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Recent results and activities of the Integrated Petroleum Resource Potential and Geoscience Studies of the Bowser and Sustut Basins Project, British Columbia[1]

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Abstract: Recent research on energy resource potential of the Bowser and Sustut basins includes identifying effective petroleum systems, increasing geographic coverage of thermal maturity data, initiating paleomagnetic studies, and geological mapping. Crude oil samples extracted and characterized from four locations yield results that confirm a recently published revised thermal maturity model for the region and identify potential petroleum systems with sources in the Stikine Assemblage and younger strata. Identification of Stikinia sources and recognition of possible reservoirs in the Hazelton Group indicates that strata below the Bowser Lake Group might also be prospective for petroleum accumulation. Paleomagnetic sampling of Permian to Late Jurassic strata has the capacity to recognize several periods of deformation, burial history, igneous heating, and fluid migrations. New mapping in McConnell Creek area significantly revises distribution of upper Hazelton Group clastic rocks, assigns lithofacies assemblages to Bowser Lake Group strata, and modifies Sustut Group map distribution and structures.

Résumé : Des recherches récentes sur le potentiel énergétique des roches des bassins de Bowser et de Sustut consistaient à identifier des systèmes pétroliers effectifs, à accroître la couverture géographique des données sur la maturité thermique, à entreprendre des études paléomagnétiques et à effectuer des levés géologiques. La caractérisation de pétrole brut extrait en quatre lieux différents a permis de confirmer l'exactitude d'un modèle de maturité thermique de la région présenté dans une publication récente et de localiser des systèmes pétroliers potentiels qui prendraient leur source dans l'Assemblage de Stikine et des strates plus jeunes. L'identification de sources de pétrole dans la Stikinie et l'existence possible de roches réservoirs dans le Groupe de Hazelton indiquent que les strates sous le Groupe de Bowser Lake seraient aussi le siège d'une accumulation de pétrole. L'analyse paléomagnétique de roches datant du Permien au Jurassique tardif pourrait permettre de reconnaître les périodes de déformation, l'histoire de l'enfouissement, le réchauffement dû au magmatisme et les migrations de fluides. Suite à de nouveaux levés dans la région cartographique du ruisseau McConnell, la répartition des roches clastiques de la partie supérieure du Groupe de Hazelton a été considérablement modifiée, les strates du Groupe de Bowser Lake ont été divisées en assemblages de lithofaciès, et des changements ont été apportés à la distribution géographique des strates du Groupe de Sustut ainsi qu'aux éléments structuraux qui s'y rapportent.

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[1] Northern Resource Development Program

INTRODUCTION

Project overview

A primary goal of the Northern Resource Development Program of Earth Sciences Sector, Natural Resources Canada, is to increase the economic opportunities (and quality of life) of northern Canadians by providing improved geoscience knowledge and data to spark new private sector investment. The project "Integrated Petroleum Resource Potential and Geoscience Studies of the Bowser and Sustut Basins" is a collaborative research project of the BC Ministry of Energy and Mines (Oil and Gas Emerging Opportunities and Geoscience Branch) and the Geological Survey of Canada.

Previous petroleum assessment work of the region identified a significant petroleum potential while recognizing that there are several poorly understood, but significant risks (P.K. Hannigan, P.J. Lee, and K.G. Osadetz, unpub. internal report, 1995). It is essential to re-evaluate resource estimates by considering new stratigraphic and tectonic models and by 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. Comparing the thermal character and history of potential petroleum source rocks to the diagenetic and tectonic history of potential secondary migration pathways and reservoirs will facilitate identification of regions and strata most prospective for exploration. Integration of these data, models, and interpretations with an improved stratigraphic and structural framework will increase the robustness of petroleum resource assessments and aid in attracting investment to this frontier region.

Previous Geological Survey of Canada–BC Ministry of Energy and Mines research resulted in a profound shift in perceptions of organic maturity of the Bowser and Sustut basins (Evenchick et al., 2002). This first regional reflectance data set illustrated that large areas, including the lowest stratigraphic levels of the Bowser Basin, have sufficiently low organic maturity levels to be favourable for the formation and preservation of a significant petroleum resource. This result is a fundamental 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. The current four-year project is multidisciplinary in scope and has been expanded to cover the breadth of the Bowser and Sustut basins. Primary activities include improving the geological framework (through a range of stratigraphic, structural, and thematic studies) and conducting energy resource studies and resource assessment. The results of these studies will be an integrated, fundamentally revised, pan-basin geological framework and a digital basin atlas.

Regional geological overview

The Bowser and Sustut basins are located in north-central British Columbia (Fig. 1), in the Intermontane Belt 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. They overlie Devonian to early Middle Jurassic strata of allochthonous Stikinia.

