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BRITISH COLUMBIA MINISTRY OF ENERGY AND MINES

PETROLEUM GEOLOGY OPEN FILE #2002-1

Vitrinite and bitumen reflectance data and preliminary organic maturity model for the northern two thirds of the Bowser and Sustut basins, north-central British Columbia

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C.A. Evenchick, M.C. Hayes, K.A. Buddell, and K.G. Osadetz

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INTRODUCTION

This open file presents interim results of a new collaborative project between the Geological Survey of Canada and the British Columbia Ministry of Energy and Mines. The purpose of the project is to provide new data and resource models relevant to the petroleum resource potential of the Bowser and Susut basins, and to use these to calculate improved petroleum resource assessments of these basins. Previous work identified a significant petroleum potential in this region while recognising that there are several poorly understood, but significant risks (Hannigan et al., 1995). These risks give rise to concerns about reservoir quality and petroleum accumulation and preservation. It is essential to re-evaluate existing resource estimates by considering new stratigraphic and tectonic models and determining if the physical environment, primarily temperature, and the temporal relationships among hydrocarbon generation, migration, entrapment and preservation, are conducive for the existence of a major undiscovered petroleum resource in this region. Comparing the thermal character and history of potential petroleum source rocks and associated strata in the Bowser Basin to the diagenetic and tectonic history of potential secondary migration pathways and reservoirs will facilitate identification of regions and strata most prospective for petroleum exploration. The integration of these data, models and interpretations into the updated stratigraphic and structural framework will improve petroleum resource assessments and assist explorers dedicated to the goal of transforming a significant, but unproven, potential into a robust and economical source of petroleum supply and regional employment.

The purpose of this interim report is to release thermal maturity and reflectance data of the northern two thirds of the Bowser and Sustut basins on a geological map base of the basins. Future work on the thermal maturity aspect of the project will: 1) include additional samples to fill large gaps in data; 2) incorporate previously published data sets; and 3) integrate and interpret these data in the context of the structural and thermal histories of the region.

LOCATION

The Bowser and Sustut basins are located in north-central British Columbia, between 55 N and 58 N, and occupy an area of more than 60,000 km^2 (Figure 1). They are in the Intermontane Belt

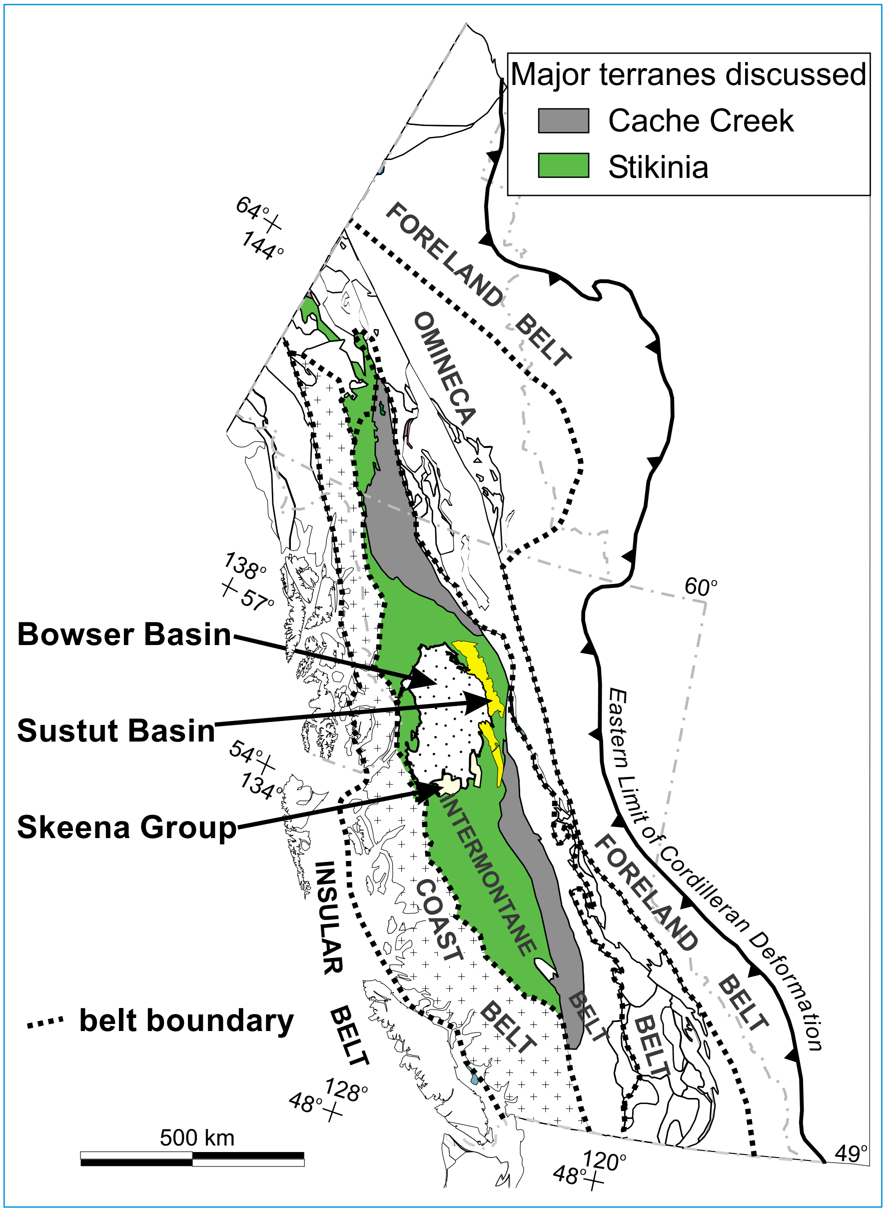


Figure 1. Terranes and morphogeologic belts of the Canadian Cordillera and location of the Bowser and Sustut basins. Modified after Wheeler and McFeely, 1991

of the Canadian Cordillera, a region of low metamorphic grade (mainly greenschist facies and lower) relative to the bounding metamorphic and plutonic Omineca and Coast belts (e.g. Read et al., 1991). They overlie Devonian to early Middle Jurassic strata of Stikinia. Stikinia is an allochthonous terrane that accreted to the western margin of North America in the Early Jurassic to early Middle Jurassic.

GEOLOGICAL SETTING

Regional Stratigraphic Framework

The region to be examined is underlain by three broad stratigraphic successions, in part overlapping in age.

Bowser Lake Group

The Bowser Lake Group is the oldest, and by far the most widespread succession. It ranges in age from late Middle Jurassic to mid-Cretaceous and includes strata deposited in environments ranging from distal submarine fan, to deltaic, to fluvial, and lacustrine (e.g. Tipper and Richards, 1976; Evenchick et al., 2001, and references therein). It was deposited directly on volcanic arc strata of Stikinia, and clasts were derived primarily from the oceanic Cache Creek terrane to the east, as a result of closure of the Cache Creek ocean and accretion of Stikinia to North America in the Middle Jurassic (e.g. Gabrielse, 1991; Ricketts et al., 1992). Syntheses of stratigraphic aspects of the Bowser Lake Group include those by Eisbacher (1974a; 1981), Tipper and Richards (1976), Bustin and Moffat (1983), Koo (1986), Moffat et al. (1988), Cookenboo and Bustin (1989), MacLeod and Hills (1990), Green (1992), Evenchick et al. (1992), Cookenboo (1993), Ricketts and Evenchick (1999), Evenchick (2000), Evenchick et al. (2000), Evenchick et al. (2001).

Skeena Group

The Skeena Group is Early Cretaceous to mid- Cretaceous age. It occurs south of the Bowser Basin, and its stratigraphic relationship to Bowser Lake Group is not entirely clear. Sediments were deposited in a range of marine to nonmarine environments, which locally included volcanic influence. Studies of the Skeena Group include those by Tipper and Richards (1976), Bassett and Kleinspehn (1997), and Haggart et al. (1998).

Sustut Group

The Sustut Group is mid-Cretaceous to latest Cretaceous age and occurs along the northeast side of the Bowser Basin. Sediments were deposited primarily in fluvial and lacustrine environments, with possibly minor marine influence. On the southwest side of the Sustut Basin strata overlie deformed Bowser Lake Group and Stikinia strata, and on the northeast side they overlie Stikinia strata. The Sustut Group was examined by Eisbacher (1974b) and Bustin and McKenzie (1989). Significant revisions to age of the Sustut Group based on analysis of palynomorphs by A.R. Sweet are presented by Evenchick et al. (2001).

Regional Structural Framework

Strata of all 3 successions, and underlying Stikinia, are folded and thrust faulted. These contractional structures define the Skeena Fold Belt, a thin skinned fold and thrust belt of Cretaceous age (Figure 2). The dominant structures are open to close folds of hundreds of metres to 1 km wavelengths (Figure 3). Larger wavelength folds are associated with structural culminations of competent volcanic rocks of Stikinia. The dominant fold trend is northwest, but domains of northeast trending structures occur locally on the west side of the fold belt. Large scale features of the fold belt are presented by Evenchick (1991a,b; 2001). Structural studies more restricted in space include those by Moffat and Bustin (1993), and Bone (2002).

