data and interpretations include a wide range of digital and organizational work being carried out in parallel with the scientific work. This includes maintaining and upgrading an application for digital capture of field data (using handheld computers); managing data in the field; follow-up checking and cleaning of databases; rectification of aerial photographs used in the cartographic process; extracting data subsets for analysis and distribution; compiling archival data from previous field work in the region with current work; maintenance of the project website; creation of CDs of recent project presentations and results for distribution at major meetings; customization of specialized tools for integration, display and communication of thematic datasets for final compilation and release; sample curation and distribution of the various sample suites to labs; digital graphics for publications; and analysis of datasets. To emphasize the time involved in the publication process alone, the deliverables for the other elements of this targeted project for 2005-2006 will require 6 weeks. This work is fundamental to communicating results and putting new data and interpretations into the hands of explorationists for decision making.

STATUS OF WORK

The primary deliverable for this work is an open file release of digital field data on CD from all mapping seasons, to be completed in 2007. Work is progressing this year on data verification, capture of past field data and design of the format for the final synthesis.

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REFERENCES

Evenchick, C.A. (1991): Geometry, evolution, and tectonic framework of the Skeena Fold Belt, north-central British Columbia; *Tectonics*, Volume 10, pages 527–546.

Evenchick, C.A. (2001): Northeast-trending folds in the western Skeena Fold Belt, northern Canadian Cordillera: a record of Early Cretaceous sinistral plate convergence; *Journal of Structural Geology,* Volume 23, pages 1123–1140.

Evenchick, C.A., Ferri, F., Mustard, P.S., McMechan, M., Osadetz, K.G., Stasiuk, L., Wilson N.S.F., Enkin, R.J., Hadlari, T. and McNicoll, V.J. (2003): Recent results and activities of the Integrated Petroleum Resource Potential and Geoscience Studies of the Bowser and Sustut basins, British Columbia; *in* Current Research, *Geological Survey of Canada*, 2003-A13, 11 pages.

Evenchick, C.A., Ferri, F., Mustard, P.S., McMechan, M.E., Ritcey, D., McNicoll, V.J., Osadetz, K.G., O'Sullivan, P.B., Stasiuk, L.D., Wilson, N.S.F., Poulton, T.P., Lowe, C., Enkin, R.J., Waldron, J., Snyder, D.B., Turner, R.J.W., Nowlan, G. and Boddy, M. (2005): Highlights of recent research in the Bowser and Sustut basins project, British Columbia; *in* Current Research, *Geological Survey of Canada*, 2005-A1, 11 pages.

Evenchick, C.A., Hayes, M.C., Buddell, K.A and Osadetz, K.G. (2002): Vitrinite reflectance data and preliminary organic maturity model for the northern two-thirds of the Bowser and Sustut basins, north-central British Columbia; *Geological Survey of Canada* Open File 4343; *BC Ministry of Energy, Mines and Petroleum Resources,* Petroleum Geology Open File 2002-1.

Evenchick, C.A., Mustard, P.S., Woodsworth, G.J. and Ferri, F. (2004): Compilation of geology of Bowser and Sustut basins draped on shaded relief map, north-central British Columbia; *Geological Survey of Canada*, Open File 4638, scale 1:500 000.

Evenchick, C.A., Poulton, T.P., Tipper, H.W. and Braidek, I. (2001): Fossils and facies of the northern two-thirds of the Bowser Basin, northern British Columbia; *Geological Survey of Canada*, Open File 3956.

Evenchick, C.A. and Thorkelson, D.J. (2005): Geology of the Spatsizi River map area, north-central British Columbia; *Geological Survey of Canada*, Bulletin 577.

Ferri, F., Mustard, P.S., McMechan, M., Ritcey, D., Smith, G.T., Evenchick, C.A. and Boddy, M. (2005). Skeena and Bowser Lake Groups, West Half Hazelton Map Area (93M); *in* Summary of Activities 2005, *BC Ministry of Energy, Mines and Petroleum Resources*, pages 113–131.

Osadetz, K.G., Jiang, C., Evenchick, C.A., Ferri, F., Stasiuk, L.D., Wilson N.S.F. and Hayes, M. (2004): Sterane compositional traits of Bowser and Sustut basin crude oils: indications for three effective petroleum systems; *in* Summary of Activities 2004, *BC Ministry of Energy, Mines and Petroleum Resources*, pages 99–112.

O'Sullivan, P.B., Donelick, R.A., Osadetz, K.G., Evenchick, C.A., Ferri, F., Wilson, N.S.F. and Hayes, M. (2005): Apatite fission-track data from seventy-one Bowser and Sustut Basin rock samples; *Geological Survey of Canada* Open File Report 4840; *BC Ministry of Energy, Mines and Petroleum Resources*, Petroleum Geology Open File 2004-3.

Richards, T.A. (1990): Geology of Hazelton map area (93M); *Geological Survey of Canada*, Open File 2322.

Stasiuk, L.D., Evenchick, C.A., Osadetz, K.G., Ferri, F., Ritcey, D., Mustard, P.S. and McMechan M. (2005): Regional thermal maturation and petroleum stage assessment using vitrinite reflectance, Bowser and Sustut basins, north-central British Columbia, *Geological Survey of Canada* Open File 4945; *BC Ministry of Energy, Mines and Petroleum Resources*, Petroleum Geology Open File 2005-2.

Thomson, R.C., Smith, P.L. and Tipper, H.W. (1986): Lower to Middle Jurassic (Pliensbachian to Bajocian) stratigraphy of the northern Spatsizi area, north-central British Columbia; *Canadian Journal of Earth Sciences*, Volume 23, pages 1963–1973.

Waldron, J.W.F., Gagnon, J.-F., Loogman, W. and Evenchick, C.A. (2006): Initiation and deformation of the Jurassic–Cretaceous Bowser Basin: Implications for Hydrocarbon Exploration in North-Central British Columbia; *in* Geological Fieldwork 2005, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 2006-1 and *Geoscience BC*, Report 2006-1.

Wheeler, J.O. and McFeeley, P. (1991): Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America; *Geological Survey of Canada*, Map 1712A, scale 1:2 000 000.