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ConocoPhillips

FINAL TECHNICAL FIELD PROGRAM REPORT

Richardson Mountains Geological Field Excursion
July 19-23, 2004
(Approximately 68° 00' N; 135° 30' W)

ConocoPhillips Canada

Submitted to
NATIONAL ENERGY BOARD, YUKON ENERGY & MINES, YUKON TOURISM & CULTURE, AURORA RESEARCH INSTITUTE, and GWICH'IN TRIBAL COUNCIL

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Field team - left to right, back: Aart Dronkers (EMC), Larry Lane (GSC), Gene Ostapovich (EMC), Guy Peasley (CPC), Anh Duong (CPC); front: Gary Prost (CPC), Dave Bywater (CPC), Pete D'Onfro (COP), Denis Marquardt (CPC)

EXECUTIVE SUMMARY

Field program results suggest we should not be concerned about reservoir compartmentalization in the lower Kamik Formation sands at Parsons Lake. Joints, seismic-scale faults, subseismic faults, and deformation bands were observed. At worst faults in the thicker A1, B, and C sands should act as baffles and channel flow parallel to the fracture surface. At best they will be transparent to flow. It should be noted that we did not see examples of shale smear, which may cause faults to seal at Parsons Lake. Seismic-scale faults in the thinner A, A1, and B sands may compartmentalize those sands by juxtaposing sand against shale.

Most Kamik Fm. outcrops in the eastern Richardson Mtns. are gently deformed sandstones similar to Parsons Lake, although they have a compressional overprint. Petrographic work shows that porosity in the Richardson Mtns., as at Parsons Lake, is enhanced by dissolution of rock fragments, and is occluded to varying degrees by quartz overgrowths. Vitrinite work shows the rocks in both areas were buried about the same depth. Kamik sands in the eastern Richardson Mtns. should be good analogs to the lower Kamik Formation at Parsons Lake (100 km away and 2600 m deeper).

Devonian outcrops contain fractures, often open, and localized karst development. A preliminary environmental interpretation suggests these limestones were deposited in a marine shelf setting. Fracture, cavernous, moldic, and vuggy porosity was observed, but these samples show poor reservoir potential. The Devonian may be partly analogous to carbonates encountered in wells at Parsons Lake (65-80 km away).

CONTENTS

Introduction – Work Program Description

The purpose of this study was to observe and sample faults and fractures in Kamik Formation sandstone outcrops in the Richardson Mountains in order to assist ConocoPhillips technical staff understand and model the distribution of faults within the Kamik Formation at Parsons Lake gas field at depths of 2600 meters below the surface. The Parsons Lake gas field development is planned by ConocoPhillips Canada (CPC) and Exxon Mobil Canada (EMC). A secondary objective was to better understand the reservoir characteristics of the Ordovician-Silurian carbonates below Parsons Lake field.

The trip was led by Dr. Larry Lane of the Geological Survey of Canada and was attended by Gary Prost, David Bywater, Guy Peasley, Anh Duong, Denis Marquardt, and Pete D'Onfro, all professional employees of ConocoPhillips. In addition Aart Dronkers and Gene Ostapovich, professional employees of Exxon Mobil Canada, attended this trip. On the two days that the party was able to fly (July 19, 20) they were accompanied by Dale Semple, a wildlife monitor arranged by the Gwich'in Tribal Council. Travel to the outcrops from Inuvik was by helicopter. The field party remained in Inuvik for the duration of the program, arriving on July 18 and departing on July 23.

Sites visited during the program, and the objective at that site were (maps 1-5):

1) Grizzly Gorge - Kamik [UTM zone 8; 47500; 7573400: lat. 68-16-28, long. 135-36-19]
2) Willow River - Kamik [482200; 7564900: lat. 68-11-55, long. 135-25-36]
3) Martin Creek - Kamik [475900; 7565100: lat. 68-12-00, long. 135-34-53]
4) Gilbert Anticline - Kamik [429100; 7593600: lat. 68-26-52, long. 136-43-46]
5) Rat River - Kamik [453200; 7508500: lat. 67-41-23, long. 136-06-13]
6) Campbell Lake north quarry - Devonian [lat. 68-18-00, long. 133-20-00]
7) Campbell Lake south quarry - Devonian [lat. 68-12-30, long. 133-24-00]
8) Trevor Fault – Kamik [lat. 67-11-00, long. 135-49-00]
9) Trevor Fault quarry - Kamik [lat. 67-10-30, long. 135-51-00]

Several hand samples were collected for petrographic, vitrinite, and mercury injection analysis.

Suitability of Analogs

The suitability of Kamik outcrops as analogs to the Kamik Formation at 3000 m depth at Parsons Lake is of concern. While the question has not been conclusively answered, we were able to determine that outcrops at Grizzly Gorge, Willow River, and Martin Creek are quartz arenite sandstones similar to the reservoir at Parsons Lake. Although deformation at the outcrops includes a Late Cretaceous to Recent compressional event, the outcrops are only gently deformed and in all cases dip less than 5°. This suggests that the structural expression of the Kamik sandstone in outcrop is representative of the Kamik in the subsurface at Parsons Lake. Whereas weathering mitigates their usefulness as analogs, the weathering is dominantly mechanical. Petrographic work shows that porosity in the Richardson Mtns., as at Parsons Lake, is enhanced by diagenetic dissolution of rock fragments and that porosity in both areas is occluded to varying degrees by quartz overgrowths. Vitrinite shows that rocks in both areas are at 0.5 to 0.6%Ro, or in the early oil window of maturity. When considering the stratigraphic section, amount of rock eroded, and geothermal gradient, both areas appear to have been buried to roughly the same depth, i.e., around 3500 to 4000 meters. Thus, the Kamik B and C sandstones in the Richardson Mtns. should be good analogs for the lower Kamik at Parsons Lake.

Outcrops at Gilbert Anticline and Rat River were effectively quartzite, i.e. pressure solution due to deep burial (the GSC estimates burial up to 7 km) has mobilized silica from the original quartz arenite and redeposited it as quartz overgrowths in the pores. Visual examination suggests porosity is low, on the order of 0-5%. Pressure solution is indicated by stylolites along bedding planes. These western outcrops are poor analogs for the Kamik at Parsons Lake.