PREVIOUS WORK - CONVENTIONAL PETROLEUM POTENTIAL ASSESSMENT

Method

Conventional petroleum potential in the Bowser Basin region was assessed using a probabilistic play-based volumetric method (Hannigan et al., 1995; Canadian Gas Potential Committee, 2001). The method (Lee, 1993) employs distributions of potential petroleum field parameters; these are combined to give a conditional petroleum accumulation size distribution. Individual reservoir parameter distributions are determined using, or constrained by, available data. Where data are missing estimates are made subjectively with reference to appropriate analogues. For example, field areas can be estimated by measuring the area of mapped structures. The largest mapped

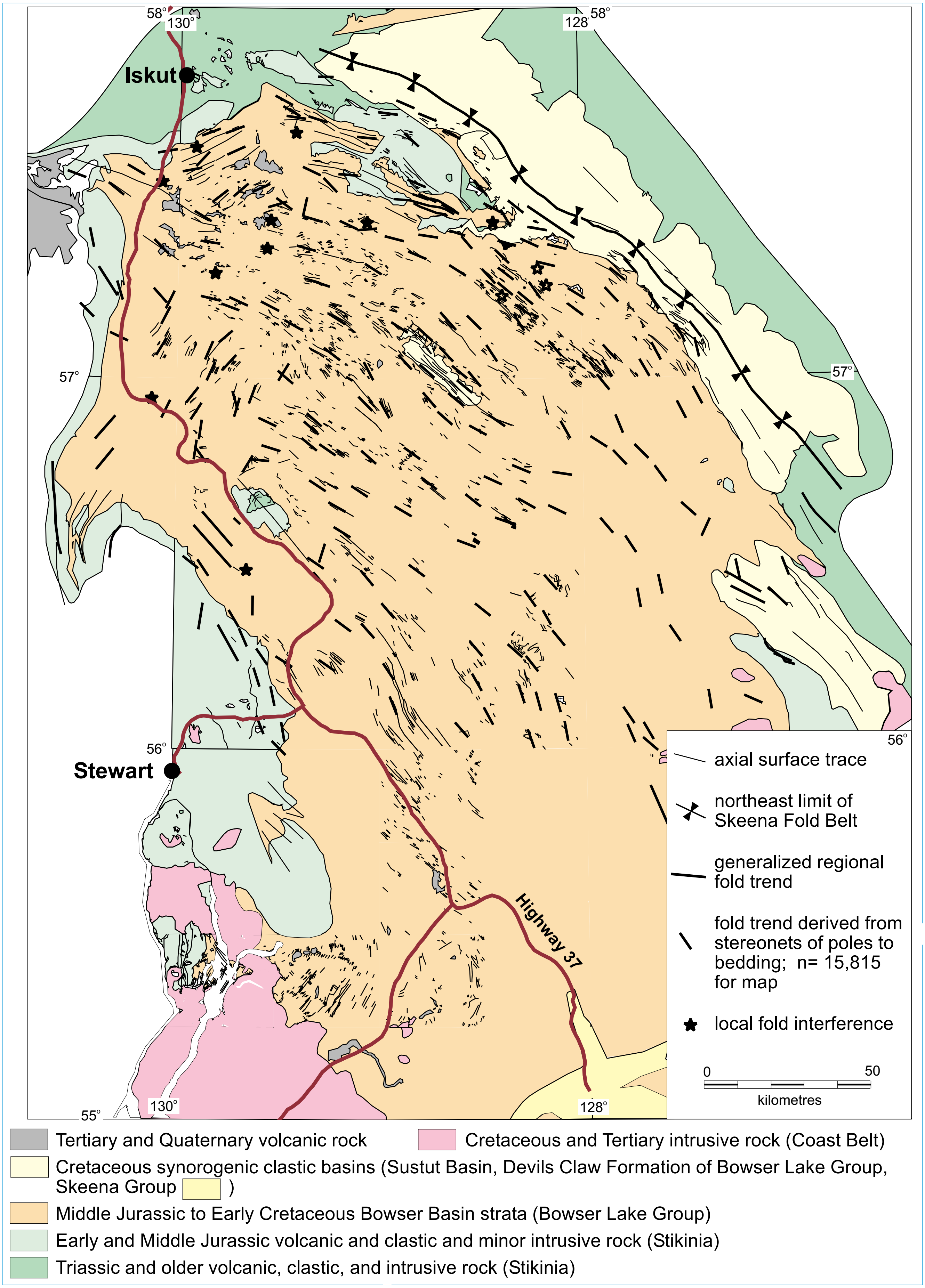
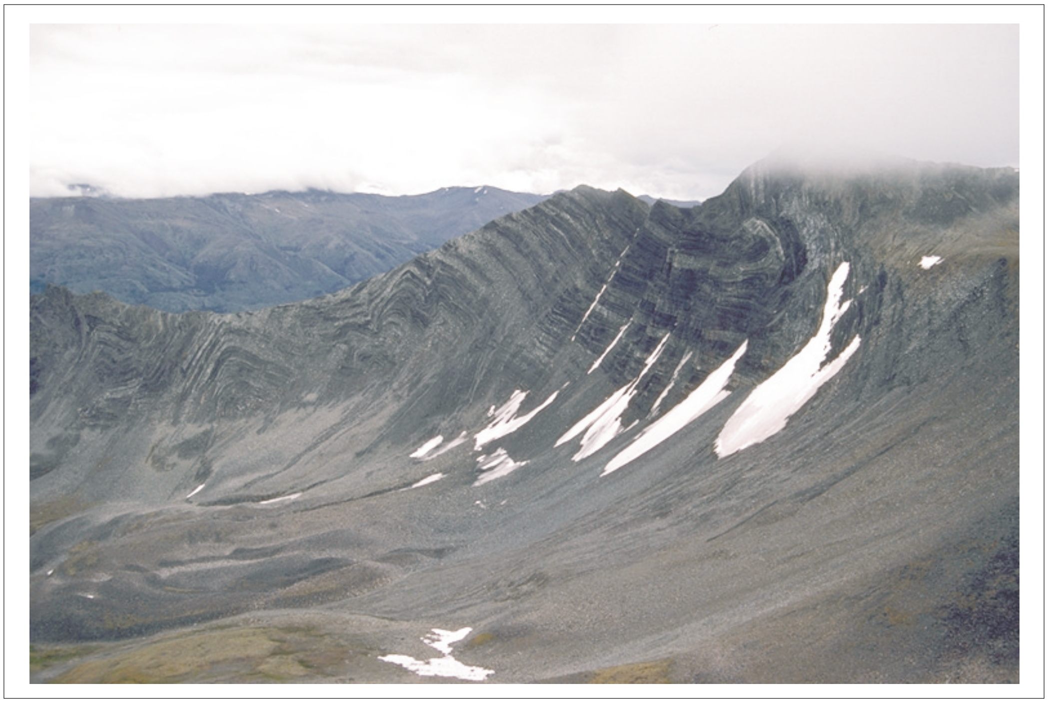
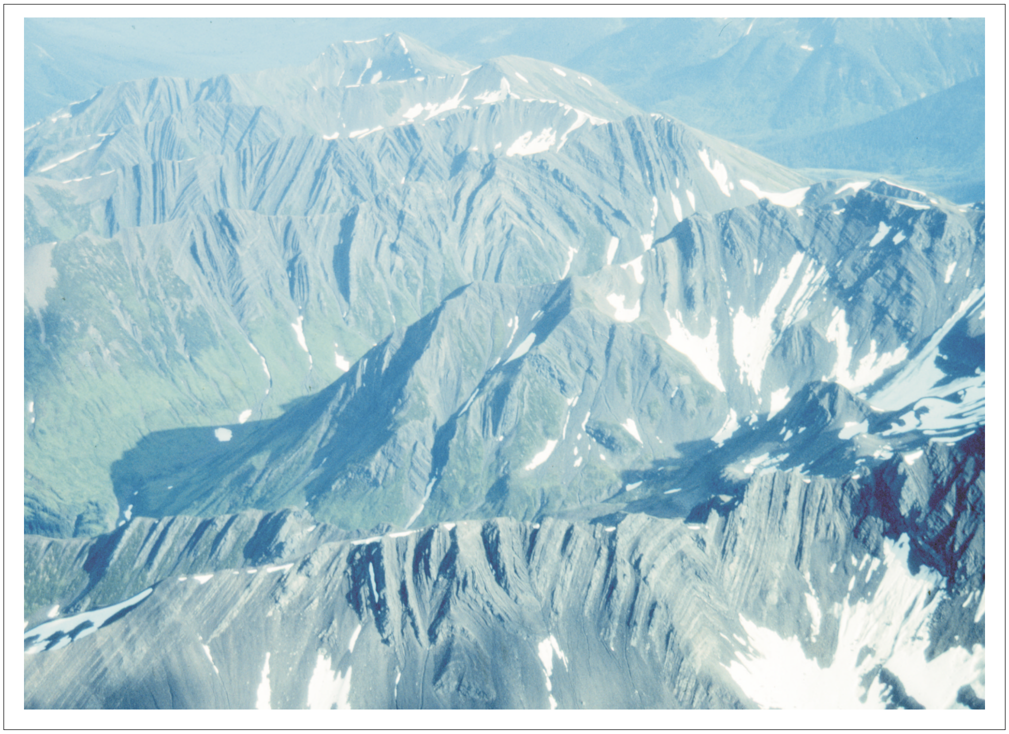


Figure 2 Regional geological setting of the Bowser Basin, and major structural trends of the Skeena Fold Belt (Evenchick, 2001). Areas lacking axial surface traces are areas not compiled or not mapped.



Folded Tango Creek Formation (Sustut Group) in footwall of thrust fault, in triangle zone at the northeast front of the Skeena Fold Belt. Viewed to southeast



View southeast to northwest trending folds typical of the central Skeena Fold Belt. In Bowser Lake Group north of Muskaboo Creek.

Figure 3 Examples of folds typical of the Skeena Fold Belt.

structure can then be used to constrain a lower probability limit (e.g. 0.01%) for a lognormal distribution of field areas. The field size distribution can then be anchored at a high probability (e.g. 99.99%) by some practical minimum prospect area (e.g. 2.56 km^2). Alternatively, the set of observed structures can be used as a biased sample of the total distribution of prospect areas. By estimating both the number of potential prospects and the prospect-level risk it is possible to infer the likely number of petroleum accumulations to be found. This is convolved, using order statistics, with the conditional pool size distribution to produce a set of distributions that describe the probability of pool size for a pool of a given size rank. For example, it is possible to calculate that the 95th and 5th percentiles of the first rank, or largest pool, is 30 and 50 million cubic metres, respectively. As a result, there is a 90% probability that the largest undiscovered pool size will have the same size range. Likewise, the play-level risk modifies the calculated total play potential. For example, if there is a finite probability that the play does not exist, perhaps because it is unknown if potential reservoir horizons are porous, then there will be an equivalent expectation for a zero play potential. The results of this method are comparable to the results of sequential sampling (discovery process) models that are applied to plays with significant numbers of discoveries. This allows both an objective comparison of undiscovered potential and an economic evaluation of conditions required to transform undiscovered resources into proven reserves.

