

PETROLEUM SOURCE ROCK POTENTIAL OF LOWER TO MIDDLE JURASSIC CLASTICS, INTERMONTANE BASINS, BRITISH COLUMBIA

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INTRODUCTION

The presence of suitable petroleum source rocks is a necessary condition for the presence of an effective total petroleum system which constrains the petroleum potential of under-explored basins such as those within the Intermontane region of British Columbia (Curiale, 1994). Hayes (2002), in his report on the crude oil and natural gas potential of the Nechako area of British Columbia, indicated that a major issue for the basin was the lack of recognition of a good petroleum source rock horizon. This perception is applicable to all the Intermontane basins due to the limited amount of crude oil and natural gas exploration activity and a subsequent lack of relevant information.

This paper summarizes some of our current understanding of Early and Middle Jurassic stratigraphy within parts of the Intermontane region of the Canadian Cordillera which may have petroleum source rock potential. It also provides an update on the activities undertaken by the Resource Development and Geoscience Branch (RDGB) of the British Columbia Ministry of Energy and Mines to address the issue through recognition and basic characterization of potential source bed horizons within the Intermontane region. This is part of a much larger collaborative program which began in 2001, between the Geological Survey of Canada (GSC) and the RDGB to look at energy related aspects of the Intermontane Basins. The RDGB is also collaborating with the GSC on a new, multiyear initiative, which started in 2003 entitled "Integrated Petroleum Resource Potential and Geoscience Studies of the Bowser and Sustut Basins".

Subsurface characterization of potential Cretaceous and Tertiary petroleum source rocks within the Nechako area has been documented by Hunt (1992) and Hunt and Bustin (1997). Osadetz *et al.* (2003) obtained RockEval pyrolytic and total organic content (TOC) data for well cuttings from all bore holes within the Nechako and Bowser basins. Evenchick *et al.* (2003) reported bleeding crude oil from paleomagnetic coring operations in fine grained clastics that may be either migrated petroleum or residual crude oil stains in potential petroleum source rocks. The purpose of the present study was to sample potential source bed horizons of Early and Middle Jurassic age in areas where subsurface data is lacking. In addition, the following brief summary on the extent of potential source bed horizons of this age within certain parts of the Canadian Cordillera indicates these units are potentially regionally distributed.

The author, as part of the regional mapping program examining Bowser Lake and Sustut group rocks within the western portion of the McConnell Creek sheet (094D; see Evenchick *et al.*, 2003), sampled potential petroleum source rock horizons in this area (Figures 1, 2). In addition, one week was spent examining possible source beds on the east side of the Nechako area, within the Quesnel Trough (Figures 1, 3 and 4). Approximately 25 samples were collected in the McConnell Creek area and 12 samples were taken from the Quesnel Trough. Further sampling is planned in both regions during the 2004 field season.

Current research in the Bowser Basin has recognized crude oil staining in surface and subsurface samples of the Bowser and Sustut groups (Osadetz *et al.*, 2004, 2003; Evenchick *et al.*, 2003). The data suggests the presence of at least three source bed horizons, one of Jurassic to Cretaceous age, another within carbonate sequences of Paleozoic age and a third of fresh water origin. Data in this paper, in part, reviews sampling undertaken in the field in an attempt to locate the stratigraphic horizons responsible for the staining.