Outcrops at the Trevor fault and Trevor quarry are for the most part fine- to medium-grained quartz arenites, although in some cases stylolites were seen and at these locations the rock appears to have little porosity due to silica cementation. These rocks are at 0.8%Ro, or in the main oil maturity window, and were likely buried somewhat deeper than those at Parsons Lake. These outcrops are fair analogs for rock seen at Parsons Lake.

Devonian outcrops may be fair proxies for the potential deep reservoir at Parsons Lake. They are slightly younger than rock encountered in wells, dated by the GSC as Ordovician-Silurian, but they would have undergone a similar post-depositional history with a major period of uplift and erosion at the end of Permian time, then again at the end of the Lower Cretaceous, and finally at the end of Upper Cretaceous time. The main uncertainty is whether the depositional environment is the same. The argument in favor of an analog is based on the similar depositional position at the edge of the continent during Ordovician through Silurian time (Figures 1, 2, 3).

Figure 1: Middle Ordovician tectonic setting, from Scotese, http://www.scotese.com/earth.htm.

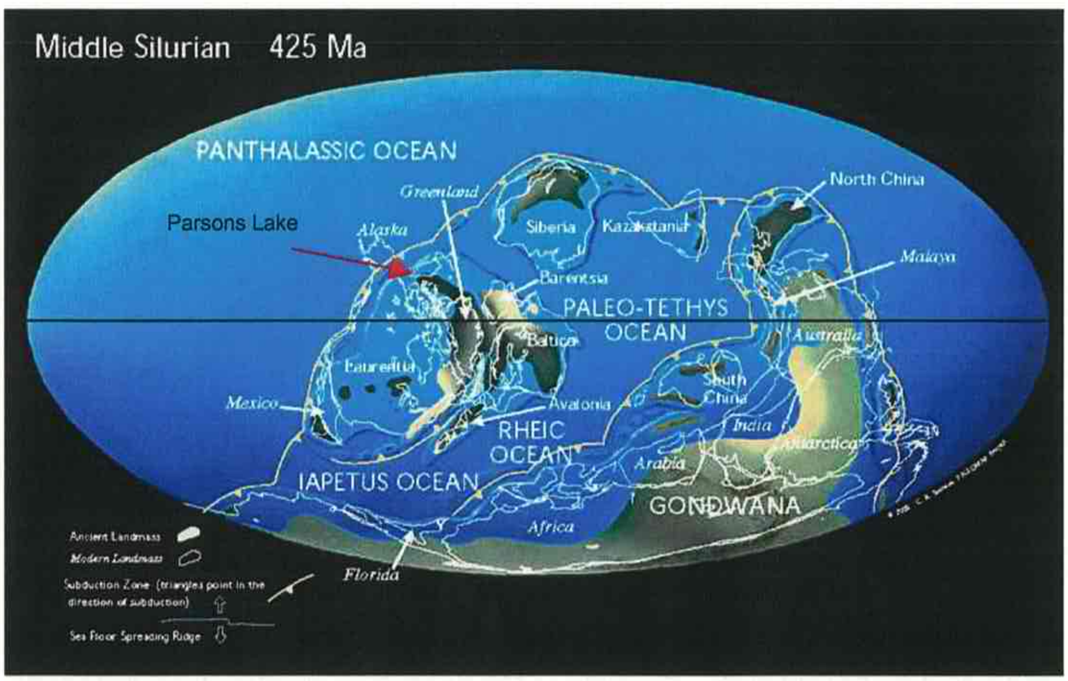


Figure 2: Middle Silurian tectonic setting. From Scotese, http://www.scotese.com/earth.htm..

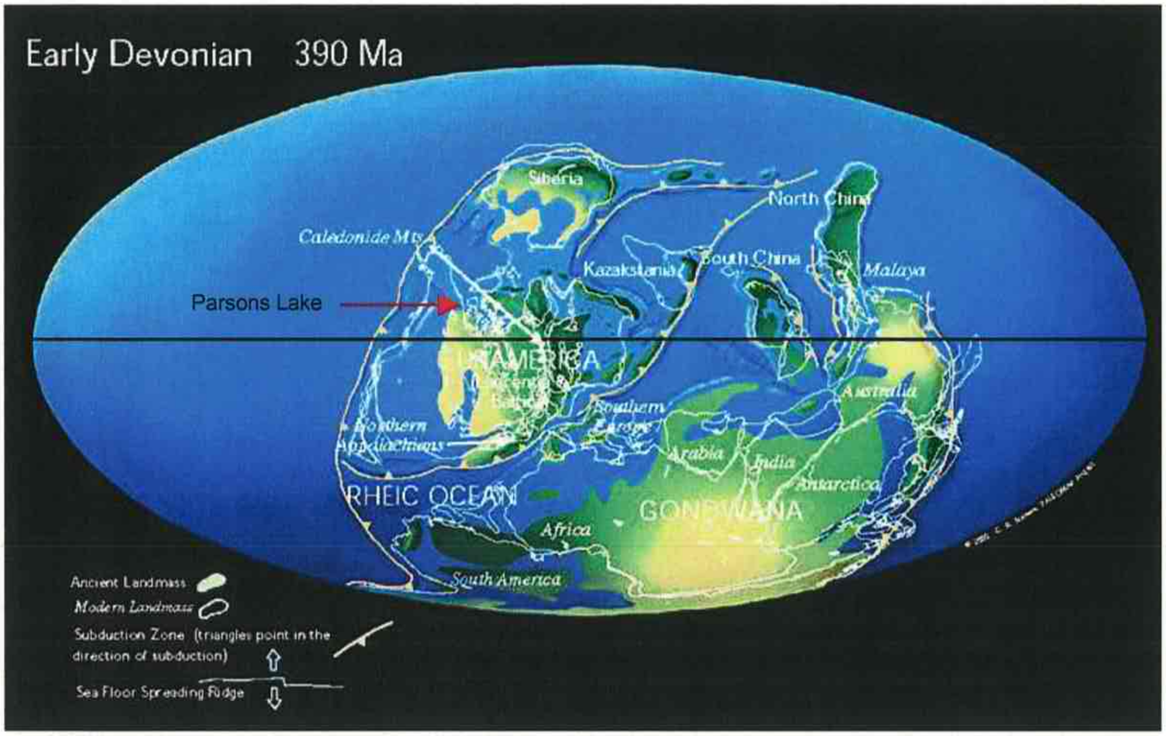


Figure 3: Early Devonian tectonic setting. From Scotese, http://www.scotese.com/earth.htm..