Play Definition, Play Parameters and Risks

Existing conventional resource assessments are in Hannigan et al. (1995) and Canadian Gas Potential Committee (2001). Plays defined for both these assessments (the CGPC assessment relies on the 1995 GSC assessment for objective data) are reconnaissance evaluations conducted prior to completion of the most recent geological investigations. The plays defined for these assessments, listed below, were appropriate for the geoscience database of that time, but they are now being revised to accommodate new geoscience data and interpretations. Separate plays for both oil and gas were identified in two distinctive play areas, Bowser Basin proper, underlain by potential Bowser Lake Group and Skeena Group reservoirs, and the Sustut segment, on the northeastern margin of the Bowser Basin, where younger successions are preserved. Plays consider only anticlinal accumulations, which are the first prospects explored in Frontier Basins. The potential for stratigraphic accumulations is recognized but not assessed.

Play parameters were estimated from measured and described geological characteristics using contemporary geoscience maps, stratigraphic models and data from two exploration wells. Prospect volumes and potential reserves were estimated from available data. Play- and prospect-level risks attempt to consider the lack of data regarding reservoir porosity and permeability. There is a significant concern that porous reservoirs may not have survived burial and diagenesis, especially in Bowser Lake Group strata. However, if reservoirs exist, then the potential of the region is considerable, as both marine and terrestrial source rocks are abundant and at suitable levels of thermal maturity, especially for natural gas generation.

Play Resource Potentials

Resource potentials for the five anticlinal plays assessed in the Bowser Basin region are taken from the 1995 GSC assessment (Hannigan et al., 1995).

Skeena Group structural gas play

Skeena Group structural gas play has a play-level risk of 1.0, signifying confidence in the existence of the play, and a prospect-level risk of 0.04 were assigned to this play. The total mean play potential of natural gas in-place is 7.19x1010 m^3 (2.54 TCF) suggesting a mean recoverable potential of 5.03x1010 m^3 (1.78 TCF). The in-place resource estimate for the largest field size is between 3.25x109 to 5.05x1010 m^3 (114 to 1783 BCF) and the median size of the largest field is 1.47x1010 m^3 (519 BCF) in place. The associated recoverable field size for this largest potential accumulation is 2.28x109 to 3.53x1010 m^3 (80 to 1248 BCF). It is expected that exploration of this play will discover 19 gas fields and that no more than 45 gas fields will be found.

Skeena Group structural oil play

Skeena Group structural oil play has a mean in-place oil potential of 2.01x108 m^3 or 1264 million barrels. The largest undiscovered in-place field size is between 1.00x107 and 1.42x108 m^3 or 63.1 to 893.3 million barrels. The largest recoverable oil field is 2.01x106 to 2.89x107 m^3

(12.6 to 181.5 million barrels) with a median field size of 4.36x107 m^3 (274.4 million barrels). The expected number of fields is 16 and this number will not exceed 37 oil fields.

Bowser Lake Group structural gas play

Bowser Lake Group structural gas play has a play-level risk of 0.12, reflecting concerns regarding the survival of reservoir porosity and permeability, suitable top seals, and the potential for thermal destruction of petroleum. The total mean in-place gas potential of the play is 5.78x1010 m^3 or 2.0 TCF. The median of the largest undiscovered field (in-place) is 1.80x1010 m^3 (637 BCF), which is calculated to have a potential size range of 8.04x109 to 4.26x1010 m^3 (284-1505 BCF). The recoverable size range of largest field size is 6.43x109 to 3.41x1010 m^3 (227-1204 BCF). If gas fields exist in Bowser Lake Group strata then the mean number of fields is 173 and it is extremely unlikely that more 2473 fields will be found. No oil potential is currently assigned to Bowser Lake Group reservoirs.

Sustut Group structural gas play

Sustut Group structural gas play is among the most attractive plays in the region. There are, however, significant concerns regarding a number of prospect parameters, including the relative timing of trap formation to hydrocarbon generation. An overall prospect-level risk of 0.1 has been calculated. The mean play potential (in-place) is 5.27x1010 m^3 or 1.86 TCF of gas. The largest undiscovered field (in-place) is between 2.54x109 to 4.48x1010 m^3 (90 to 1581 BCF). The median of the largest field size is determined to be 1.24x1010 m^3 (438 BCF). The associated recoverable largest field size is 1.78x109 to 3.13x1010 m^3 (63-1106 BCF). The expected number of fields in the play is 14, and it is extremely unlikely that more than 34 gas fields are present.

Sustut Group structural oil play

Sustut Group structural oil play has play parameters and risks similar to the associated gas play. The mean in-place play potential is 1.84x108 m^3 (1158 million barrels). The range of the largest undiscovered field (in-place) is 9.57x106 to 1.38x108 m^3 (60 to 865 million barrels). The median of the largest field size is 4.17x107 m3 or 262 million barrels. The associated recoverable largest undiscovered field size range is 1.92x106 to 2.79x107 m^3 (12 to 176 million barrels). The expected number of fields in the oil play is also 14.

NEW PLAYS AND CONCEPTS

Revised stratigraphic and structural frameworks are key elements in improved calculations of petroleum potential of the Bowser and Sustut basins. Primary among these are division of the Bowser Lake Group into a number of lithofacies assemblages, and recognition of the structural style across both basins as that of a classic fold and thrust belt, complete with frontal triangle zone. The previous assessments (Hannigan et al., 1995; CGPC, 2001) have significantly depreciated the petroleum potential because of perceptions that observed levels of thermal maturity in some of the highest stratigraphic levels were unfavourable for both the diagenesis of reservoirs (a play-level risk) and the function of the petroleum systems, in particular the preservation of petroleum accumulations. Changes in the description of organic maturity history can have a profound impact on how the petroleum resource potential of the basin is perceived and risked.

Lithofacies Assemblages of the Bowser Basin

In the new stratigraphic framework of the basin the Bowser Lake Group is divided into a number of lithofacies assemblages based on associations of lithologies, cycles, and sedimentary structures (Figure 4). Each is interpreted to represent a particular environment of deposition. The broad assemblages are inferred to be a result of deposition in submarine fan, slope, shallow marine shelf, deltaic (3 types), and fluvial environments. This framework has been integrated with a comprehensive fossil database, permitting the first interpretation of depositional history of the Bowser Basin based on data across the basin (Evenchick, 2000; Evenchick et al., 2001). Although the mapping is at reconnaissance scale in some parts of the basin, this presentation of distinctive lithofacies assemblage distributions is a major improvement that enhances both petroleum system analysis and play trend elucidation. These greatly facilitate the search for reservoirs and traps while identifying regions suitable for advanced geophysical surveys.

Skeena Fold Belt

Resolution of Skeena Fold Belt geometry is a fundamental advance in the understanding of Bowser and Sustut basins. First order characteristics of the fold belt are: 1) folds in most of the

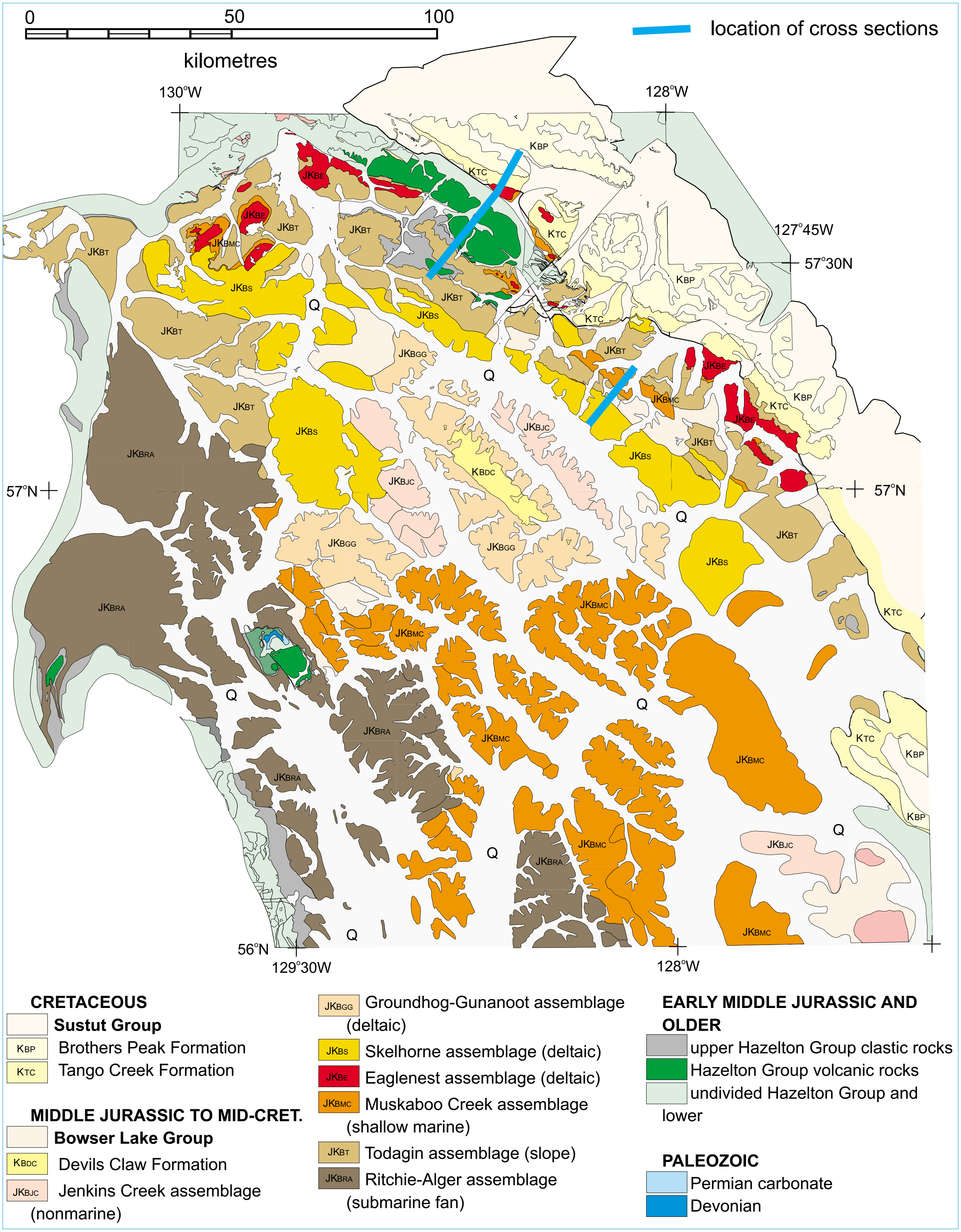
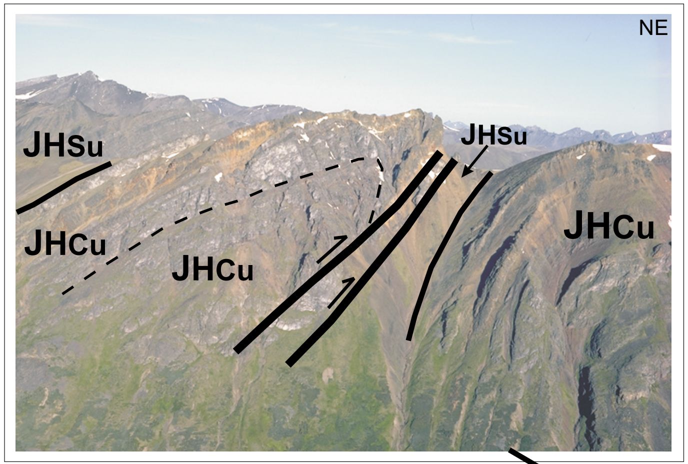


Figure 4 Generalized lithofacies assemblage map of the Bowser Basin, and geology of bounding strata.