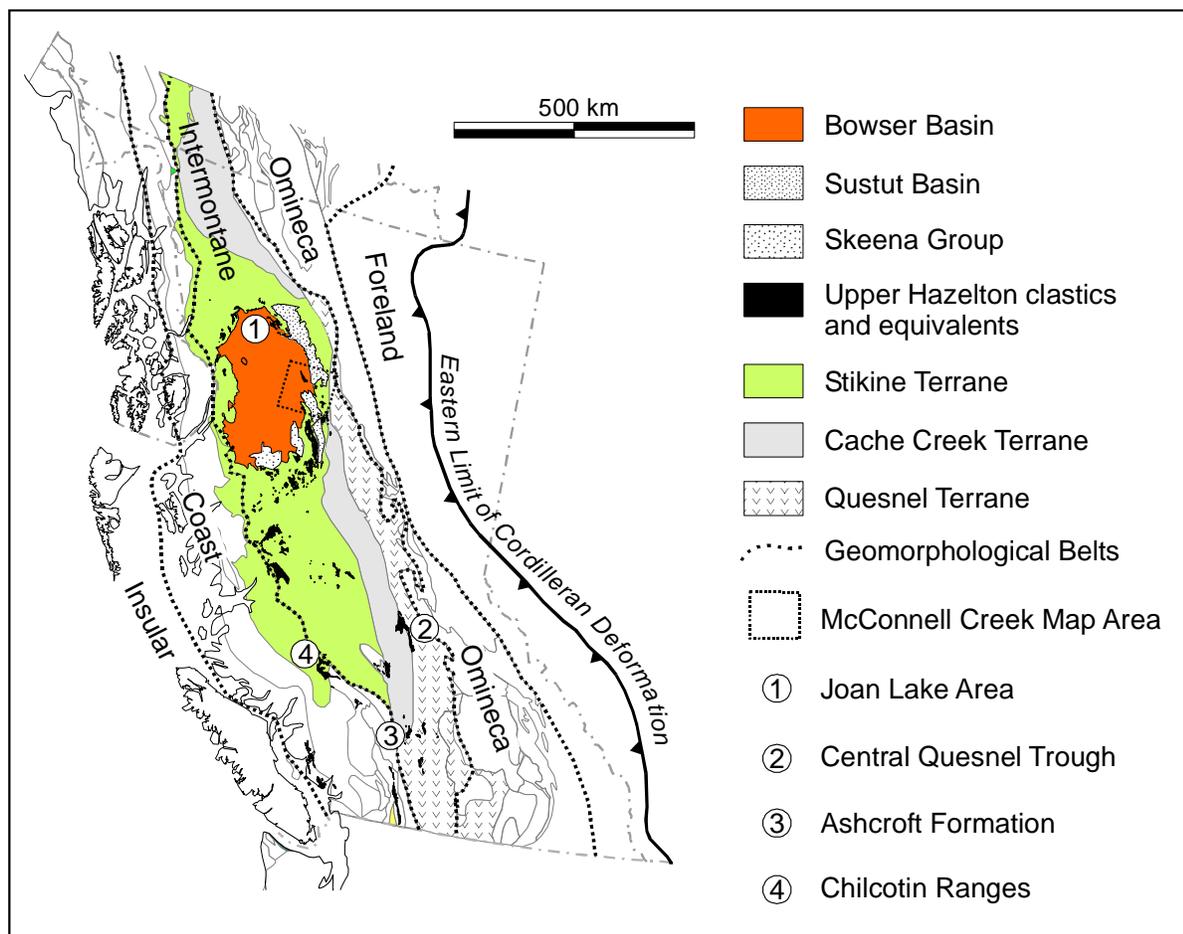


Figure 1. Geomorphological belts of the Canadian Cordillera together with selected terranes and locations of areas mentioned in text or shown in subsequent diagrams. The regional distribution of Early to Middle Jurassic clastics is also indicated. Base map modified from Osadetz *et al.*, 2003.

In Bowser-Sustut and Quesnel Trough areas, the focus of sampling was within black carbonaceous sequences of Early to Middle Jurassic age which are believed to underlie coarser clastic units of the basins. This stratigraphic interval encompasses the Toarcian – Aalenian time period, which on a world-wide scale, is inferred to record an interval of anoxic water conditions resulting in enhanced preservation of accumulated organic material (Jenkyns, 1988).

World wide oceanic anoxic events are documented at several stratigraphic levels within Jurassic and Cretaceous sedimentary rocks. In addition to the Toarcian, these include intervals within the Aptian-Albian, Cenomanian-Turonian and the Santonian stages (Jenkyns, 1980, 1988). Most of these time periods are well represented within the Western Canada Sedimentary Basin and have contributed a large proportion of the petroleum within known pools (e.g. First and Second White Speckled Shale, Base of Fish Scales and Fernie Formation; see Creaney *et al.*, 1994).

BOWSER AND SUSTUT BASINS

The Bowser and Sustut basins are overlap assemblages deposited on an allochthonous terrane of the Canadian Cordillera. Located in north-central British Columbia, they are found within the northern part of the Intermontane Belt and sit on Devonian to Jurassic rocks of Stikinia (Figure 1).

There are three main successions within these basins: the Middle Jurassic to mid-Cretaceous Bowser Lake Group; the Lower to mid-Cretaceous Skeena Group and the mid- to Upper Cretaceous Sustut Group. Bowser Lake strata represent a southwestward, prograding delta to distal submarine fan sequence and contains marine to non-marine sediments (Evenchick *et al.*, 2001). Skeena rocks, located along the southern part of Bowser Basin, are inferred to have been deposited in marine to non-marine deltaic environments, but their relationship to Bowser Lake stratigraphy is uncertain (Tipper and Richards, 1976). The Sustut Group is inferred to have been deposited in fluvial to lacustrine environments (Eisbacher, 1974) which were deposited in a foreland basin east of deforming Bowser Lake strata (Evenchick and Thorkelson, *in press*).