Seismic Scale Faulting

The Trevor fault is a regional strike-slip fault with 20-50 kilometers of lateral offset and hundreds of meters of vertical throw. This was one of two seismic scale faults observed, and deformation is intense. The fault zone exposes up to 300 m of highly sheared and internally folded shales of the Arctic Red River and Mount Goodenough formations (Figure 4), and sheared and brecciated Kamik sandstone (Figure 5). Shale beds within the Kamik are tectonically thinned in places (Figure 6), and sandstones indicate bedding plane slip (Figure 7) as well as intense, apparently randomly oriented shear surfaces. In one case a brecciated pod of sandstone is entirely encased within shales (Figure 8).

Faulting in the Parsons Lake field is dominantly normal and throws rarely exceed 100 m, with a maximum around 300 m. The Trevor fault may be analogous to the Eskimo Lakes fault east of the field, but is probably not a good analog for faulting within the Parsons Lake field.

Figure 4: Mt. Goodenough Formation deformed within the Trevor fault zone.

Figure 5: Brecciated Kamik Formation sandstone in the Trevor fault zone.

Figure 6: Tectonically thinned Kamik shale interbed, Trevor fault zone.

Figure 7: Slickensides indicate bedding plane slip within the Kamik along the Trevor fault zone.

Figure 8: Pod of pervasively sheared Kamik sandstone within shales along the Trevor fault zone.

A strike-slip fault with about 20 m normal throw exists in Willow River canyon. This fault is marginally seismic-scale. Left-lateral offset is indicated by slickensides on multiple slip surfaces. Faults in the hanging wall (downthrown side) extend at least 4 m vertically in outcrop, and the deformed zone is approximately 30 m wide. Spacing between slip surfaces is 0.15-0.30 m (Figure 9). This zone may act as a conduit to flow both parallel to and across the fault zone. This fault may be analogous to some seismic scale faults at Parsons Lake

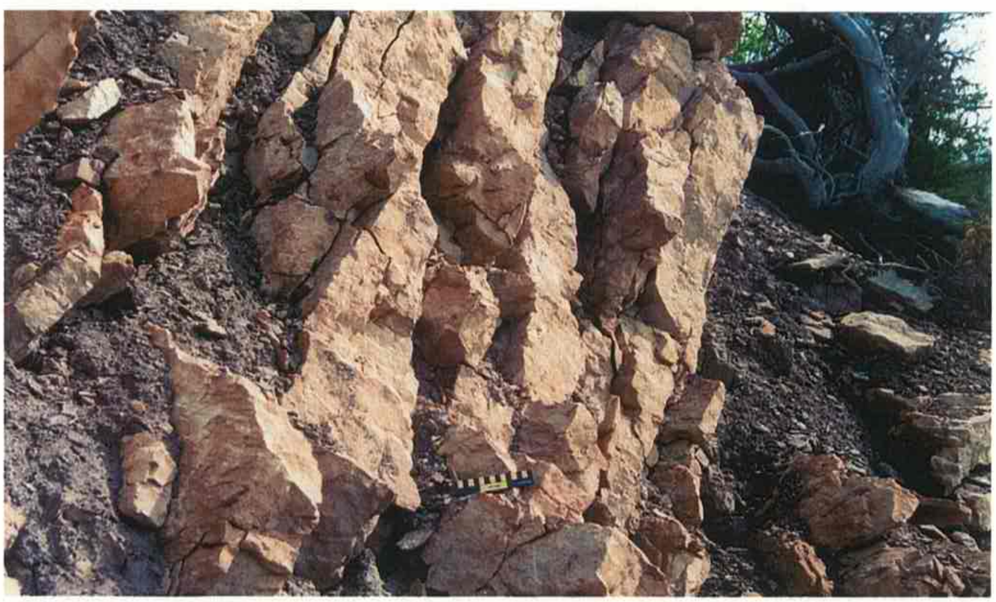


Figure 9: Brecciated Kamik B or C sandstone in fault zone at Willow River.

Subseismic Faults

The smallest displacement visible on the 3D seismic at Parsons Lake is on the order of 15-20 m. Two of the faults observed in outcrop had 10 to 30 m throw, that is, they are probably good analogs for subseismic faults.

A normal fault in Martin Creek valley has about 10 m offset across a 15 m wide zone. The fault zone in the footwall (upthrown side) consists of 2 m of discrete fault planes, and deformation bands in the Kamik C sandstone (Figures 10, 11, 12). Mercury injection work has been performed on the deformation bands to determine permeability relative to undeformed Kamik. Pervasive fault-parallel shear fabric can be seen in the hanging wall Mt. Goodenough Formation (Figure 13). This suggests that the fault would act as a baffle to flow across the fault (Figure 14).

A reverse fault viewed from across the canyon in Grizzly Gorge has 20-30 m throw and possible fractures in the hanging wall adjacent to the fault. The fault zone appears to be about 3 m thick.