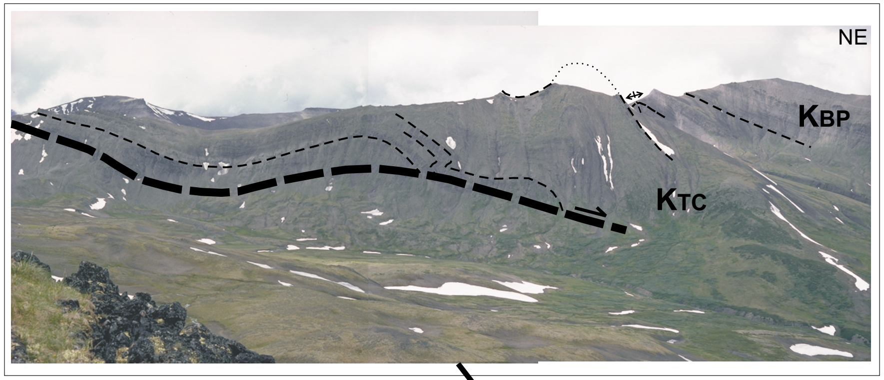
Involvement of Stikinia

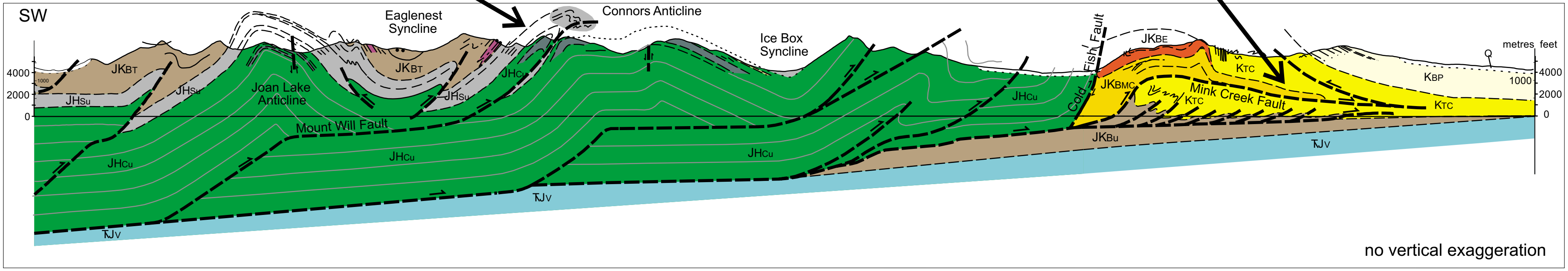
Folded Hazelton Group volcanics in hanging wall and footwall of thrust fault, northeast Skeena Fold Belt. Heavy solid lines are faults; narrow solid lines delineate the stratigraphic contact between Hazelton Group volcanics and overlying Hazelton Group clastics.

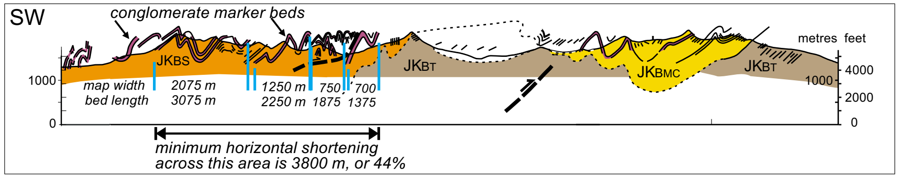


Triangle zone

Folds and northeast dipping contractional fault in Tango Creek Formation in triangle zone at the northeast front of the Skeena Fold Belt. Monocline forming northeast roof of triangle zone is at far right. Northeast is on right (photo reversed to view in same direction as cross section shown below, and is of a ridge ca. 30 km southeast of the cross section).







see Figure 3 for legend for KBP, KTC, JKBT, JKBMC, JKBS, JKBE;
JHSu - undivided Hazelton Group clastic rocks (Lower Jurassic and lower Middle Jurassic);
JHCu - undivided Hazelton Group, Cold Fish Volcanics (Lower Jurassic);
TJv - undivided Triassic and Lower and Middle Jurassic volcanic and clastic rocks.

Figures 5 Cross sections of the northern Skeena Fold Belt, illustrating some of its major features. The top cross section shows: 1) involvement of Stikinia strata (e.g. JHCu) in contractional deformation of the Skeena Fold Belt; 2) the large scale of folds in the immediate vicinity of the competent units of Stikinia relative to those structurally higher that are entirely within the Bowser Lake Group (e.g. the lower cross section); and 3) the triangle zone at the front of the fold belt. The lower cross section shows the typical scale of folds in the Skeena Fold Belt, and an example of an estimate of minimum horizontal shortening using measurements of bed lengths. Locations of cross sections shown in Figure 4.

belt trend northwest, are close to tight, and upright to inclined to the northeast; 2) thrust faults are present, but difficult to recognise because Bowser Lake Group lacks distinctive regional stratigraphic markers; 3) contractional structures affect underlying volcanic, clastic, and carbonate successions of Stikinia; 4) the fold belt accommodated a minimum of 44% horizontal shortening; 5) it terminates to the northeast in a triangle zone within Sustut Group; and 6) it is rooted in the Coast Belt to the west (Figure 5; Evenchick, 1991a,b; 2001). The relationships between structures and stratigraphic units indicates that orogenic shortening began prior to Albian (mid-Cretaceous) time, and continued into the Maastrichtian (latest Cretaceous) or later (Evenchick, 1991a; 2000). The chert clasts derived from Bowser Lake Group and paleocurrent directions (Eisbacher, 1974b) indicate that the Sustut Basin subsided, at least in part, in response to Skeena Fold Belt formation. Sustut Group and Devils Claw Formation are both inferred to be synorogenic clastic basin fill linked to Skeena Fold Belt formation (Evenchick, 2000). The scale of folds is controlled by the proximity to mechanically strong volcanic units in Stikinia (e.g. Figure 5). Primary orogenic structures, including a triangle zone, are important structural elements that must be considered in a revised petroleum assessment.

VITRINITE AND BITUMEN (PYROBITUMEN) REFLECTANCE DATA

Sources of Data and Optical Procedures

The majority of analyses presented herein are from samples collected by C.A. Evenchick, C.J.Greig, P.S. Mustard, S.P. Porter, G.M. Green, and assistants during regional mapping of the northern two thirds of the Bowser Basin from 1988 to 1992. Figure 6 illustrates of density of samples. Samples were processed in the laboratories of the Geological Survey of Canada, in Calgary. Additional data (ca. 50 values) for the area in the immediate vicinity of the Groundhog Coalfield are from Bustin (1984).

Analyses were conducted by M. Tomica, F. Goodarzi, and L.D. Stasiuk at the Geological Survey of Canada, Calgary, where the histogram for each of the averaged reflectance values included in this report reside. Sample preparation, optical apparatus and procedures for new data followed, depending somewhat on microscope specifics, the standard analytical practices of reflectance