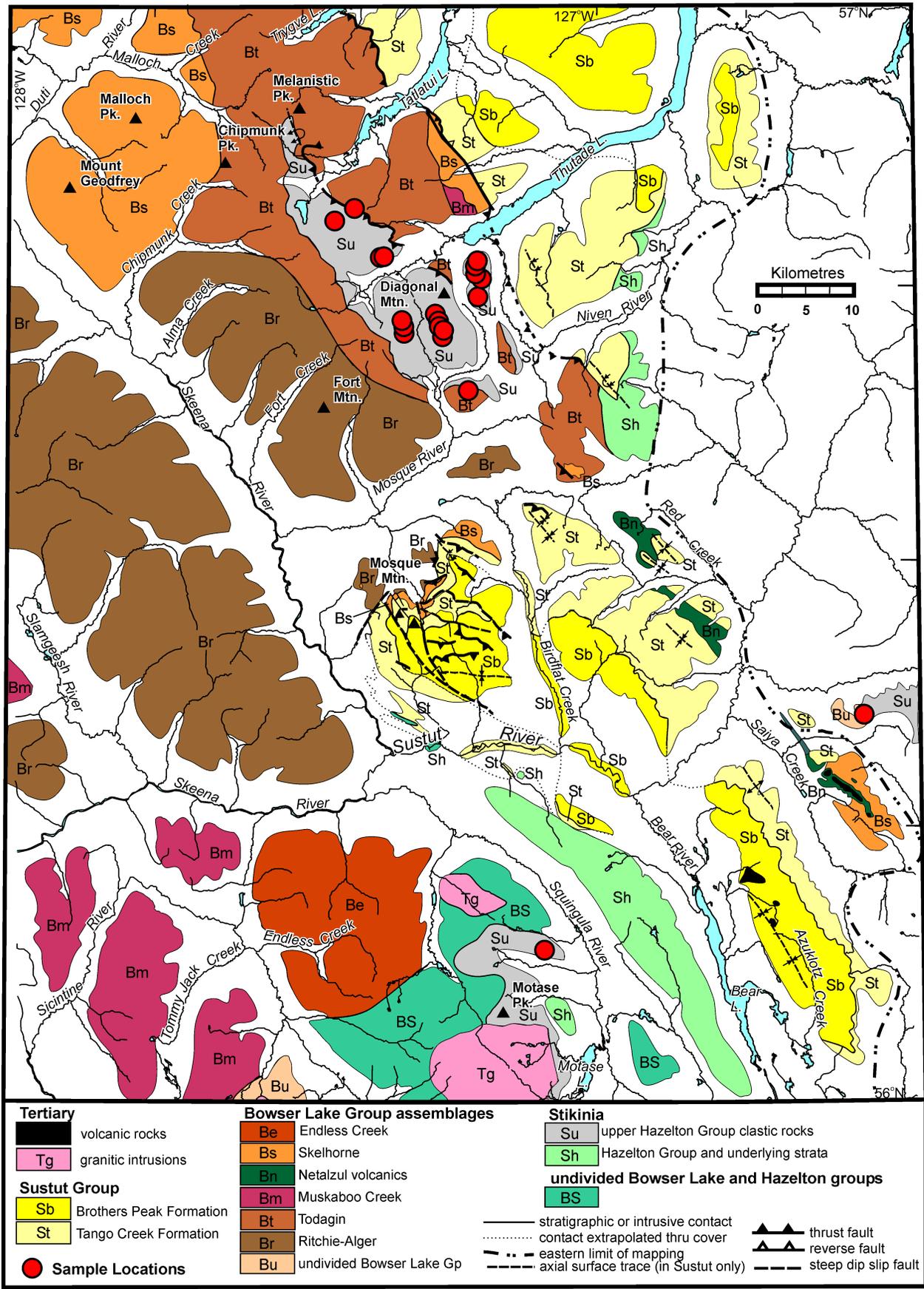


Figure 2. Generalized geology of the McConnell Creek map area showing sample locations. Modified from Evenchick *et al.*, 2003.