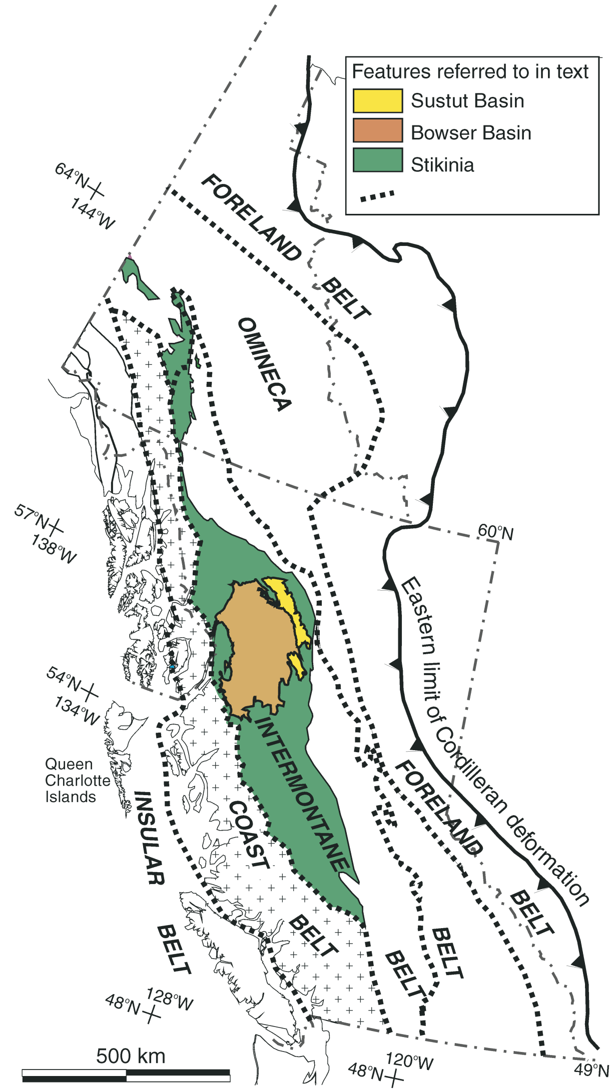

Figure 1. *Location of the Bowser and Sustut basins on base map of morphogeological belts.*

The basins comprise three stratigraphic successions, in part overlapping in age. The Bowser Lake Group is the oldest, ranging from late Middle Jurassic to mid-Cretaceous. It includes strata deposited in distal submarine fan, slope, shallow-marine shelf, deltaic, fluvial, and lacustrine environments (e.g. Tipper and Richards (1976); Evenchick et al. (2001), and references therein). It was deposited directly on volcanic arc strata of Stikinia, including clastic rocks of the upper Hazelton Group. The Skeena Group is Early Cretaceous to mid-Cretaceous. It occurs south of the Bowser Lake Group and the stratigraphic relationship between the two is unclear. Skeena Group sediments were deposited in a range of marine to nonmarine environments, with local volcanic influences (Tipper and Richards, 1976). The Sustut Group is mid-Cretaceous to latest Cretaceous and occurs east of most Bowser Basin strata (Fig. 2), overlying deformed, older successions. Sediments were deposited in fluvial and lacustrine environments (Eisbacher, 1974).

Strata of all three successions, and underlying Stikinia, are folded and thrust faulted. These structures define the Skeena Fold Belt, a thin-skinned fold and thrust belt of Cretaceous (to possibly earliest Tertiary) age (Evenchick, 1991). The dominant structures are northeast vergent, open to close folds of about 100 m to 1000 m wavelengths. Larger

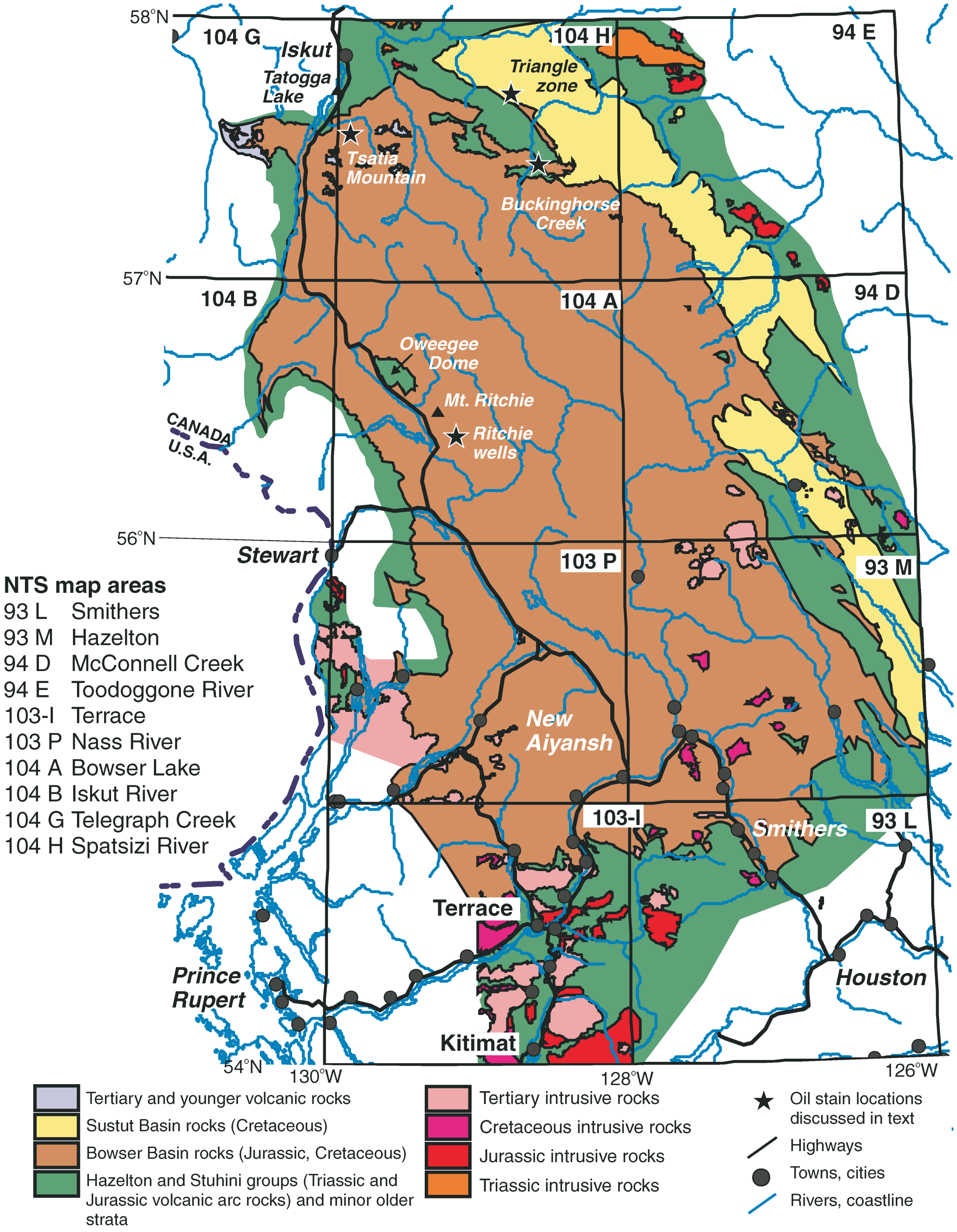

Figure 2. *Map of Bowser and Sustut basins outlining areas of study and locations of crude oil samples discussed in text.*