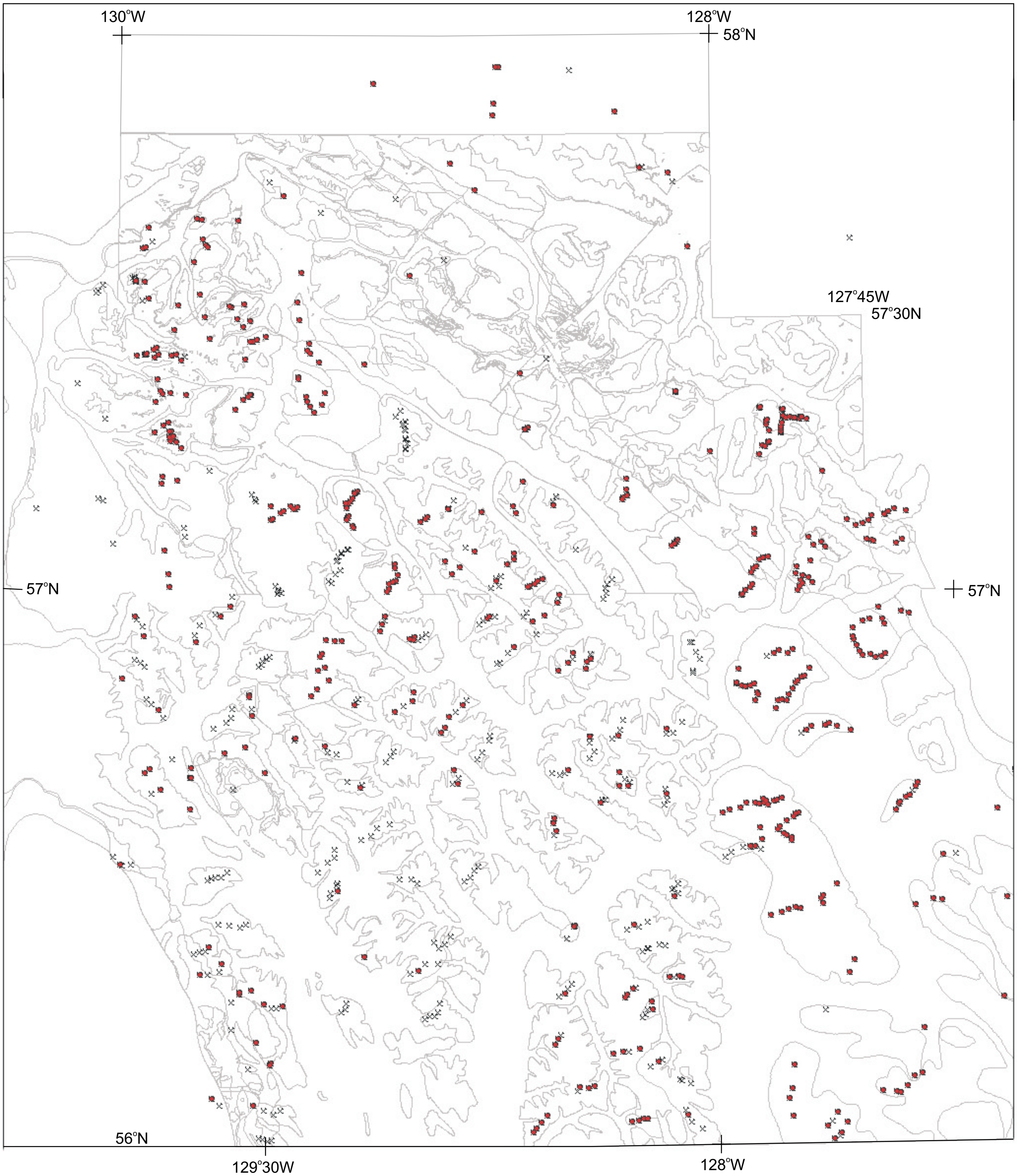


Figure 6. Density of samples in the northern two-thirds of the Bowser and Sustut basins collected by GSC personel. Circles represent samples analysed and presented in this report. Crosses represent samples to be processed and presented in future compilations.

measurement at the GSC Calgary organic petrology laboratory. In general that procedure is as follows. Rocks for particulate mounted samples (for reflectance measurements) were crushed to approximately 2 to 4 mm diameter and placed in Teflon molds; the molds were then filled with a cold-setting epoxy mixture and cured. Grinding and polishing of the pellets was conducted using a technique similar to the modified version (Stasiuk, 1988) of the procedure used for polishing coal as described by Mackowsky (1982).

Optical data were collected using an incident light microscope, a Leitz MPM II microscope, equipped with a Koelhler illuminator and white and ultraviolet light sources. Reflectance in oil (%Ro) was detected with a MPM II photomultiplier unit. Mean random or maximum vitrinite reflectance, bitumen reflectance for Type I (primary bitumen, derived from amorphous kerogen or liptinite macerals such as alginite or sporinite), Type 2 (secondary bitumen, migrabitumen likely derived from asphalitic components of petroleum) and Type 3 (residual pyrobitumen derived from petroleum cracking) were recorded on standard data tables and subsequently entered into a computer file.

Random (fixed stage) and maximum %Ro (rotated stage for anisotropic macerals) values were measured under plane-polarized, monochromatic, light using a Berek-type triple-prism vertical illuminator, Epiplan-neofluor oil immersion objective (X40; N.A. 0.90 oil) and Cargille type A immersion oil (n = 1.5180 at 23ºC for 546 nm), or equivalent apparatus. Reflectance standards used for %Ro measurements were selected such that the value of the standard was within approximately 20% of the maximum % Ro of the maceral being measured. Several glass standards (0.50, 1.025, 1.82) and a diamond standard (5.26% Ro) were used for maceral %Ro greater than 0.20. A maximum of 50 readings (n = 50) was recorded and average (%Ro mean) for pristine macerals in each sample. A Leitz photometer software package was used for %Ro data handling.

Presentation of Data

The accompanying map shows reflectance data on a base map of lithofacies assemblages. The data are symbolized according to type of data: mean maximum vitrinite reflectance (square), mean random vitrinite reflectance (diamond), and bitumen reflectance (circles). Values of the latter two are converted, respectively, to equivalent mean maximum vitrinite values using the linear formulae of England and Bustin (1986) and Jacob (1984; 1985). Original values and recalculated values are listed in the accompanying database. The mean calculated equivalent maximum vitrinite reflectance values ($R_{o\ max\ eq}$) are colour coded to represent critical cut off values, so that blue represents the immature zone ($R_{o\ max\ eq}$ 0.00 - 0.50%), yellow represents the marginally mature zone ($R_{o\ max\ eq}$ 0.50 - 0.70%), green represents the oil window ($R_{o\ max\ eq}$ 0.70 - 1.20%), red represents the wet gas zone ($R_{o\ max\ eq}$ 1.20 - 1.80%), orange represents the dry gas zone ($R_{o\ max\ eq}$ 1.80 - 2.50%), and white represents the zone of little hydrocarbon generation ($R_{o\ max\ eq}$ > 2.50%).

The base map is modified from Evenchick et al. (2001). Primary sources of information for the compilation are Souther (1972), Eisbacher (1974b), Evenchick and Thorkelson (1993), Evenchick and Porter (1993), Evenchick (1997a,b,c), Lewis et al. (1996), Evenchick et al. (2000), and unpublished map data of C.A. Evenchick. Previous 1:250 000 scale maps of the region are those by Geological Survey of Canada (1957) and Gabrielse and Tipper (1984).

Summary of Data and Preliminary Interpretations

The resulting map illustrates that large regions in the northern two thirds of the Bowser Basin have sufficiently low organic maturity levels that both the generation and preservation of hydrocarbons and the diagenetic history of reservoirs is favourable for the formation and preservation of a significant petroleum resource. This result is a significant change from previous views that considered the high thermal maturity of some of the stratigraphically highest coals as a negative indication for hydrocarbon potential in all stratigraphic levels of all regions of the basin (e.g. Hannigan et al., 1995). While there are regions of the map that are at very high thermal maturity levels, such that there is a real risk to the preservation of both petroleum and reservoirs, there are clear regional variations in the thermal maturity of outcrops such that even the lowest stratigraphic units are marginally to fully mature in select regions of the basin, as described below. In addition, the presence of type 2 migrabitumen is a positive indication for the generation and migration of liquid petroleum within the Bowser Basin. Together the revised patterns and levels of thermal maturity, combined with positive indications for the generation and migration of liquid petroleum, provides a much more positive indication for petroleum system function and petroleum preservation than was held previously.

The preliminary data show a number of first-order patterns of thermal maturity not previously recognized.

1) The highest levels of thermal maturity (R_o > 2.5%) underlie a broad area and cross a wide range of stratigraphic units (marked LOW in Figure 7). This region coincides approximately with a broad aeromagnetic high. The high thermal maturity and aeromagnetic anomaly are possibly a result of buried Late Cretaceous and/or Tertiary plutons similar to those that outcrop in the southeast-most part of the study area. In this interpretation the plutons are the source of increased heat flow.

2) The northwest limit of the region described above coincides with areas of highest thermal maturity reported by Bustin and Moffat (1989). Although we recognize the same general pattern of reduced thermal maturity to the northwest noted by Bustin and Moffat (1989), in several areas near the highest range we observe and report lower thermal maturity than Bustin and Moffat (1989). This difference will be addressed in future analyses.

3) Significant portions of the northwest and western Bowser Basin are within the range of R_o values compatible with oil and gas preservation (GOOD in Figure 7). These regions were not previously recognized, and the lower thermal maturation than formerly assumed indicates a greater possibility for oil and gas generation and preservation, and reduced exploration risk.

4) A broad band of strata in the northeast Bowser Basin and southwest Sustut Basin (Fig. 7), coinciding with the roof of the triangle zone and regions structurally below the roof, reached peak thermal maturity in the main stage of oil generation. These relationships are highly

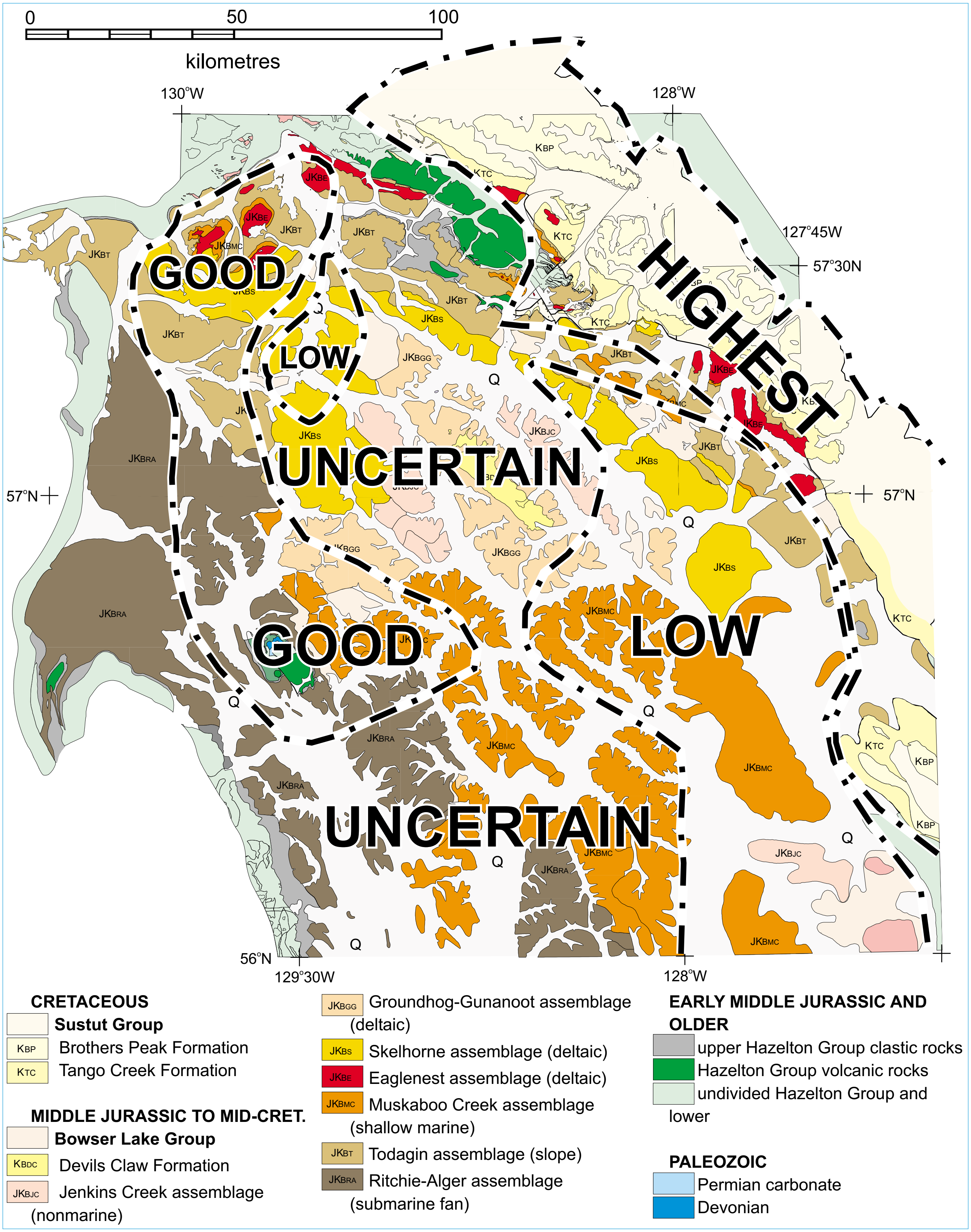


Figure 7 Relative regional prospectivity for petroleum potential as constrained by outcropping organic maturity level, superimposed on the generalized lithofacies assemblage map of the Bowser Basin, and the geology of bounding strata.

favourable for the potential triangle zone play.