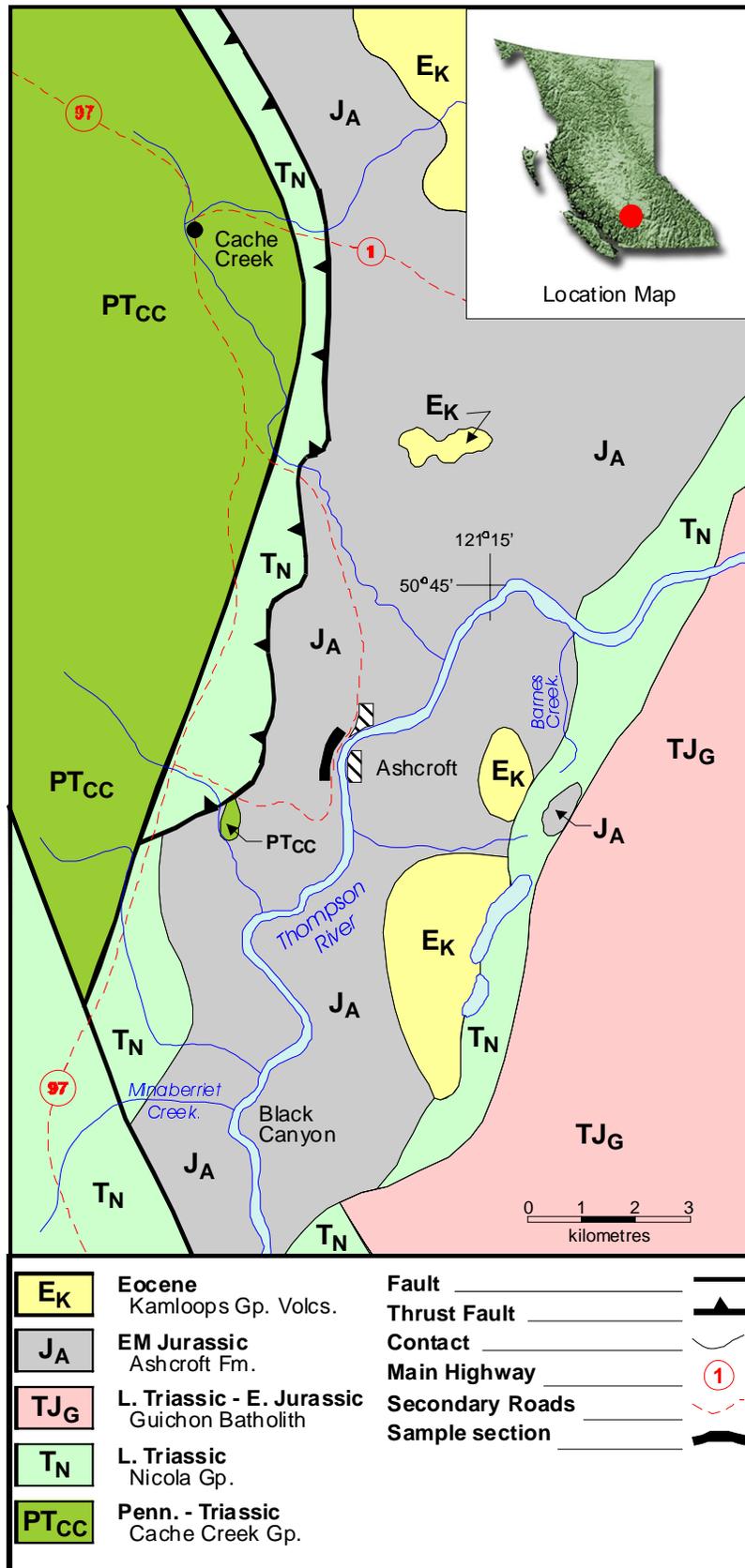


Figure 3. Generalized geology map of the Ashcroft area showing extent of Ashcroft Formation and sample locations. Modified from Travers, 1978.

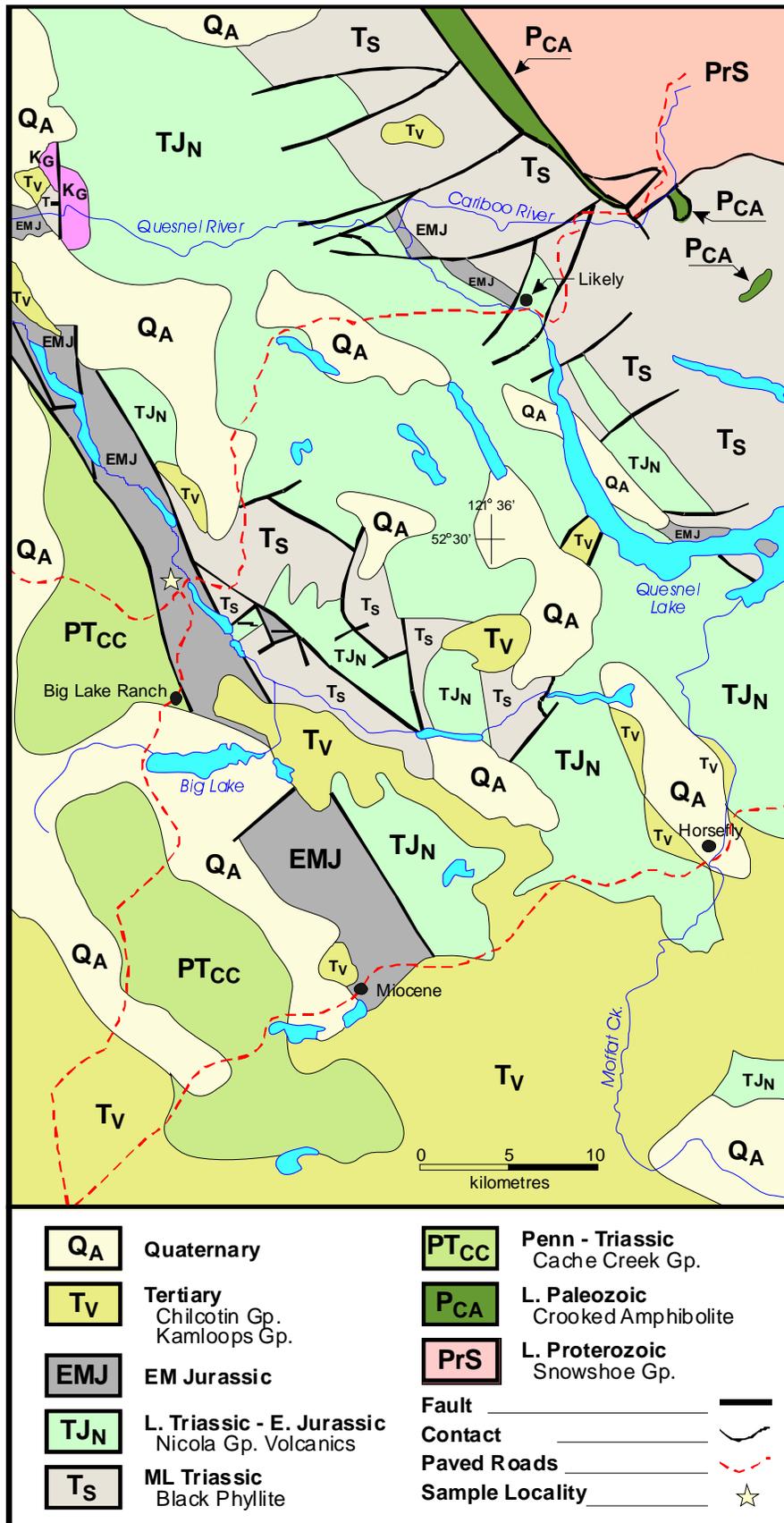


Figure 4. Generalized geology of Quesnel Terrane west of Quesnel Lake, showing distribution of Early to Middle Jurassic clastics and sample location.