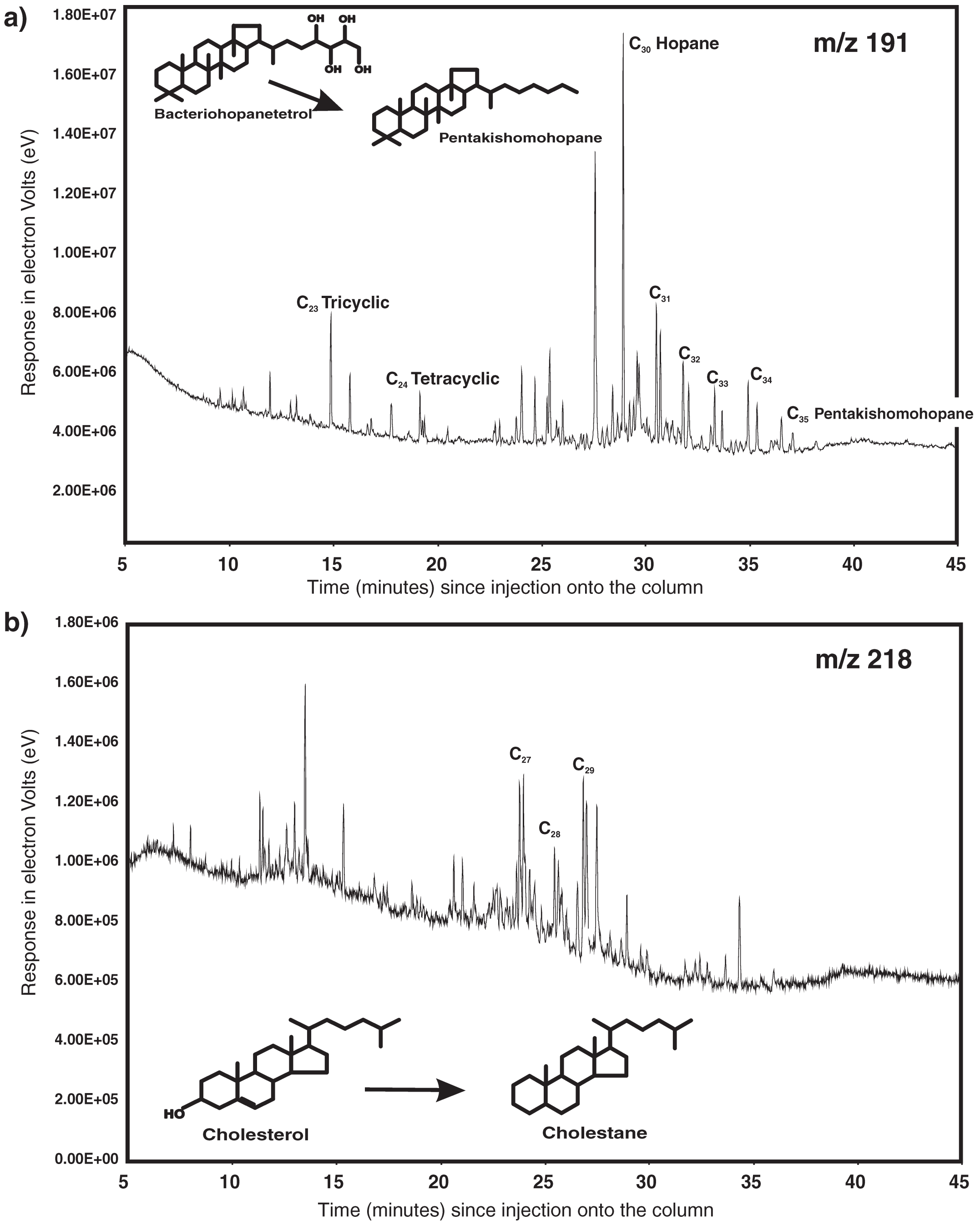

***Figure 3. a**) Gas chromatograph mass fragmentogram showing the hopanoid alkanes, which are primarily derived from bacteriohopanetetrol, a cell wall rigidifier in prokaryotic organisms. The ratio of hopanes in the homologous group indicated by double peaks on the right is controlled by depositional environment physical conditions. This sample shows that C34 hopanes are prominent, due to the accumulation of the source rock in an environment where anhydrite of gypsum was accumulating. This indicates that the source rock of the oil stains in the Muskaboo Creek assemblage at Tsatia Mountain was deposited in a carbonate-evaporite marine depositional environment, probably in the underlying Stikine succession. **b**) Gas chromatograph mass fragmentogram showing the cholestane-like molecules, which are primarily derived from cholesterol, a cell wall rigidifier in eucaryotic organisms. The ratio of C28 to C29 steranes is known to increase with geological age, due to biochemical evolution in the marine biosphere. The ratio of C28/C29 steranes observed here indicates that the source rock of the oil stains in the Muskaboo Creek Assemblage at Tsatia Mountain is a Paleozoic marine rock, probably in the underlying Stikine succession.*

wavelength folds are associated with structural culminations of competent volcanic rocks of Stikinia and locally with competent thick conglomerate units. The dominant fold trend is northwest; domains of northeast trends occur locally on the west side of the fold belt.