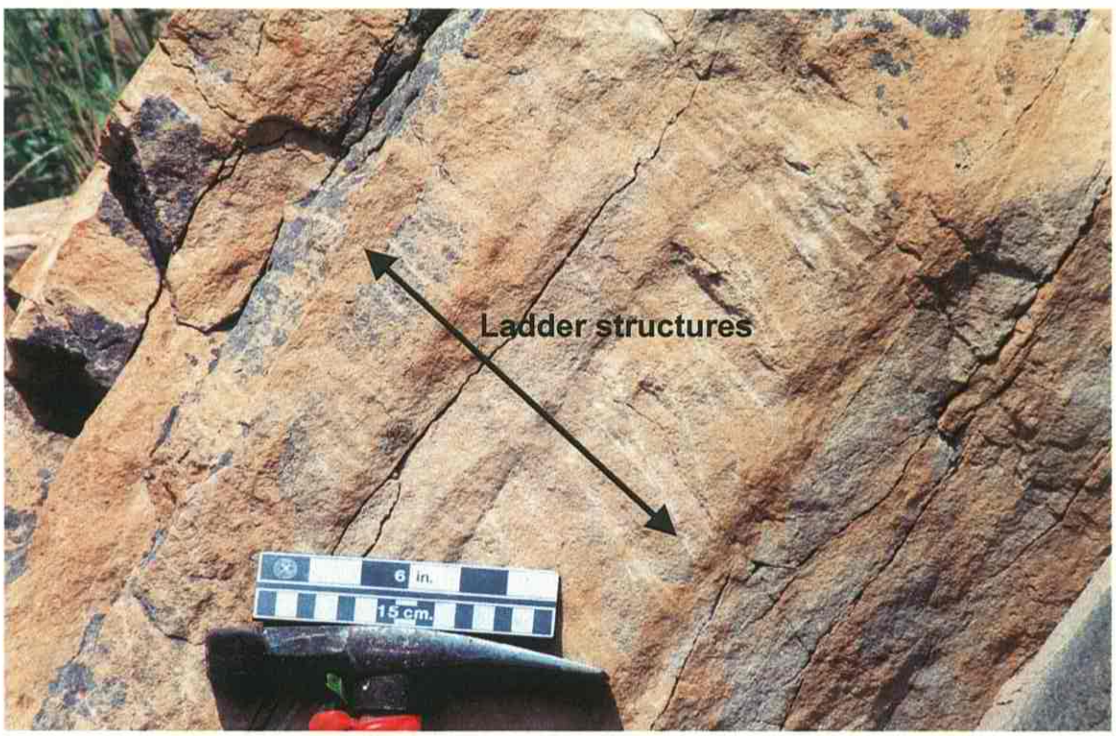


Figure 10: Ladder structures (arrow).

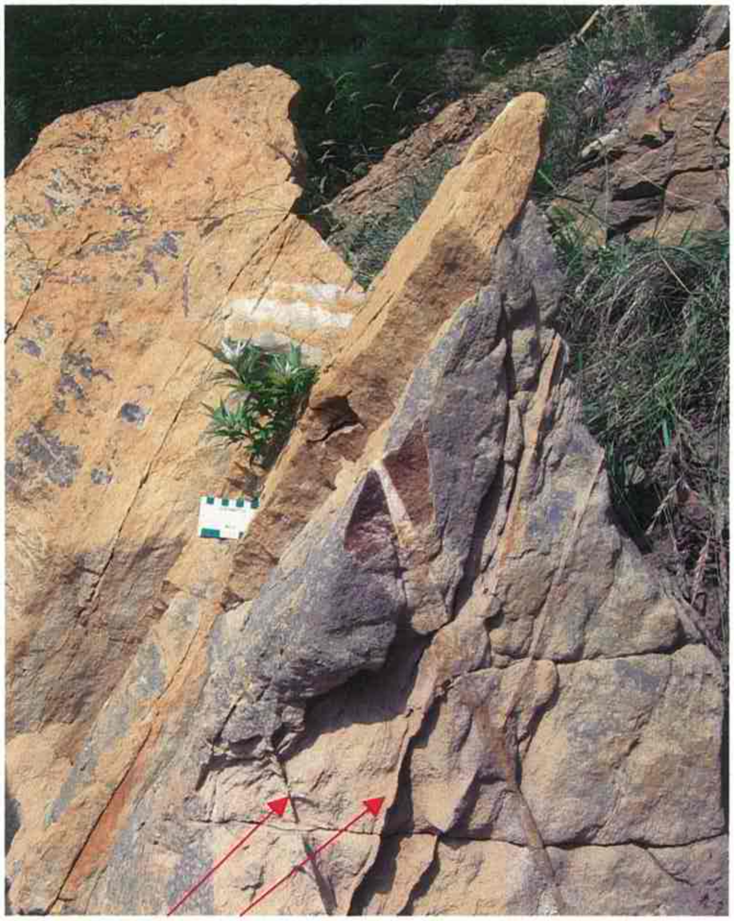


Figure 11: Conjugate deformation bands in the Kamik sandstone. Slip surface is in upper left.

Figure 12: Detail of deformation band in Kamik C sandstone showing decreased porosity within the deformation band (white zone).

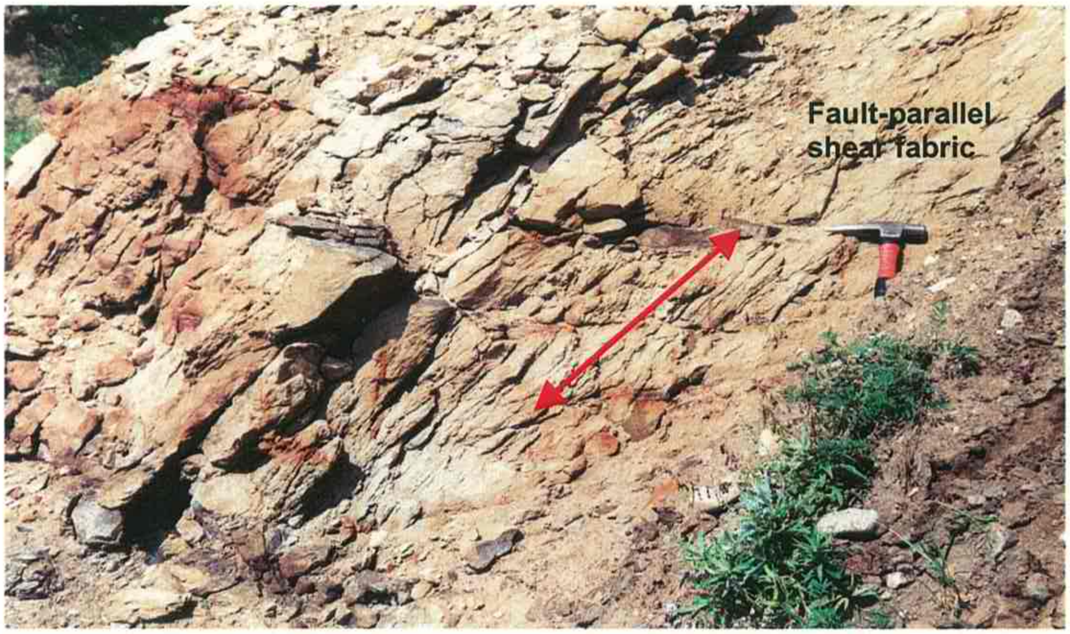


Figure 13: Two meter wide fault-parallel fabric (arrow) developed in Mt. Goodenough on hanging wall of normal fault, Martin Creek canyon. Fault has about 10 m throw.