Bowser, Skeena, Sustut and underlying Stikinia rocks are deformed into dominantly northwest-trending fold and thrust structures comprising the Skeena Fold Belt (Evenchick, 1991). Evenchick (1991) demonstrated that this thin skinned structural belt of mid-Cretaceous age contains a well developed triangle zone at its northeastern margin within Sustut strata.

Potential Source Beds

In the area of the Bowser and Sustut basins, black organic-rich shales have been recognized within the Lower to Middle Jurassic sediments of the upper Hazelton Group (Thomson *et al.*, 1986). In addition, slope and submarine fan facies of the Bowser Lake Group contain abundant sections of black shale which may have elevated organic contents.

Effective Mesozoic and Paleozoic petroleum source rocks are postulated based on analysis of crude oil stains from surface and subsurface samples of Bowser and Sustut lithologies (Evenchick *et al.*, 2003; Osadetz *et al.*, 2003; 2004). Indirect confirmation of a Paleozoic source horizon is indicated by crude oil staining in cored paleomagnetic samples taken from Permian and Triassic sequences (Evenchick *et al.*, 2003). Stikine Assemblage strata contain black, carbonaceous sequences of Devon-Mississippian age (Logan *et al.*, 2000) similar in composition to other time-equivalent sequences throughout Cordilleran terranes and within the miogeocline (*e.g.* Exshaw and Bakken formations).

HAZELTON GROUP

Strata of the Bowser Lake Group overlie fine grained clastic sedimentary rocks of the upper Hazelton Group (Figure 2). This latter succession is dominantly a volcanic sequence of broadly Early to Middle Jurassic age (Tipper and Richards, 1976). Although upper Hazelton clastics are well developed below the Bowser Lake Group, these rocks locally grade into dominantly volcanic sequences.

Terminology of the Hazelton Group varies along the basin margins. In the northwestern part of the basin, upper clastics are termed the Spatsizi Formation (Evenchick and Thorkelson, *in press*) whereas further west, in the Eskay Creek and Forrest Kerr areas this horizon contains 3 facies with varying proportions of volcanic rocks and is referred to as the Salmon River Formation (Anderson, 1993; Logan *et al.*, 2000). In southern Bowser Basin, Tipper and Richards (1976) subdivided upper Hazelton clastics into the Nilkitkwa and Smithers formations.

Upper Hazelton Group clastic rocks span Early Pliensbachian to Bajocian-Bathonian times in the northern Bowser Basin (Thomson, *et al.*, 1986; Evenchick *et al.*, 2001). Volcanic rocks become increasingly volumetric northward in Spatsizi River map area (Thomson *et al.*, 1986). There, upper Hazelton Group rocks have been

formally assigned to the Spatsizi Formation (Evenchick and Thorkelson, *in press*). In the Joan Lake area of this map region, Thomson *et al.* (1986) initially assigned these rocks to group status and defined the Joan, Wolf Den, Melisson, Abou and Quock formations. Although subdivision of this horizon is possible in the Joan Lake area, Evenchick and Thorkelson (*ibid.*) suggested this succession be lowered to formation status (and the constituent formations to members) because it was difficult to recognize all units on a regional scale and strata in similar stratigraphic positions around the Bowser basin are formations in the Hazelton Group.

In the Joan Lake area, Upper Pliensbachian to Middle Toarcian Wolf Den and Aalenian Abou members are dominated by black to dark grey shales which, together with their faunal assemblages, suggest anoxic water conditions (Thomson *et al.*, 1986). The Bajocian Quock Member, with its distinctive sections of interlayered black siliceous carbonaceous siltstone, shale and light coloured ash tuff ("pyjama beds"), are also inferred to have been deposited in anaerobic conditions. Thomson *et al.* (*ibid.*) describe parts of these lithologies as containing up to 20 per cent organic material. The authors speculated this horizon would have acted as an excellent petroleum source rock and noted its well-placed stratigraphic position at the base of the Bowser Lake sequence.

Although the members of the Spatsizi Formation in the Joan Lake area may represent a restrictive facies of the upper Hazelton Group, the overall basinal, anoxic conditions (as inferred for upper Hazelton clastics around the margins of the Bowser Basin, and within structural windows or culminations) suggests that these organic-rich lithologies may underlie much of the basin (Thomson *et al.*, 1986).

MCCONNELL CREEK MAP AREA (094D)

The author spent approximately 5 weeks in the western and central parts of the McConnell Creek map area as part of a provincial-federal cooperative regional mapping program (Evenchick *et al.*, 2003). During this time sections of the upper Hazelton Group were examined and sampled in the Diagonal Mountain and Motasse Peak areas for characterizing of organic content. In addition, parts of the lower Bowser Lake Group together with black siltstone or shales in the Ritchie-Alger and Todagin assemblages were also sampled.