Initial research has been to identify and determine the nature of effective petroleum systems from samples previously collected, and to begin new geoscience studies involving mapping, sampling, and analysis. Preliminary results are presented below.

PROGRESS IDENTIFYING EFFECTIVE PETROLEUM SYSTEMS

New fieldwork and the analysis of existing samples has identified, extracted, and characterized crude oil occurrences from four locations in Bowser and Sustut basins (Fig. 2): 1) Tsatia Mountain, a breeched oil field in Bowser Lake Group (Osadetz et al., 2003); 2) Tango Creek Formation (Sustut Group) sandstone in the roof of the triangle zone; 3) Eaglenest (deltaic) assemblage of the Bowser Lake Group in the footwall of the Crescent Fault near the mouth of Buckinghorse Creek; and 4) south of Oweegee Dome, where one of the two Ritchie wells, Amoco Ritchie a-3-J/104-A-6, shows extensive oil stains which were extracted from samples at depths of 2115.7' (644.9 m), 4337.0' (1321.9 m), 4723.4' (1439.7 m), and 6745.0' (2055.9 m). This well may also contain a porous interval containing either 'by-passed petroleum pay' or fresh water. The nature of the wireline-log resistivity anomaly is uncertain as some of the crude oil extracts are biodegraded, and fresh water, like hydrocarbons, is resistive. In the same well Koch (1973) reported other petroleum shows including both dry and wet gas in cuttings samples at depths less than 2600' (792.5 m) where the gas detector indicated more than 40 units, compared to background readings of 10–20 units. In addition to the stains noted above, there is an anecdotal report of an unconfirmed flammable natural-gas seep into Tatogga Lake (Osadetz et al., 2003).

Analysis of the molecular composition of these oil stains and seepages has identified at least two distinct compositional families of crude oils. One is inferred to be derived from Paleozoic carbonate source rocks in underlying Stikinia (Fig. 3a, b) and the other is inferred to be derived from Jurassic or younger sources in the Hazelton-Bowser-Sustut successions. The source rocks of these petroleum systems have not been identified explicitly, nor have the oils been correlated to solvent extracts from potential source rocks, although potential source rock intervals have been identified in a variety of stratigraphic positions.

These results are important for two reasons. First, the preservation of crude oils is strong confirmation of the revised thermal maturity model for the basin (Evenchick et al., 2002) and second, the identification of potential petroleum systems with sources in the Stikine Assemblage indicates that Hazelton Group potential reservoirs might also be prospective for petroleum accumulation. Existing petroleum resource assessments (P.K. Hannigan, P.J. Lee, and K.G. Osadetz, unpub. internal report, 1995) do not attribute petroleum potential successions underlying Bowser Lake Group strata, which must, because of these discoveries, be attributed a significant petroleum potential.

New field examples of rocks potentially stained with crude oil were identified during paleomagnetic sampling, which involves forcing water past a diamond-drill bit. Oil was released from all Stikinia rocks (limestone, volcanic flows, volcaniclastic turbidite and conglomerate) sampled at Oweegee Dome and from Bowser Lake Group sandstone turbidite at Mount Ritchie (Fig. 2, 4). Evidently oil has been forced through the entire stratigraphy in these areas.

MAPPING AND RELATED SAMPLING ACTIVITIES

Regional thermal maturity study

Sampling for organic maturity and petrology studies will provide broader geographic coverage in support of the effective petroleum studies described above. K. Osadetz and T. Poulton collected 35 samples from the southeastern

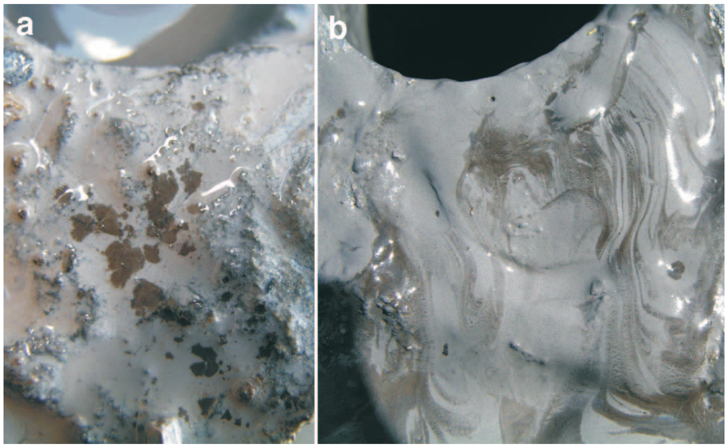

Figure 4.

*Oil (medium brown) released from **a**) Permian limestone at Oweegee Dome and **b**) Late Jurassic sandstone at Mount Ritchie during paleomagnetic sampling. At the top of each photograph is the lower quarter of a drill hole 3 cm in diameter.*

Bowser Basin, J. Haggart collected 41 samples from the south-central Bowser Basin, and the mapping team in McConnell Creek area collected 125 samples from the Bowser and Sustut basins.

Paleomagnetic study

The diagenetic processes associated with hydrocarbon maturation and migration also transform magnetic minerals (iron oxides and sulphides). Thus, paleomagnetic methods provide a means of characterizing diagenetic processes and constraining the relative timing of tectonic and diagenetic events. For example, in the southern Canadian Rockies a diagenetic front which swept ahead of the deformation front and a late syntectonic uplift and cooling event were recognized (Enkin et al., 2000).