5) Northeast of the triangle zone, samples in the Sustut Group are consistently in the main stages of hydrocarbon generation. Although data are sparse, they are widespread in a large area of favourable stratigraphic and structural traps, and suggest reduced play-level risk. The combination of thermal maturity and structure in the triangle zone are most favourable revisions of the geological parameters constraining petroleum potential. Not only was the triangle zone play not explicitly considered in the previous assessments (Hannigan et al., 1995; CGPC, 2001), but it presents a clear analogue to some of the most prospective and productive settings in the thrust and fold beld of the Foreland Belt of the southern Canadian Cordillera (Stockmal et al., 2001) .

CONCLUSIONS

Geological framework data and initial petroleum resource assessments indicate significant undiscovered conventional petroleum potential in the Bowser and Sustut basins. The stratigraphic succession provides clear indication for both oil and gas-prone source intervals, in select portions of the Bowser and Sustut basins. The geological framework has recently been improved significantly as the result of new mapping, stratigraphic analysis and tectonic studies.

The new thermal maturity data set presented herein provides the first widespread, albeit sparse, data set for a large part of the Bowser and Sustut basins. First-order conclusions are that: 1) there are distinct regions characterized by specific ranges of thermal maturity that impact on the petroleum potential of the basins; 2) along the entire length of the triangle zone at the front of the Skeena Fold Belt samples in the roof of the triangle zone, and within the triangle zone, are in the stage of liquid hydrocarbon generation, improving the oil potential of the previously unassessed triangle zone play; 3) similar levels of thermal maturity farther northeast in the Sustut Basin indicate a broad region of marginal to full maturity that is favourable for both petroleum system function and reservoir diagenesis; 4) thermal maturities ranging from marginally mature with respect to oil, to the dry gas zone along the northwest and west regions of the Bowser Basin are indicative of a broad region favourable for hydrocarbon generation and preservation; 5) a large region within the east-central basin exhibits very high thermal maturity, suggesting a significant risk to both petroleum generation and reservoir preservation; 6) the pattern and timing of maturation within the central part of the basin is not clear from available data, but the possibility of significant gas cannot be discounted.

The observation of type 2, or migrabitumen, provides a significant indication that petroleum systems probably generated liquid hydrocarbons within the basin. The full implications of the migrabitumen observations is beyond the scope of this report that focuses on thermal maturity patterns. However, these observations and their relationship to the timing of peak maturity and trap formation could have significance for both play- and prospect-level risks that will be discussed in subsequent reports.

Additional work is planned to evaluate the thermal and diagenetic history of potential petroleum systems, with a special focus on identifying and characterizing prospective reservoir intervals. The improved characterization of these petroleum systems and their evaluation in a revised assessment of petroleum potential will be a useful guide to both the true economic potential of the region and the most prospective regions and successions. Much work remains to transform this frontier region into a producing petroleum province. The positive indications for potential resulting from this study, however, in a vast region of complex and diverse geological and thermal history, indicate significant improvements in play- and prospect-level risks, compared to previous assessments. These factors should contribute to a favourable revision of the undiscovered petroleum potential estimate, while motivating exploration of this part of the Intermontane Belt.

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OPEN FILE 4343

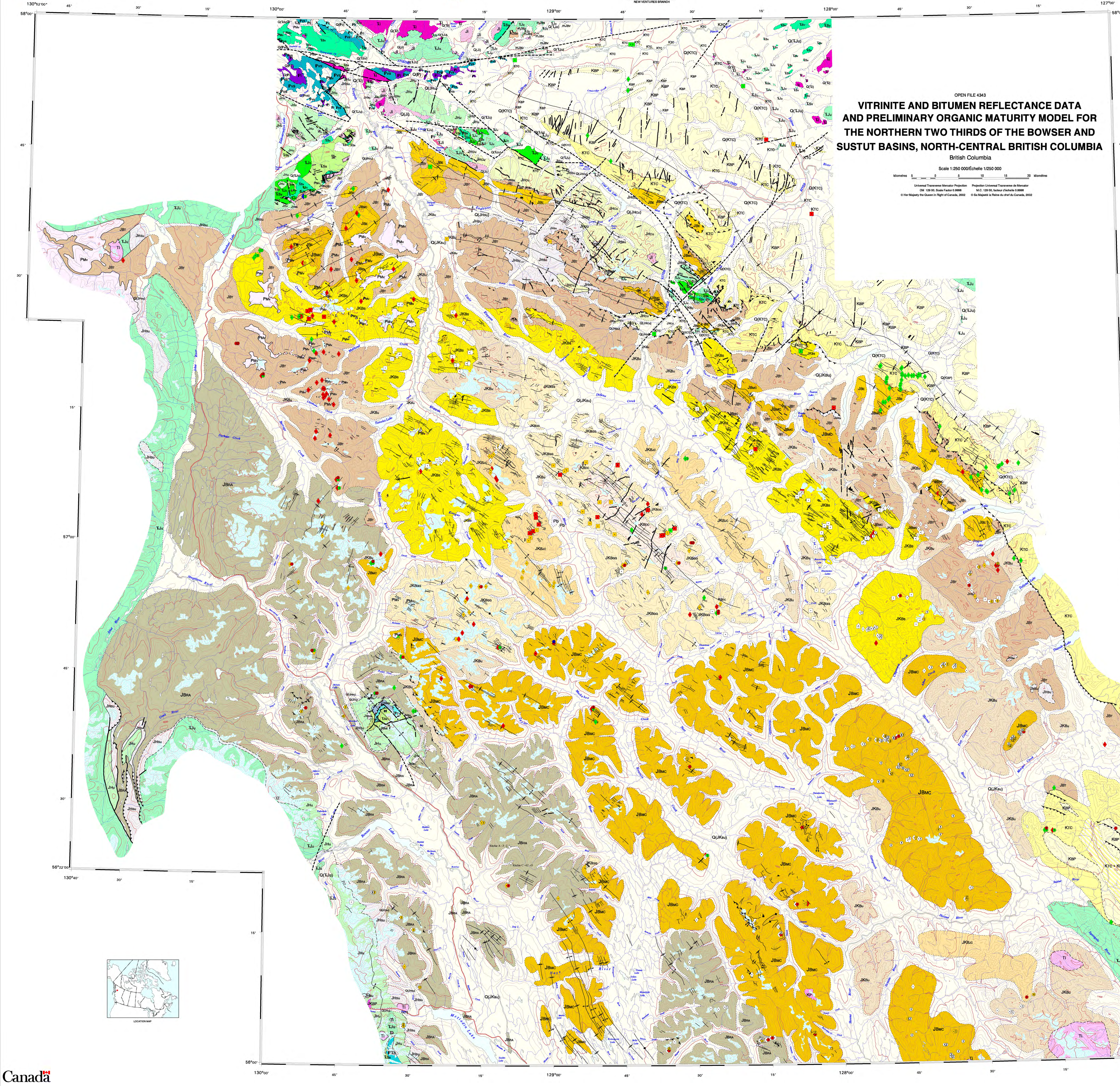
VITRINITE AND BITUMEN REFLECTANCE DATA AND PRELIMINARY ORGANIC MATURITY MODEL FOR THE NORTHERN TWO THIRDS OF THE BOWSER AND SUSTUT BASINS, NORTH-CENTRAL BRITISH COLUMBIA

British Columbia

Scale 1:250 000/Échelle 1/250 000

kilometres 5 0 5 10 15 20 kilomètres

Universal Transverse Mercator Projection / Projection Universal Transverse de Mercator
CM 129 00, Scale Factor 0.9996 / M.C. 129 00, facteur d'échelle 0.9996



LEGEND

STRATIFIED ROCKS

CENOZOIC

QUATERNARY
PLEISTOCENE AND RECENT

Q	*Glacial till, alluvium, colluvium; letters in brackets are inferred underlying bedrock units*

PLEISTOCENE

Pb	*Basaltic (basanite) intrusion east of Spatsizi River (1.3 Ma (K-Ar)); pillow basalt in Nass Valley*

TERTIARY
PLIOCENE

PMv	*MAITLAND VOLCANICS: olivine basalt necks and flows; columnar jointed, with rare pillows and breccia; 5.2 to 4.6 Ma (K-Ar)*

MESOZOIC

CRETACEOUS
UPPER LOWER AND UPPER CRETACEOUS
SUSTUT GROUP
CAMPANIAN AND MAASTRICTIAN

KBP	*BROTHERS PEAK FORMATION: sandstone, siltstone, conglomerate and tuff; sandstone and siltstone is cream and grey weathering; tuff is cream weathering; conglomerate in laterally continuous sheets are most common near base*

APTIAN OR ALBIAN TO CAMPANIAN

KTC	*TANGO CREEK FORMATION: micaceous sandstone, siltstone, mudstone and minor quartz grit and pebble conglomerate; sandstone grey and green weathering, occurring as laterally continuous sheets and as lenses; siltstone and mudstone grey, black, and maroon weathering*