Upper Hazelton rocks in this area have been previously described by Tipper and Richards (1976), Jeletzky (1976), Evenchick and Porter (1993), Jakobs (1993) and Evenchick *et al.* (2003). The largest area covered by these rocks in the western McConnell Creek map sheet is roughly centred on Diagonal Mountain. The total thickness of the upper Hazelton Group is difficult to determine as the base is not exposed, however the exposed section is conservatively in the order of 300 m thick. The dominant lithology is variably cleaved, rusty to orange weathering, blocky, dark grey to black, siliceous

siltstones and shales with variable proportions of thin bedded white to pinkish tuff (Photo 1). These tuffaceous lithologies comprise the typical Toarcian to Bajocian sections of the upper Hazelton Group seen around the Bowser Basin and are informally referred to as the “pyjama beds”. The amount of tuff is variable within sections exposed in the Diagonal Mountain area, but is usually less than 30 per cent of the section, where present. Tuff varies from less than 1 mm to 10 centimeters thick and, although usually homogenous, can display graded bedding or ripple-marks. Parts of the sequence are composed almost entirely of dark grey to black, platy siltstone or shale. Some sections are blue-grey in colour and quite carbonaceous.

Minor lithologies include light grey to grey weathering, calcareous siltstone exhibiting a dark grey-brown colour on fresh surface and brown to grey-brown weathering, grey, micritic to clastic limestone up to 30 centimetres thick, which forms lenses up to several metres in length. Sections of this sequence are rusty weathering and contain several per cent authigenic (or detrital?) pyrite. Pyrite is best developed within tuffaceous sections, although it is also present siliceous siltstone. The anoxic conditions inferred for this sequence, together with the abundance of pyrite, suggests the potential to host sedimentary exhalative mineral deposits.

The contact between the upper Hazelton clastics and overlying Bowser Lake Group is transitional (Evenchick *et al.*, 2003; Jakobs, 1993). Interbedded tuff is lost up-section and the siliceous nature of the siltstone disappears resulting in well cleaved, rusty to brown weathering shales and slate up to 20 m thick. The first thin beds of chert? sandstone are observed at the top of this lithology,

together with the first indications of bioturbation in shale and siltstone. Sandstone becomes more abundant up section and the percentage of rusty weathering horizons decreases. The contact has been placed at the top of the rusty-weathering section, occurring some 100 m above the first sandstone horizon and approximately 15 metres below the base of the first chert pebble conglomerate typical of the Bowser Lake Group (Evenchick *et al.*, 2003).

The present interpretation of the upper contact for the Hazelton Group, would make it as young as late Bathonian (*see* Evenchick *et al.*, 2001; 2003). Evenchick *et al.* (2003) argue that considering the Oxfordian ages for the Bowser Lake Group in the area, the age of this contact may be younger and within the Callovian. The oldest ages for the Hazelton Group in the Diagonal Mountain area are Toarcian (Evenchick *et al.*, 2001). Palfy *et al.* (2000) reported an age of 167.2 +10.5 –0.4 Ma for tuff sampled from ‘pyjama beds’ approximately 4.5 km south-southeast of Diagonal Mountain.

Lithologies at Diagonal Mountain are similar to those of the Quock Member (Thomson *et al.*, 1986). Based on fossil ages (Evenchick *et al.*, 2001), sections at Diagonal Mountain would also be equivalent age to units of the Abou, Melisson and Wolf Den members. The lack of shallower water lithologies at Diagonal Mountain (represented by the Melisson Member) suggests that this unit was either removed below the Late Toarcian unconformity or that it was not deposited. Descriptions of the Wolf Den, Abou and Quock members are entirely consistent with lithologies observed at Diagonal Mountain, although they are not distributed in a simple stratigraphy that can be mapped.

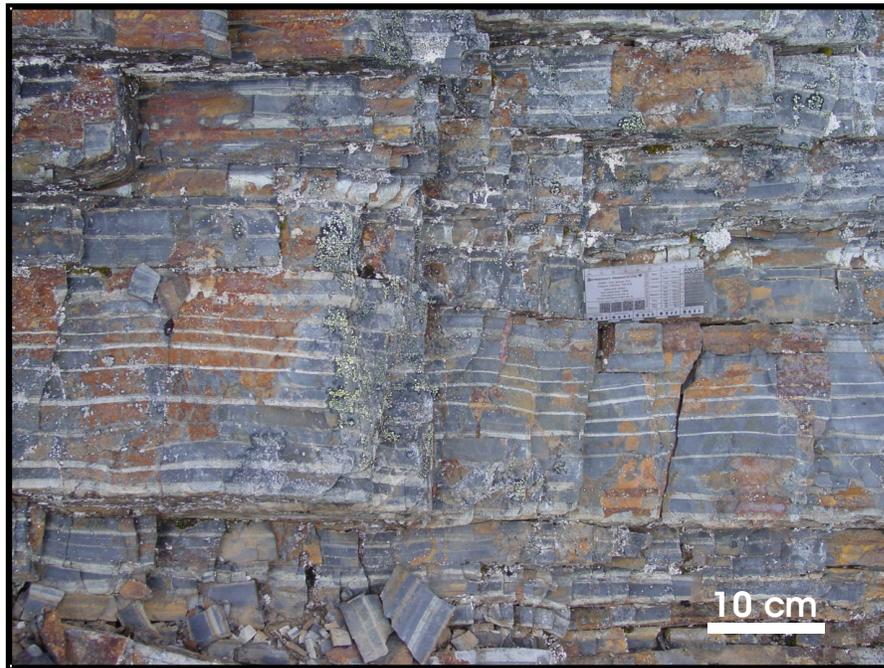


Photo 1. Typical interlayered tuff and dark grey to black siliceous siltstone of the “pyjama beds”, upper Hazelton Group clastics, McConnell Creek map area.