The Oweegee Dome and Mount Ritchie (Fig. 2) areas expose a Devonian, Permian, Triassic, and Jurassic stratigraphy that offers many opportunities for paleomagnetic field tests (clast, contact, and tilt tests). Over four days, 22 sites consisting of four to eight oriented cores (2.5 cm diameter, approximately 10 cm long) were collected. These should allow determination of ages of diagenesis, although statistical robustness will require additional sampling. With tilt tests based on two ages of deformation, and clast tests in primary depositional settings (conglomerate) and in late-stage vein deposits, diagenetic events which occurred between the Triassic and Tertiary may be dated.

The mode of diagenesis (e.g. heating, local or transported fluids) can be characterized by analyzing the magnetic carriers and their history in the different rock types. As previous studies have shown, orogenic regions with rich diagenetic histories can produce rocks containing several components of magnetic remanence, each providing evidence for phases of deformation, burial history, igneous heating, and fluid migrations.

Geoscience framework studies in McConnell Creek (NTS 94 D) map area

McConnell Creek map area (Fig. 2, 5) was chosen for stratigraphic and structural mapping because the level of understanding of the distribution of map units there was considered to be the most rudimentary, and because parts of the Bowser Lake and Sustut groups have organic maturity levels conducive to the generation of natural gas (Evenchick et al., 2002). The first systematic mapping of west McConnell Creek map area, which is underlain mainly by Bowser Lake and Sustut group strata, was a brief reconnaissance in late June and July of 1992 (Evenchick and Porter, 1993); this was the basis for assignment of lithofacies assemblages in the compilation of Evenchick et al. (2001). Biostratigraphic studies include those of the Bowser Lake Group (Jeletzky, 1976) and upper Hazelton Group (Jakobs, 1993). The most recent systematic mapping of east McConnell Creek map area, which is underlain primarily by Sustut Group and strata underlying Bowser Lake Group was conducted by Richards (1976). Regional study of the Sustut Basin was by Eisbacher (1974).

Stratigraphy

Upper Hazelton Group

Clastic rocks of the upper part of the Hazelton Group were examined in the two major areas of exposure, Diagonal Mountain and Motase Peak (Fig. 5). In both, the areal extent of Hazelton Group is greater than previously represented (Jakobs, 1993; Evenchick et al., 2001). Its contact with Bowser Lake Group is difficult to place because it is gradational, neither unit has a consistent prominent stratigraphic marker near the contact, and structural complexity obscures stratigraphic relationships.

Strata examined by Jakobs (1993) near Diagonal Mountain are rusty-weathering, varicoloured, thinly bedded to laminated siliceous siltstone and tuff. These beds, described more thoroughly by Jakobs (1993), are typical of coeval (Toarcian to Bajocian) upper Hazelton Group clastic successions elsewhere around the Bowser Basin where they are known informally as ‘pyjama beds’. The section includes intervals of strongly to weakly rusty-weathering, cleaved, black or dark grey siltstone with varying proportions of white or light grey laminae assumed to be tuffaceous. Jakobs (1993) noted that the contact with Bowser Lake Group is transitional; in the siltstone described above the proportion and thickness of tuff decreases upsection to the contact and the intensity of cleavage increases. Our observations are that the contact mapped by Jakobs (1993) is approximately at the lowest sandstone, and that rusty-weathering siltstone beds with tuffaceous laminae and tuff beds occur higher in the section. In the section west of Diagonal Mountain the highest rusty-weathering strata, at least 100 m above the lowest sandstone, include tuff beds to 30 cm thick, and the lowest chert-pebble conglomerate is about 15 m higher. Because the contact previously mapped is within the rusty-weathering succession, and the lowest sandstone is difficult to trace laterally, we place the contact at the top of the rusty-weathering succession. Additional work is required to test this preliminary interpretation. The previous contact included late Bathonian strata in the Hazelton Group, as does our current interpretation (Jakobs, *in* Evenchick et al. (2001) for ages). Moreover, all definitive Bowser Lake Group within 70 km of Diagonal Mountain is Oxfordian or younger. Therefore, the contact is likely younger (?Callovian) here than elsewhere in the northern basin (Bajocian–Bathonian). Fossil collections and U/Pb (zircon) samples from tuff in the highest strata will aid resolution of the age of the contact. Although the new contact (Fig. 5) is only about 200 m higher stratigraphically than previously depicted, the extent of Hazelton Group is over five times greater because folds and thrust faults repeat the section.

Near Motase Peak (Fig. 5), identifying the contact is further complicated by the absence of conglomerate in the lowest Bowser Lake Group, and by the abundance of rusty-weathering zones presumably related to Tertiary intrusions. Typical rusty-weathering, striped, upper Hazelton Group clastic rocks are overlain by a thick section of brown- to rusty-weathering siltstone punctuated by subordinate horizons of chert sandstone and rare polymict volcanic clastic