LOWER CRETACEOUS
BOWSER LAKE GROUP

KBDC	*DEVILS CLAW FORMATION: conglomerate, sandstone, siltstone; a high proportion of pebble conglomerate (30-80%) in laterally continuous grey weathering sheets with large scale cross bedding; conglomerate forms bases of fining up cycles with medium grained sandstone, fine grained sandstone, carbonaceous siltstone, and minor coal; sandstone is dark green and grey weathering with platy and trough cross bedding; fossil plants common; marine fossils absent*

JURASSIC AND CRETACEOUS
UPPER JURASSIC AND LOWER CRETACEOUS
BOWSER LAKE GROUP

JKBU	*undivided Bowser Lake Group*
JKBJC	*JENKINS CREEK ASSEMBLAGE (nonmarine assemblage): mudstone, siltstone, fine grained sandstone, medium grained sandstone, rare conglomerate and coal; commonly arranged in fining up cycles; sandstone is grey, green, and brown weathering and occurs as laterally continuous sheets, discontinuous sheets, and lenses; lenses are planar and trough cross bedded; fossil plants abundant, including in-situ roots, and plants with delicate structure; marine fossils absent*
JKBGG	*GROUNDHOG-GUNANOOT ASSEMBLAGE (deltaic assemblage): sandstone, siltstone, carbonaceous and calcareous mudstone, with minor conglomerate and coal; locally arranged in fining up cycles; sandstone is fine to medium grained with planar bedding and planar-tabular cross bedding; a large proportion of sandstone is thin and thick bedded, medium grained, recessive drab green or brown weathering wacke; resistant and light grey weathering arenite is less common and forms discontinuous sheets and lenses; finer grained strata are thinly bedded and locally include densely packed plant fossils; conglomerate sheets and lenses comprise 10% of the unit; they are light grey weathering, with large scale cross bedding; plant fossils common and include in-situ trees; marine fossils rare*
JKBS	*SKELHORNE ASSEMBLAGE (deltaic assemblage): thinly intermixed and vari-coloured siltstone, sandstone, and conglomerate (with or without coal), commonly arranged in coarsening and thickening upward cycles; common features of sandstone are parallel bedding, cross bedding, ripples, burrows, bivalve coquina, and brown, green, and grey weathering; conglomerate is rusty and grey weathering, but comprises a lower proportion (15 - 30%) of the unit than in the Eaglenest assemblage; conglomerate units up to 50 m thick cap cycles up to 70 m thick, and tops locally have megaripples; plant and marine fossils are ubiquitous, trace fossils including Skolithus and Diplocraterion are present, as are tree fragments several metres long*

JURASSIC
UPPER MIDDLE TO UPPER JURASSIC
BOWSER LAKE GROUP

JBE	*EAGLENEST ASSEMBLAGE (deltaic assemblage): conglomerate, sandstone, siltstone, mudstone, and rare coal; arranged in coarsening and fining up cycles of mudstone to pebble or cobble conglomerate; prominently rusty weathering and 30 to 80% conglomerate; sheets of conglomerate to 50 m thick include planar beds, tabular- planar cross stratification and trough cross stratification, sets locally up to 10's of metres thick; sandstone is green, brown and grey weathering, has planar cross stratification and hummocky cross stratification; sparse marine fossils but abundant plant fossils, including silicified tree fragments*
JBMC	*MUSKABOO CREEK ASSEMBLAGE (shelf assemblage): sandstone, siltstone, conglomerate; primary lithofacies is sandstone forming laterally continuous thin to thick bedded sheets; less common are siltstone interbedded with sandstone, and lenses of conglomerate; sandstone is green, brown, and grey weathering, thin to thick bedded, locally arranged in coarsening up cycles; includes burrows, bivalve coquina, and other marine fossils, common ripple marks and cross bedding, with local hummocky cross stratification; conglomerate increases in proportion and thickness up-section*
JBT	*TODAGIN ASSEMBLAGE: (slope assemblage) siltstone, fine grained sandstone, conglomerate; mainly laminated siltstone/fine grained sandstone which is dark grey to black weathering, and includes thin orange weathering claystone beds and syndepositional faults and folds; chert pebble conglomerate occurs as lenses; marine fossils*
JBRA	*RITCHIE-ALGER ASSEMBLAGE (submarine fan assemblage): sandstone, siltstone, rare conglomerate; about equal proportions of sheet-like intervals up to 50 m thick dominated by either siltstone and very fine grained sandstone, or by medium grained sandstone; siltstone/fine grained sandstone is dark grey and black weathering, sandstone is medium and light grey weathering; abundant turbidite features (eg. Bouma cycles, flame structures, flute and groove casts); conglomerate includes debris flow units; marine fossils*

LOWER MIDDLE JURASSIC
BOWSER LAKE GROUP

mJBv	*Maroon plagioclase porphyry flows and breccia, green and grey-green aphyric and plagioclase porphyry flows, breccia and tuff*
mJBs	*Maroon sandstone and siltstone, chert pebble conglomerate, local grey and green sandstone*

LOWER AND LOWER MIDDLE JURASSIC
HAZELTON GROUP

JHu	*undivided volcanic and intercalated clastic rock of the Hazelton Group; includes felsic volcanic, volcanoclastic and epiclastic rocks, andesitic volcanic breccia and conglomerate, and mafic volcanic rocks*
JHsu	*undivided clastic rocks of Spatsizi Formation and Salmon River Formation; dominated by siltstone and shale, including siliceous well bedded tuffaceous(?) siltstone, limy siltstone, calcareous to siliceous organic shale, calcareous to siliceous siltstone, fine-grained sandstone; minor constituents are mudstone, limestone, conglomerate, coarse grained arkose, and basalt*
JHcu	*undivided Cold Fish Volcanics; includes subaerial and marine mafic volcanic rocks and epiclastic rocks; felsic volcanic rocks include sills, dykes, welded and nonwelded ignimbrite, airfall tuff breccia; epiclastic and bioclastic rocks, include lahar, breccia, conglomerate, siltstone, shale, and limestone*

UPPER TRIASSIC TO LOWER JURASSIC
CARNIAN(?) AND NORIAN(?) TO HETTANGIAN AND/OR LOWER SINEMURIAN

ŦJc	*Conglomerate, sandstone, shale, mafic to intermediate volcanic breccia, and olistostrome. Conglomerate clasts are mainly hornblende and plagioclase porphyry andesite, but include augite phyric mafic lava and other volcanic rocks, felsic to intermediate granitoid, and limestone*
ŦJu	*undivided Triassic and Jurassic volcanic and epiclastic rocks*

TRIASSIC
UPPER TRIASSIC
CARNIAN(?) TO NORIAN
STUHINI GROUP

ŦSv	*Mafic lava flows, mainly aphyric to augite phyric, minor conglomerate, sandstone, mudstone, limestone and olistostrome*
ŦSs	*Mudstone, shale, sandstone and olistostrome; minor conglomerate and mafic lava, minor limestone*

PALEOZOIC

TRIASSIC OR OLDER

PŦb	*Dark green, resistant and poorly stratified, crowded feldspar-phyric trachybasalt; commonly contains discontinuous, irregularly-oriented, crowded trachytic fabric outlined by tabular, fine- to medium- grained plagioclase feldspar phenocrysts; fine-grained phenocrysts of magnetite and(or) ilmenite yield conspicuous positive magnetic anomalies at outcrop and regional scales*

CARBONIFEROUS TO PERMIAN

Pc	*Marble and limestone*

LOWER CARBONIFEROUS AND OLDER?

Pvs	*Metavolcanic and metasedimentary rock: includes green chlorite phyllite, brown phyllitic argillite, grey-green to tan quartz-sericite schist (felsic metavolcanic rocks are ca. 342 Ma U-Pb); minor chert, rare limestone*

DEVONIAN AND LOWER CARBONIFEROUS

DMSv	*Mafic to intermediate plagioclase-pyroxene phyric lapilli tuff, lapilli tuff-breccia, and flows; plagioclase-phyric amygdaloidal andesite(?) flows; rhyolite and rhyodacite lapilli tuff-breccia*

INTRUSIVE ROCKS

CENOZOIC

TERTIARY

Ti	*undivided early Tertiary intrusive rocks; includes granodiorite, monzogranite, monzodiorite*

MESOZOIC

CRETACEOUS

KP	*POISON PLUTON; fine to coarse grained quartz monzodiorite; massive; 84.1 +/- 0.5 Ma (U-Pb on zircon)*

JURASSIC OR CRETACEOUS

JKBP	*BEAR PASS PLUTON; biotite (?-) hornblende quartz monzodiorite or granodiorite; fractured and altered*
Ji	*undivided Jurassic intrusive rocks; includes granite, granodiorite, diorite, quartz diorite, monzonite, quartz monzonite*

TRIASSIC OR JURASSIC

ŦJi	*undivided Triassic and Jurassic intrusive rocks*

TRIASSIC

Ŧi	*undivided Triassic intrusive rocks; includes metagranite, metadiorite, metagabbro, granite, diorite and foliated granodiorite, quartzmonzonite and monzodiorite*

PALEOZOIC

PALEOZOIC

Pi	*undivided Paleozoic intrusive rocks; includes Carboniferous (ca. 342-353 Ma) granodiorite, quartz diorite, diorite, quartz monzonite and tonalite; and mylonitic to massive leucogranite, leucogranodiorite, quartz diorite, and minor gabbro of uncertain age*

Geological contact (defined, approximate, assumed)

Faults, sense of displacement unknown (defined, approximate, assumed)

Faults, normal (ornament on down thrown side; defined, approximate, assumed)

Faults, contractional (teeth on hanging wall side; defined, approximate, assumed)

Anticline (trace of axial surface; upright or inclined, overturned)

Syncline (trace of axial surface; upright or inclined, overturned)

Axial Surface trace (type of fold unknown, interpreted from aerial photographs)