At Motasse Peak, the Hazelton Group also contains the striped, interlayered siltstone and tuff as described in the Diagonal Mountain area. Tuff is also lost up-section resulting in rusty weathering siltstone and shale. The recognition of the upper contact is difficult because of the thick section of rusty weathering siltstones and shales together with a lack of coarse clastic lithologies typical of the basal Bowser Lake Group. There is no definite break in the rusty nature of the siltstone lithologies. This may be due to the presence of nearby Tertiary intrusions, in conjunction with structural complication.

Ritchie-Alger and Todagin assemblages represent coeval, slope and submarine fan assemblages, respectively, of Late Jurassic to Early Cretaceous age. These units have an abundance of dark grey and black fine grained lithologies which may have accumulated abundant organic matter. The Todagin assemblage contains dark grey and black weathering siltstone and shale which are not as dominant within the Ritchie-Alger. These units also are inferred to have been deposited in turbidic deposits and higher energy sequences of chert sandstone and conglomerate, which are volumetrically more important in the Ritchie-Alger assemblage as compared to the Todagin (Evenchick *et al.*, 2001; 2003).

Siltstone units are typically orange-brown to dark grey weathering and massive to thickly bedded. They can display poor cleavage, but are typically blocky to crumbly weathering. They commonly contains thin, orange-brown weathering laminae which are commonly bioturbated. Nodules or discontinuous horizons of orange weathering, grey limestone up to several 10's of centimeters thick are also present within sections of the siltstone. Several horizons (up to 5 m thick) of rusty weathering, black siltstone were also observed in these units.

QUESNEL TROUGH

The senior author spent several days sampling sections of organic-rich shale within parts of the Quesnel Trough. These localities are described by Macauley (1984) as potential oil shale horizons based on descriptions of earlier workers. These sections are within Lower to Middle Jurassic fine clastic rocks, similar in composition to the upper Hazelton Group, and include the Ashcroft Formation in the south and an unnamed sequence near the town of Likely. Both units overlie Triassic to Jurassic arc sequences of the Quesnel Terrane and are considered part of the overlap succession.

Ashcroft Formation

The Ashcroft Formation is well exposed in the area of Ashcroft and comprises approximately 1200 to 1600 metres of carbonaceous shale, siltstone and minor sandstone and conglomerate (Travers, 1978; Duffell and McTaggart, 1952). Exposures east of Ashcroft are

believed to be non-marine in origin (McMillan, 1974; Monger, 1982). Conglomerate, although a minor constituent, is distinctive by its polymict nature, containing clasts derived from Ancestral North America and the Cache Creek and Quesnel Terranes (Travers, 1978; Duffell and McTaggart, 1952). The unit rests unconformably on the volcanics of Quesnellia and possibly the Cache Creek Terrane (Travers, 1978; Monger, 1982).

The age of the Ashcroft Formation is broadly Early to Middle Jurassic and a compilation of fossil localities show this succession to be possibly Sinemurian to Callovian in age (Monger and Lear, 1989; Travers, 1978). Fossils collected from near the base of the unit are possibly Sinemurian in age (Travers, 1978, Frebald and Tipper, 1969) and range up to Bajocian at the same locality (Monger and Lear, 1989). Along the eastern, non-marine part of the sequence, fossil data suggest an unconformity between Pliensbachian and Callovian lithologies (Travers, 1978). Travers (1978) believed that the western succession of Ashcroft strata are inferred to have been potentially deposited during an interval of continuous sedimentation between Sinemurian to Callovian time based on the lack of regolith and channel conglomerate associated with the unconformity in eastern sections. This may be true, however no fossils of Toarcian or Bathonian age have been recovered from this area which could indicate non-deposition, erosion or lack of data.

McMillan (1974) describes up to 10 m of fetid, dark grey, crystalline limestone, in the Barnes Creek area, which he believed to be of bioclastic origin. In other sections along the creek, fetid limestone occurs as clasts within conglomerate deposited above a regolith. Associated shales, as elsewhere in the Ashcroft Formation, are black and carbonaceous. The section here contains Callovian fossils.

In Black Canyon and near the mouth of Minaberriet Creek, Duffell and McTaggart (1952) describe thick sections of black, carbonaceous shale containing Callovian age fossils. This may have been the locality of the suspected oil shale. Similar carbonaceous sequences were recently sampled along the highway into Ashcroft. Further sampling is planned in this area during 2004.

The Ashcroft Formation was sampled near the town of Ashcroft where the unit is well exposed in road and railway cuts (Figure 3). Travers (1978) shows this sequence as being an overturned panel along the footwall of a thrust carrying the Nicola Group. No fossil data is available at this locality, although fossil collections to the south along strike, are Pliensbachian or Sinemurian and Bajocian (Monger and Lear, 1989).