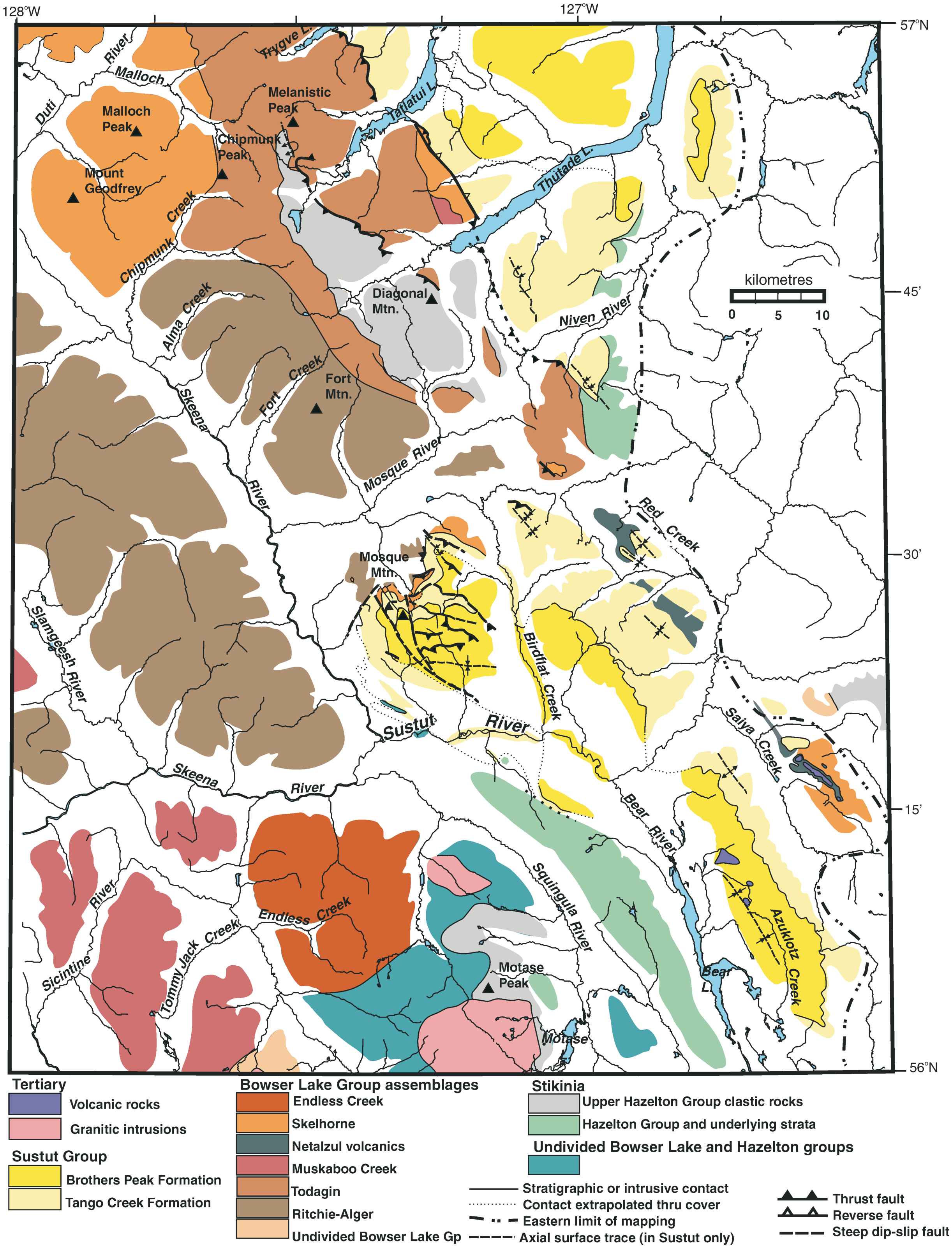

Figure 5. *Generalized and preliminary map of the distribution of Hazelton, Bowser Lake and Sustut groups, and lithofacies assemblages of the Bowser Lake Group, in the west three-quarters of McConnell Creek map area. Eastern parts* modified from *Richards (1976).*

conglomerate. Siltstone is well over 1000 m in structural thickness, but structural complexity precludes determination of primary thickness.

Bowser Lake Group

In this report we use the broad lithofacies assemblage terminology of Evenchick et al. (2001) to subdivide the stratigraphy into mappable units (Fig. 5). The terminology was devised for other parts of the Bowser Basin known in greater detail. From relatively limited number of fossil collections of the study area, all strata are assumed to be Late Jurassic.

Large parts of the preliminary compilation for NTS 94 D (Evenchick et al., 2001) are now known to be incorrect. The largest change is that the areas west of the Skeena River and from Chipmunk Peak to south of Fort Mountain (Fig. 5) appear to correspond to the Richtie-Alger assemblage, with dark grey, massive to laminated siltstone intercalated with fine-grained, thin sandstone beds which display Bouma turbidite internal features. In some areas, thin- to medium-bedded, medium-grained sandstone and rare pebble conglomerate are more common, organized into tens of metres thick successions (Fig. 6) of both fining-thinning-upward and coarsening-thickening-upward successions gradational to the siltstone-dominated parts of the unit. These coarser successions also contain Bouma turbidite features. This assemblage appears to represent distal turbidite sedimentation, with lobes of outer to middle submarine fan deposits intermittently prograding into the area.

Ridges in the Melanistic–Chipmunk Peak area and south (Fig. 5) are dominated by a siltstone and silty mudstone assemblage similar to that described above; however, this assemblage contains only about 10% individual or thin (<15 m generally) stacked successions of pebble-conglomerate (many well sorted with abundant chert pebbles) or medium- to coarse-grained sandstone beds. These laterally pinch out over tens of metres to a few hundreds of metres and occupy slightly channellized bases (Fig. 7). Beds are commonly graded and internally stratified with features typical of high-energy turbidite sequences, or less commonly, are massive and poorly sorted, suggesting debris-flow deposits. Synsedimentary deformation is common, including spectacular slump-folded layers. This unit is correlated with the Todagin assemblage of the Bowser Lake Group and is interpreted as a slope deposystem, probably laterally transitional at least in part to the Ritchie-Alger assemblage.

Northwest of Chipmunk Creek (Fig. 5), strata comprise several hundreds of metres of repeated tens of metres thick coarsening-upward successions of siltstone, sandstone, and minor conglomerate (Fig. 8). A typical succession is approximately 50 m thick with a basal 25–30 m of brown-grey, massive to laminated siltstone, which contains common plant fragments, rare bivalve fragments, and minor discontinuous coal layers; the succession changes gradationally upward to increasing amounts of coarser and thicker sandstone beds which display ripples, planar internal beds or lamination, and increasingly common trough cross-stratification. The upper

Figure 6. Folded Ritchie-Alger assemblage, west of Skeena River (looking north). Ridges are dominated by grey siltstone, very fine-grained sandstone turbidite, with minor approximately 50 thick successions of fine- to medium-bedded sandstone (more resistant beds in photograph).