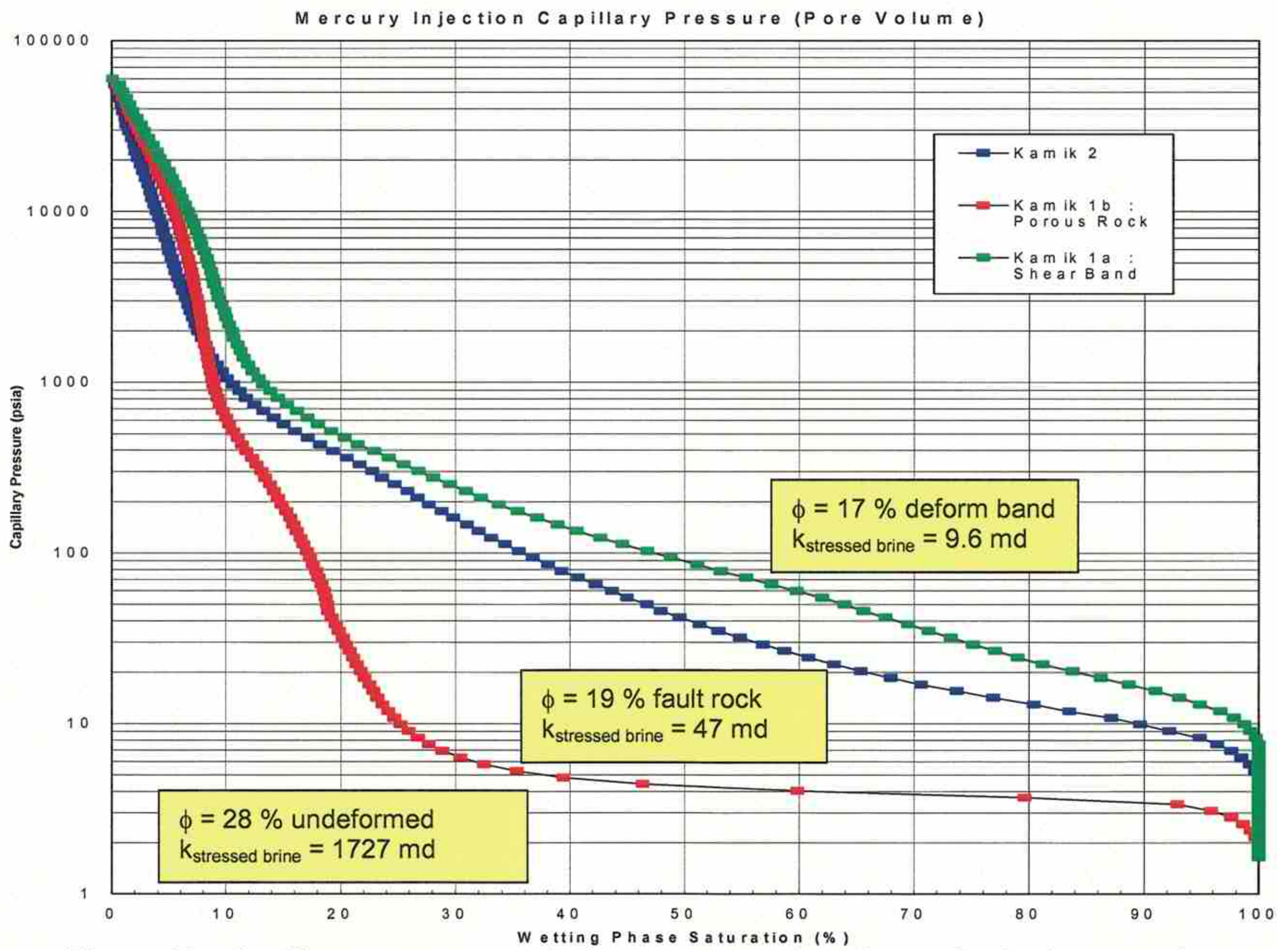


Figure 14: Capillary pressure work shows a two order of magnitude decrease in permeability from undeformed rock to deformation bands seen in Figures 11, 12.

Joints

Fracture geometry is a function of the mechanical stratigraphy of the host unit. The essentially flat-lying (dip 2°) and unfaulted section at Grizzly Gorge contains thick Kamik C sandstone with orthogonal joint sets (north-northeast and west-northwest). Another joint set or cleavage appears to be parallel to the cliff face and may be a result of erosional unloading. The north-northeast set is dominant.

The orthogonal joint sets are type I (opening) joints with no fill and rusty surface coatings. Rusty coatings may be a result of weathering or diagenesis. Small joints extend vertically up to 3 m (Figure 15), whereas major joints extend 5-10 m through the entire C sand. Small joints are spaced 0.3 to 3 m apart, whereas larger joints are spaced 6 to 10 m apart. Spacing is roughly proportional to bed thickness. Surface joints are clearly open to groundwater flow (Figure 16).

Joints seen in core indicate that the Kamik is jointed at Parsons Lake. Outcrops suggest that spacing of vertical joints is probably closer in thin sands and wider in thick sands, and that there are two sets of joints orthogonal to one another. Outcrop observations indicate that joints probably extend through the sand beds and die in shale interbeds (Figures 17, 18). If the Kamik at Parsons Lake and the outcrops have undergone a similar diagenetic history, then joints at Parsons Lake are likely to be open and act as conduits to fluid flow.