At this locality, the Ashcroft Formation consists of platy and blocky, rusty weathering, dark grey to black siliceous siltstone. Cleavage is well developed locally, but is commonly a spaced parting. Non siliceous siltstone units typically exhibit blue-grey weathering and yellow

sulpha salt residue. Discontinuous light coloured bands were observed (tuffaceous?) and locally contained authigenic pyrite crystals. Some horizons are quite coarse and texturally approached a sandstone. Interbedded with these typical siliceous siltstone sequences are sections of black, crumbly, sooty (carbonaceous) siltstone and shale ranging from 5 to 10 metres thick. These graphitic horizons locally contain 2 to 5 cm thick beds of pale to medium grey, micritic limestone. The entire section at this locality is at least 100 m thick. Both lithologies were sampled at several points along the section. Results of organic petrographic and anhydrous pyrolysis analysis of these samples will be reported subsequently.

Central Quesnel Trough

Oil shales were described southwest of Likely in the early part of the 20th century (Robertson, 1904, 1905; Ells, 1925; Macauley, 1984). Analysis of these rocks demonstrated that they contain appreciable amounts of kerogen and one report indicated a potential value of 25 litres/tonne for producible liquid petroleum (*see* Macauley, 1984). Macauley (*ibid.*) suggested that, based on descriptions and local geology, the unit that was sampled was probably part of the Lower to Middle Jurassic clastic succession overlying arc sequences of Quesnellia (Figure 4).

These Lower to Middle Jurassic sediments are considered overlap assemblages as they contain coarse clastics in their upper parts with cobbles derived from Cache Creek, Quesnel and Ancestral North American sources indicating that they formed after amalgamation of these terranes. This succession is also shown to overlap both Cache Creek and Quesnel Terrane rocks northwest and southeast of Likely (Tipper, 1978).

Panteleyev *et al.* (1996) detailed the geology and metallogeny of central Quesnel Terrane. Units described by these authors which could have potentially been the source of the early samples include the fine grained Pliensbachian to Aalenian siltstones and shales (Units 5 and 6). The older Upper Triassic "Black Phyllite", although composed of dark, fine grained clastics, is generally of too high metamorphic grade (greenschist and higher) to contain any residual kerogen.

These Pliensbachian to Aalenian sediments contain sections of thin-bedded dark grey to grey calcareous siltstone, siltstone and sandstone in the lower part. Polymictic conglomerate occurs in the top of the sequence and can also be interbedded with the finer lithologies. A Pliensbachian to possibly Toarcian age is suggested for the lower fine grained unit whereas Aalenian ammonites were extracted from interbedded fine grained lithologies within the upper conglomeratic sequence (Panteleyev *et al.*, 1996; Poulton and Tipper, 1991). The thickness of these sections is not reported, although structural sections based on the geology of Panteleyev *et al.* (1996) would suggest several hundred metres.

Numerous sections were visited in 2003 based on mapping by Panteleyev *et al.* (1996), but due to the recessive nature of the units and limited time available, only one exposure was found on a road cut along the main highway, near Beaver Lake. This exposure consists of black, sooty siltstone and dark grey to black calcareous siltstone. Both lithologies appear to be quite organic rich. The entire section at this locality was some 10 metres thick. Results of organic petrographic and anhydrous pyrolysis analysis of these samples will be reported subsequently.

REGIONAL IMPLICATIONS

Sampling of Lower to Middle Jurassic organic-rich horizons within the Stikine and Quesnel terranes has shown these lithologies to be quite similar, not only in age, but in overall composition. Both sequences were deposited after underlying terranes coalesced and amalgamated to Ancestral North America, suggesting that sedimentary basins may have been contiguous.

Deep water, fine grained sediments of Early to Middle Jurassic age (Toarcian to Bajocian) appear to be wide spread within the Canadian Cordillera and overlie many of the allochthonous terranes (Monger *et al.*, 1991; Poulton and Tipper, 1991). These units are characterized by dark shales and siltstones interbedded with varying amounts of volcanics and coarser clastics. They are found within northern and central Stikine Terrane (Tipper and Richards, 1976), along the Chilcotin Ranges underlying rocks of the Tyaughton Trough (Umhoefer and Tipper, 1998; Figure 1) and eastward within the Quesnel Terrane (Panteleyev *et al.*, 1996). Clearly the deeper water conditions leading to the deposition of these sediments were extensive in the Canadian Cordillera, although punctuated by several volcanic edifices. The present configuration of these depocentres is a result of dextral strike-slip motion along major, terrane bounding faults since the Cretaceous (Gabielse, 1991).

Lower to Middle Jurassic black shale within both northern Stikine Terrane and Quesnellia are inferred to have been deposited in anaerobic depositional conditions. This time period brackets a major, world wide anoxic event (Jenkyns, 1988) which suggests that many of these sedimentary sequences within the Canadian Cordillera were also deposited in these environments. These low oxygen conditions are conducive to the preservation of organic matter. To the east, within the Western Canada Sedimentary Basin, shale, siltstone and carbonate of the Fernie Group were deposited during the same time period and are inferred to have been deposited under similar conditions. These rocks have proven to be one of the major petroleum source horizons within this basin.

The wide geographic distribution of Lower and Middle Jurassic fine grained sediments suggests these units potentially underly coarser, clastic successions of the Interior Basins. Furthermore, the implied anoxic

depositional environment recorded by these Lower and Middle Jurassic clastics suggests that these successions could have been, under the right conditions, potential sources of petroleum that migrated into overlying clastics.

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