Figure 7. Todagin assemblage in a northeast-facing slope. Irregular and discontinuous stacked beds of medium- to coarse-grained sandstone and pebble conglomerate (cliff-forming) occur within laminated to thin-bedded siltstone and sandstone.

Figure 8. Looking north at folded and faulted coarsening-upward successions of Skelhorne assemblage, with basal siltstone and carbonaceous to coaly mudstone changing upward to fine sandstone, then resistant sandstone and pebble conglomerate.

parts of these successions in some places are pebble conglomerate, moderately to well sorted, displaying normal grading, planar bedding, and some cross-stratification. This succession is typical of the Skelhorne assemblage elsewhere and is interpreted as a series of prograding deltaic lobes with interdeltaic bay and floodplain deposits.

Near the southwest margin of the map area (Fig. 5), a few ridges contain strata the authors correlate with the Muskaboo Creek assemblage of other parts of the basin. These are dominated by fine-grained sandstone with less abundant mudstone and medium-grained sandstone. Mostly thin-bedded to laminated, these strata include sedimentary structures typical of shallow-marine (shoreface) deposition, including hummocky and swaley crossbedding, symmetrical ripples, lenticular and flaser mudstone-sandstone sets, and rare bidirectional current indicators.

In the vicinity of Endless Creek (Fig. 5) is a map unit dominated by siltstone, with less than 20% fine-grained, orange-brown and light grey sandstone interbeds. Much of the siltstone is brown-grey and massive to poorly laminated, but includes dark grey carbonaceous layers which contain abundant plant fragments in ‘mats’, commonly somewhat altered with a whitish coating (possibly zeolite). Rare in situ rooted horizons are present and marine fossils are absent. Sandstone is commonly tuffaceous, fine- to rarely medium-grained and in some places organized into thin (<5 m) fining-upward successions, with internal ripples, plane beds, and rare trough crossbeds. This unit, apparently more than 1000 m thick (but repeated internally by thrusts and with no base or top exposed, thus true thickness is unknown) appears to be a nonmarine floodplain succession with minor fluvial deposits. It resembles the Jenkins Creek assemblage elsewhere in the Bowser Basin, but contains less sandstone, is markedly less well lithified compared to other Bowser Lake Group strata (Fig. 9), and is locally tuffaceous. Pending age determinations from fossils and tuffaceous samples, we use the new term ‘Endless Creek assemblage’ for this unit.

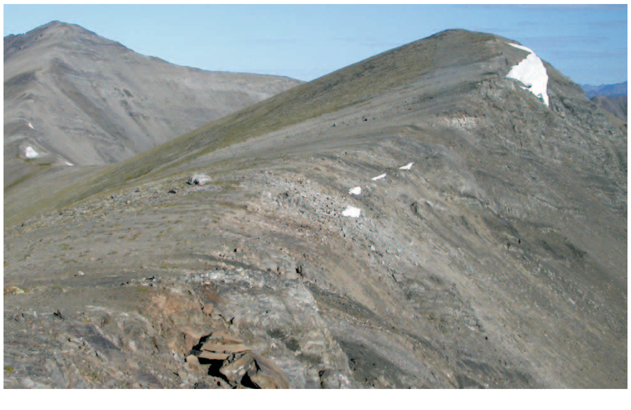

Figure 9. *Looking west along ridges of Endless Creek assemblage siltstone and sandstone. The rounded topography (versus typical Bowser Lake Group ridges) reflects the generally poor induration of this assemblage and its resultant recessive weathering style.*

Another unit absent from the previous lithofacies assemblage analysis is the Netalzul volcanics of Tipper and Richards (1976). It is composed of basaltic and andesitic volcanic breccia and flows with intercalated fine, clastic material, rich in plant fragments. It occurs in a restricted belt east of, and stratigraphically below, the Sustut Group and is associated with Skelhorne assemblage (Fig. 5; Richards, 1976). These volcanics may be the source of volcanic clasts in Bowser Lake strata farther west. Samples of sandstone for U/Pb detrital zircon studies from this unit and others should shed new light on the ages of deposition and provenance of Bowser Lake Group strata.

Sustut Group

The Sustut Group unconformably overlies the Bowser Lake and lower strata. It is a clastic succession more than 2000 m thick described in detail by Eisbacher (1974). It comprises mostly nonmarine siliciclastic rocks with a lower siltstone- and sandstone-dominated succession (Tango Creek Formation) and an upper succession more than 800 m thick, dominated by sandstone, with lesser conglomerate and siltstone, and minor, but obvious white-weathering tuffs and tuffaceous sandstone and siltstone layers (Brothers Peak Formation). New observations include realization that the Tango Creek– Brothers Peak formation contact is more difficult to map here than farther north (e.g. the type sections and farther northwest) because the lowest tuff (defined as the base of the Brothers Peak by Eisbacher (1974)) is difficult to recognize in low-lying areas, and may be significantly lower than the lowest conglomerate. For example, north of Tatlatui Lake recognition of a thin, subtle tuff horizon well below the contact mapped by Eisbacher (1974) caused the present authors to interpret the contact as lying 3 km southwest of the previous interpretation.

Northwest of the study area the Tango Creek Formation is early Albian to late Campanian and Brothers Peak Formation late Campanian to early Maastrichtian (A. Sweet *in* Evenchick et al. (2001)). Samples of tuffaceous layers for U/Pb geochronological analysis, and of sandstone beds for U/Pb detrital zircon studies, should shed new light on the age of deposition and provenance of local Sustut Group.