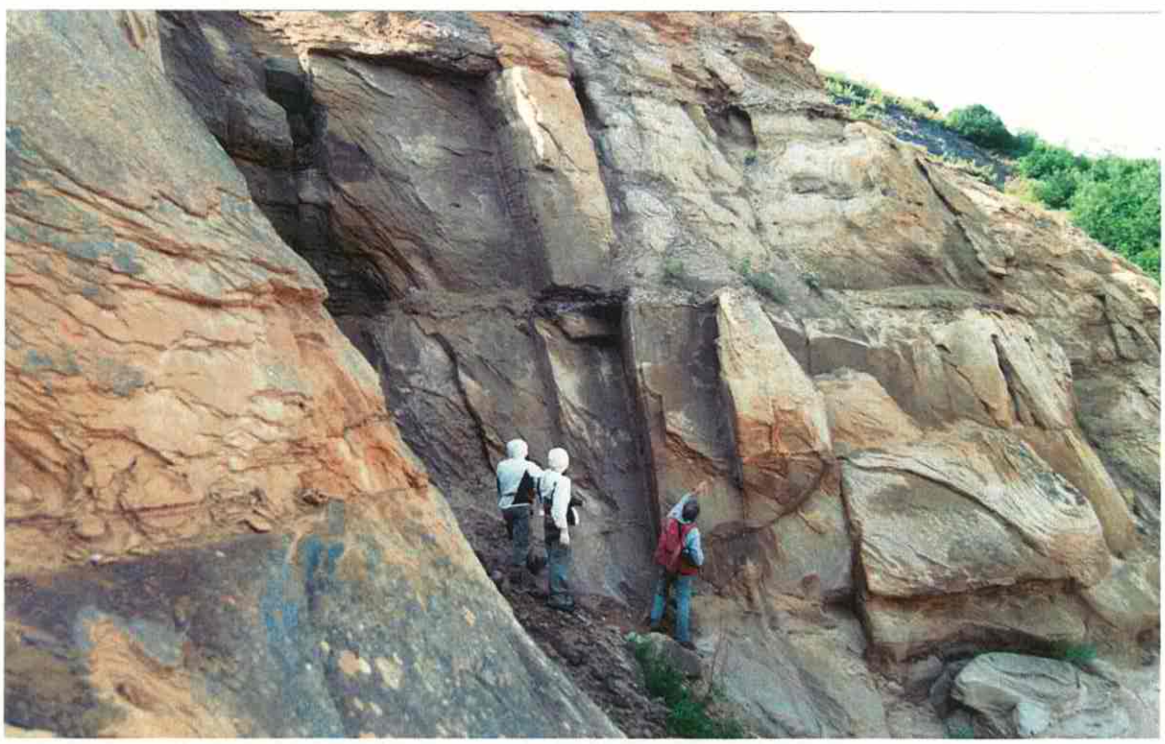


Figure 15: Small-scale joints in the Kamik C, Grizzly Gorge.

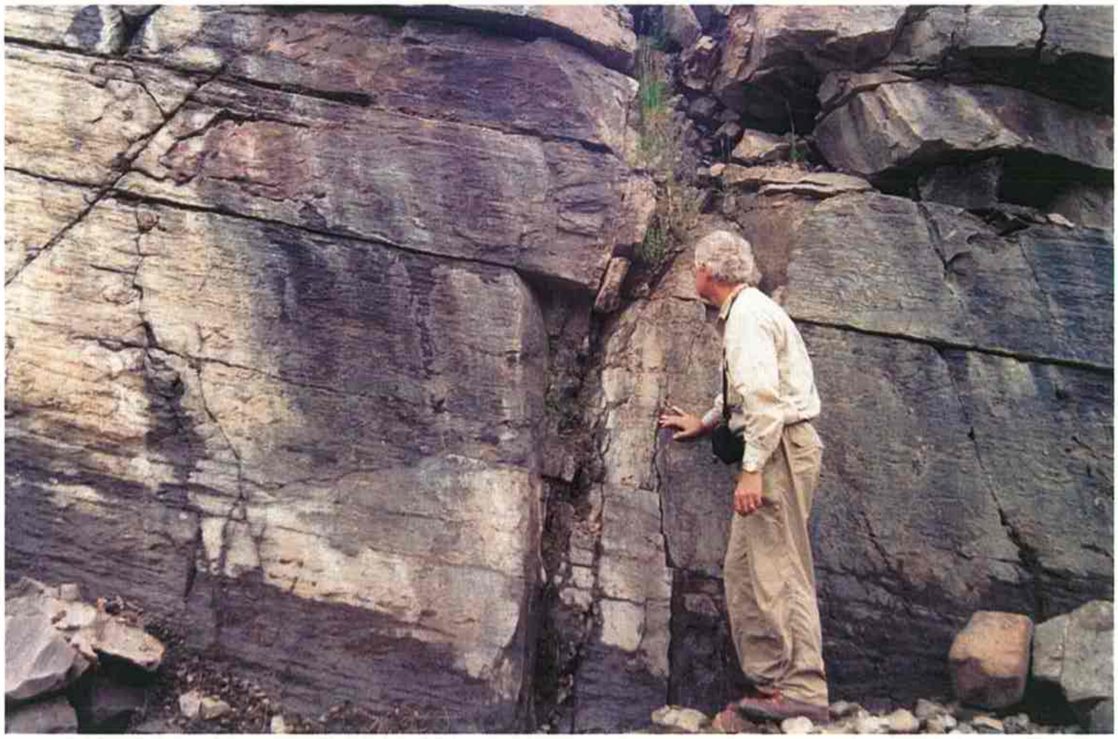


Figure 16: Surface joints flowing groundwater, Kamik quarry, Dempster Hwy.