Vitrinite as Maximum Reflectance □

Vitrinite as Random Reflectance ◇

Bitumen Reflectance (Bitumen type in circle) ① ② ③

All reflectance values converted to equivalent Mean Maximum Reflectance

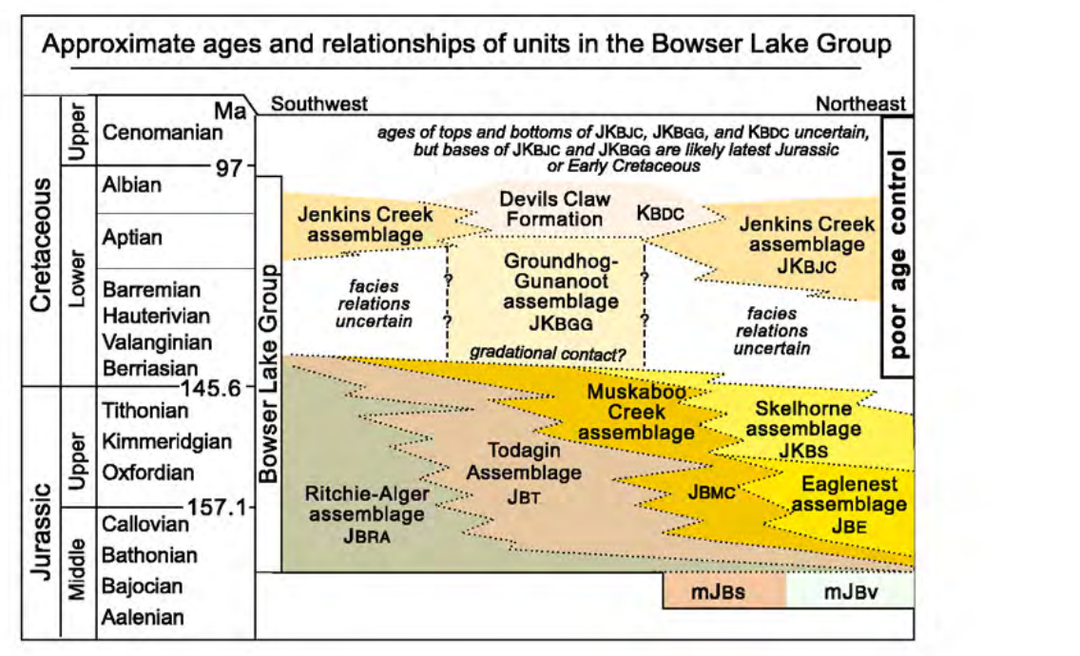
0.0% - 0.50%	◆	■	①	②	③
0.50% - 0.70%	◆	■	①	②	③
0.70% - 1.20%	◆	■	①	②	③
1.20% - 1.80%	◆	■	①	②	③
1.80% - 2.50%	◆	■	①	②	③
>2.50%	◇	□	①	②	③

Dot in symbol denotes location of sample

Abandoned well location

Highway 37

BC Railway, abandoned



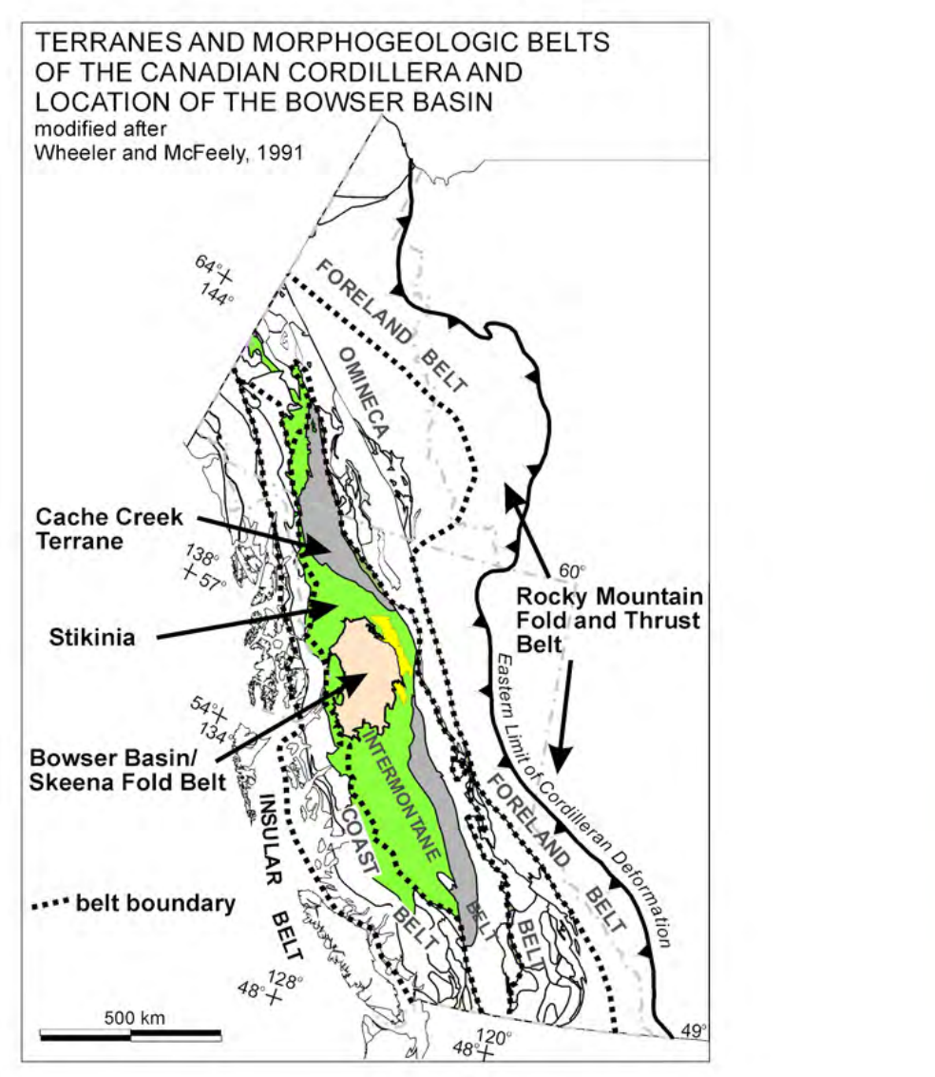
Approximate ages and relationships of units in the Bowser Lake Group

Notes

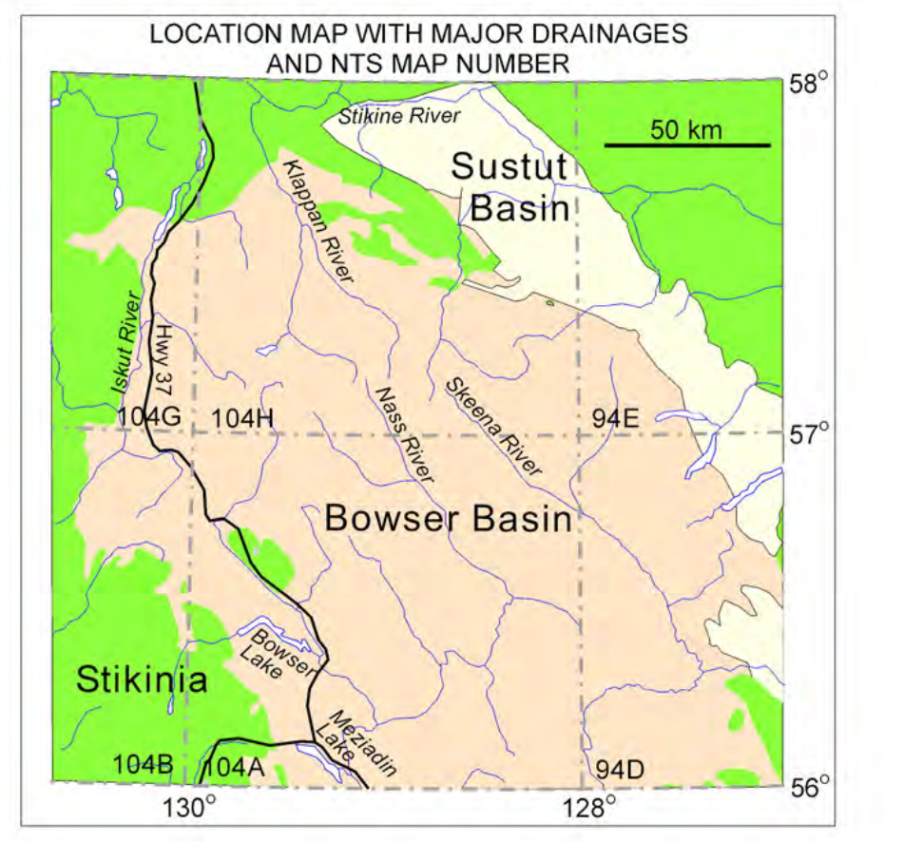
The map is accompanied by a report that provides an introduction to the open file, cites sources of information for geological base map and reflection data, and briefly discusses the reflectance data.

This map represents the most current geological base, but more detailed structural information can be found in Evenchick and Thorkelson (1993), Evenchick et al. (2000), and published 1:50,000 maps of 104H, 94E and 104A/11,12.

The level of certainty of distribution of lithofacies assemblage type varies widely. Some areas have been mapped in considerable detail and include compilations from graduate theses, whereas other areas are mapped at reconnaissance scale. Most of the southern area was mapped at reconnaissance scale, with the result that the locations of boundaries of lithofacies assemblages are not well defined. Strata within kilometres of these boundaries may belong to a lithofacies assemblage more proximal or more distal to source in origin.



TERRANES AND MORPHOGEOLOGIC BELTS OF THE CANADIAN CORDILLERA AND LOCATION OF THE BOWSER BASIN
modified after
Wheeler and McFeely, 1991



LOCATION MAP WITH MAJOR DRAINAGES AND NTS MAP NUMBER

Digital cartography by K.A. Buddell, C.L. Wagner and I.G. Braidek

Approximate magnetic declination 2002, 24° 28.1' East, decreasing 10.3' annually

Any revisions or additional geological information known to the user would be welcomed by the Geological Survey of Canada

Elevations in meters above sea level

Contour interval 200m

Contour lines and drainage have been modified from NAD83 to NAD27

OPEN FILE
DOSSIER PUBLIC
4343
GEOLOGICAL SURVEY OF CANADA
COMMISSION GÉOLOGIQUE DU CANADA
2002

BC MINISTRY OF ENERGY AND MINES
PETROLEUM GEOLOGY OPEN FILE
#2002-1

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