Structure

Northeast-verging folds and thrust faults characterize the structural style of all stratified rocks in the study area. They formed during late Mesozoic deformation of the Skeena Fold Belt (Evenchick, 1991), and are locally cut by Cenozoic extensional and oblique-slip faults. In the Hazelton and Bowser Lake groups the dominant structures are open to tight, northwest-trending detached folds which typically have very steep to overturned, northeast limbs and southwestward inclined to subvertical axial surfaces. Recumbant folds are rare. The core of a recumbant anticline in the Hazelton Group north of Diagonal Mountain is exposed for 2 km across strike. Although most folds in Bowser Lake and Hazelton groups are disharmonic detachment folds and faulted detachment folds, transported detachment folds with spectacular high-angle hanging wall cutoffs are also common (Fig. 10). Fold geometries are most readily mappable in areas with resistant-weathering sandstone, conglomerate, or siliceous siltstone beds. Individual competent beds show little or no thickening in the hinge zones (parallel 1B or 1C folds) that vary from angular chevron to more rounded concentric (Fig. 11). Fold wavelength varies from a few hundred metres to 1.5 km, with changes in wavelength inferred to largely reflect changes in depth to detachment. In excellent exposures of the turbiditic assemblage near Fort Mountain and the Skelhorne assemblage near Malloch Peak, longer and shorter wavelength folds occur together. At Malloch Peak longer wavelength folds occur where individual conglomerate bands are thicker (Fig. 12). In this area, coal seams are recrystallized to what appears to be meta-anthracite and an intense axial-planar cleavage occurs in matrix-supported conglomerate near the hinge zone of close and open folds. An axial-planar cleavage usually occurs in fine-grained turbiditic strata north of Mosque Creek and west of Skeena River; it is intense in fine-grained rocks in most of the area west of Skeena River, and locally south of the Skeena River.

Thrust faults in the Hazelton and Bowser Lake groups have strike lengths less than 10 km. They commonly occur within the faulted out cores of folds, or are associated with transported detachment folds. Mapped thrust faults in unfolded stratigraphy are uncommon. Between Trygve and Tatlatui lakes, the contact between the Bowser Lake and the Sustut groups is a relatively well exposed southwest-dipping thrust fault. Immediately north of Thutade Lake the fault separating the Bowser Lake and Sustut groups is a steep east-dipping reverse fault (Fig. 13) that has offset the southwest-dipping thrust fault several hundred metres. Rotation of strata adjacent to the fault suggests possible late normal displacement.

The intensity of deformation of the Sustut Group varies considerably. In the southern belt, south of Bird Hill, northeast-vergent folds, detached folds, and thrust faults are common. Thrust faults swing to southward dips in the Mosque Mountain area. Locally these cut pre-existent north-striking folds. Detached folds and thrust faults become uncommon south of Sustut River until east of Bear Lake, where the Sustut

Figure 10. *View south to transported detachment fold with steep hanging-wall cutoff in upper Hazelton Group, west of Diagonal Mountain.*

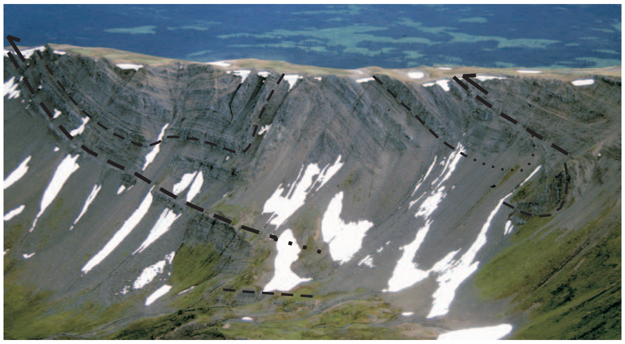

Figure 11. *Disharmonic detachment folds east of Bird Hill; view to south.*

Figure 12. *Disharmonic detachment folds and faulted out synclinal core outlined by conglomerate of the Skelhorne assemblage, west side of Malloch Peak; view to northwest.*

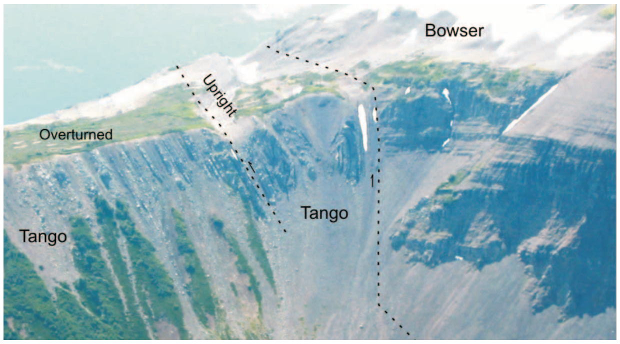

Figure 13. *Steep east-dipping fault separating Bowser Lake and Sustut group strata, north of Thutade Lake; view south. See text for discussion.*

Group is deformed by a few large wavelength, gentle to open folds. The northern belt of Sustut Group has generally similar structural style to that along strike to the northwest (Evenchick et al. (2001) and references therein), with a southwest region displaying significant shortening, and a northeast region, including much of the Brothers Peak Formation, with very minor shortening. In northern McConnell Creek map area, westernmost exposures of Sustut Group are commonly overturned, southwesterly dipping Tango Creek Formation in the footwall of a thrust fault carrying Bowser Lake Group. These overturned beds locally form the 1–2 km wide west limb of an overturned syncline. Thrust faults and most folds die out 5–10 km farther northeast where strata outline long wavelength gentle folds. North of Thutade Lake, folds a few kilometres east of the main deformation and the eastward dip of strata into a syncline indicate deformation at depth.

Cenozoic faults in the Mosque Mountain area offset compressional structures deforming the Sustut Group. Two steeply west- to southwest-dipping faults have normal stratigraphic separation and a near-vertical northeast-trending fault has north-side-up stratigraphic separation.

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