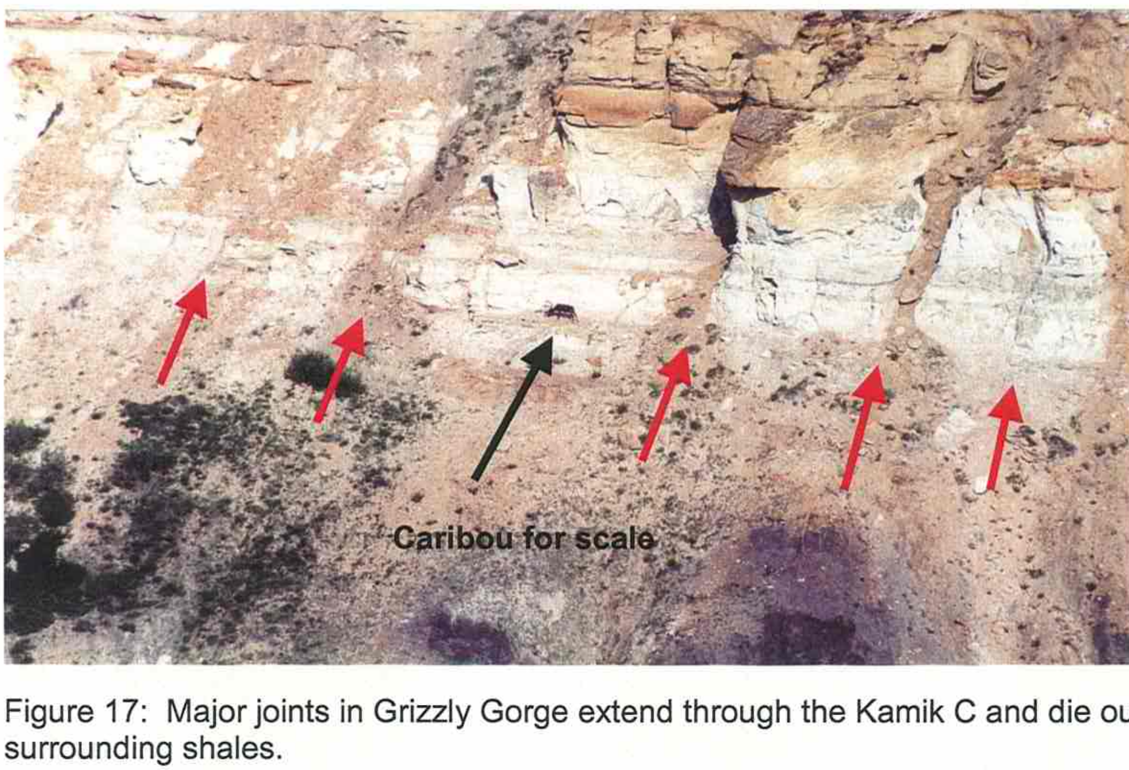


Figure 17: Major joints in Grizzly Gorge extend through the Kamik C and die out in the surrounding shales.

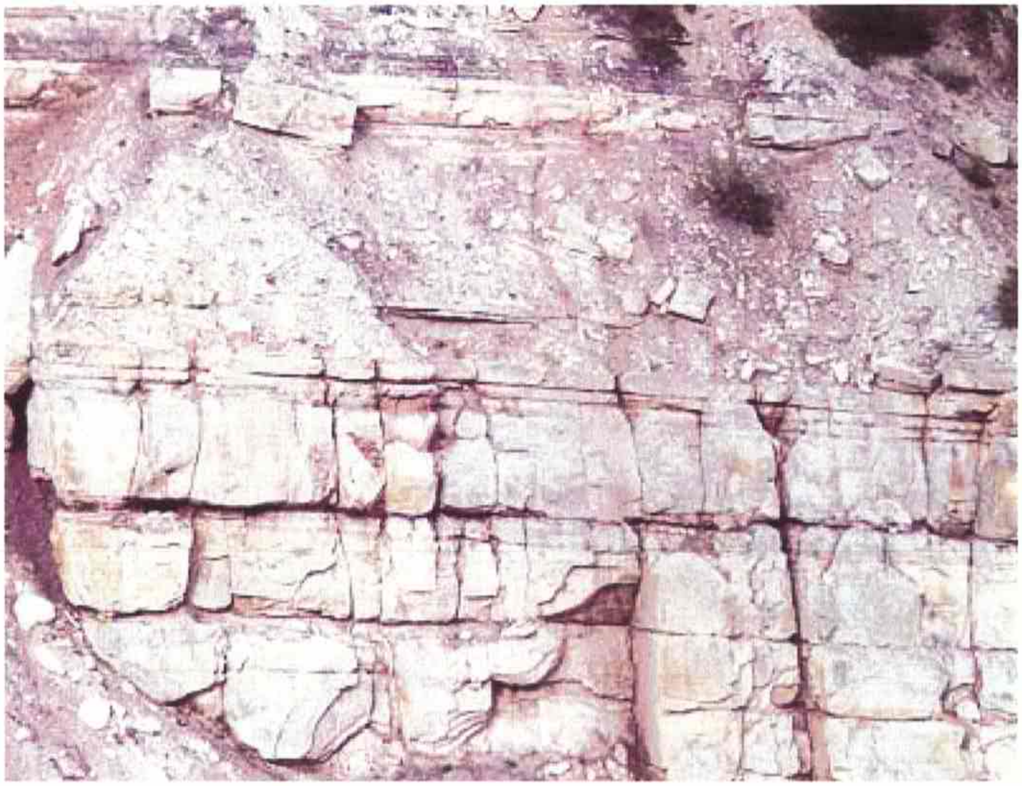


Figure 18: Joints in the Kamik C die out in adjacent shales, Martin Creek valley.

Devonian Reservoir Analog

Outcrops of Devonian limestone in two quarries along the Dempster Hwy south of Inuvik contain interbedded tight, fossil-free layers and porous shelly layers with isolated corals and trilobites. Moldic porosity is seen in the shelly layers (Figure 19). Petrographic work shows the depositional environment is open marine to shallow shelf.

The black limestone at both quarries contains fractures and karsts developed along fractures (Figures 20, 21). Some fractures are filled with calcite and some are open. Spacing ranges from 1 m to over 10 m in a given set. At least two sets exist at 30 and 60 degrees to each other. Karsts are filled with clay, brecciated limestone, and siltstone. Karst features are 2 to 5 m wide and are reported to contain Cretaceous fossils.

Petrographic work shows that diagenesis provides little or no porosity in these rocks, and they have, for the most part, very poor reservoir potential (Appendix 2).

Fracture, moldic, vuggy, and cavernous porosity may be developed in the subsurface.

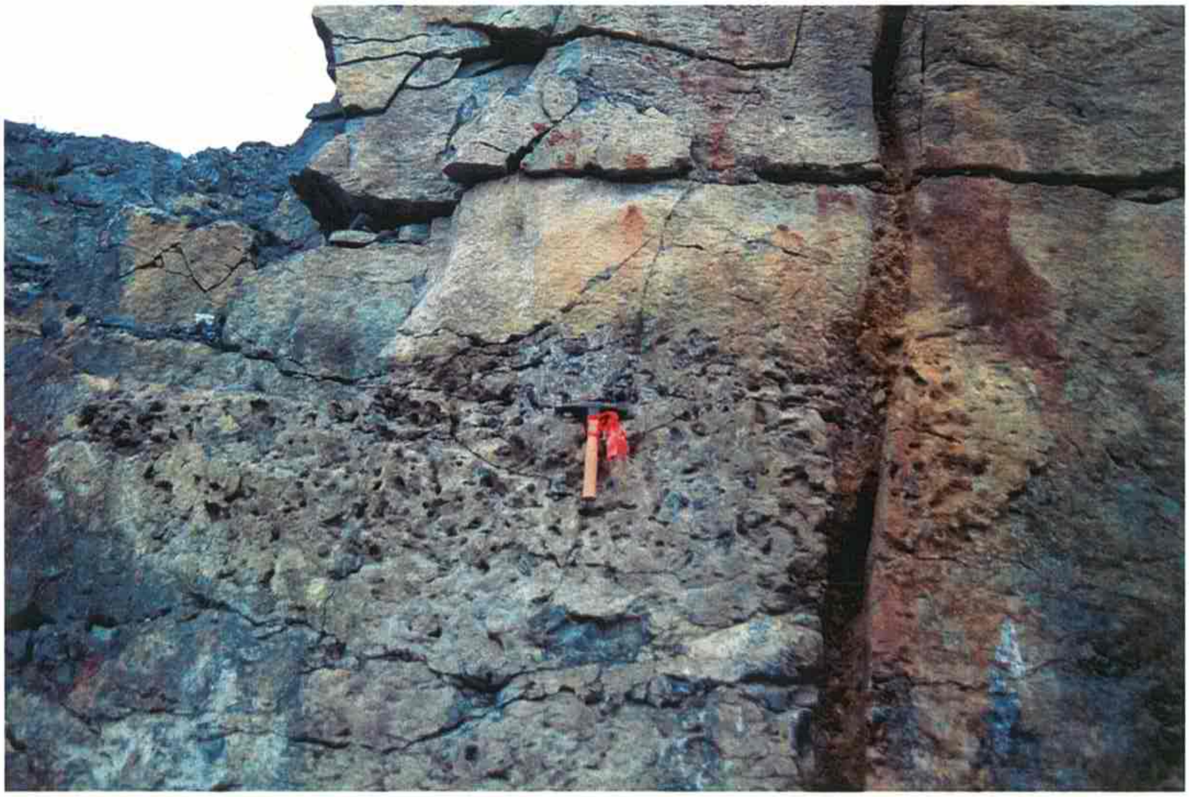


Figure 17: Devonian limestone, North Campbell Lake quarry. See fracture and moldic porosity in a shelly layer (at hammer).

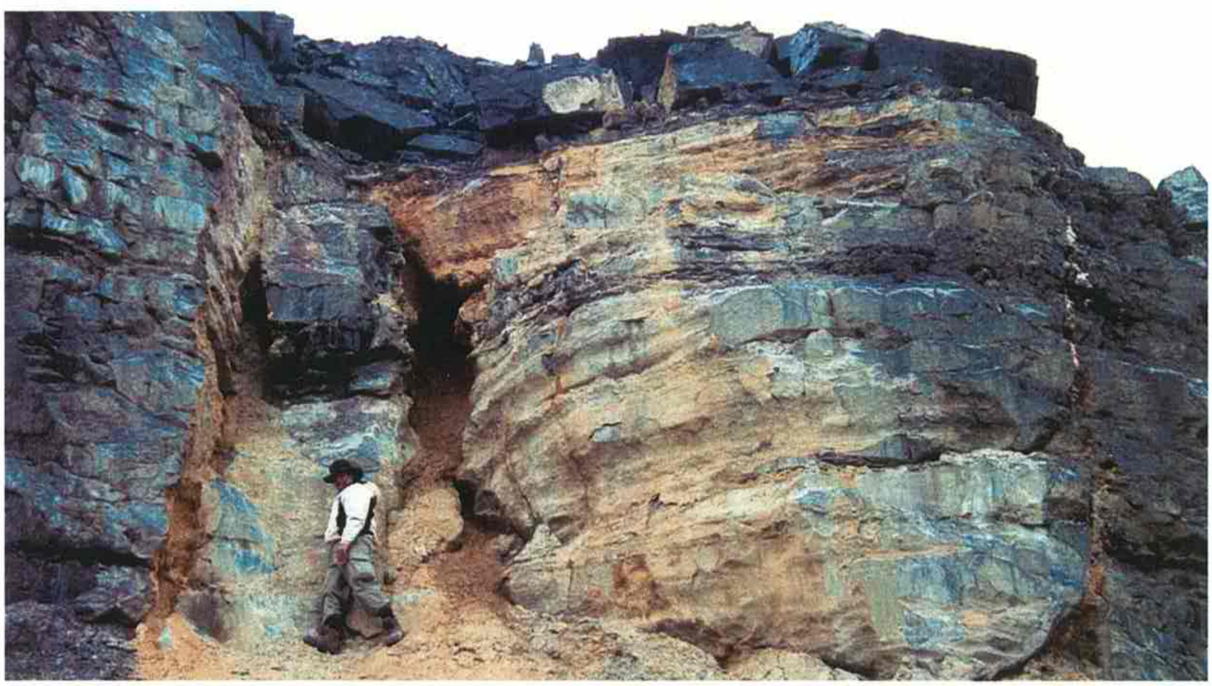


Figure 20: Karst developed along joints, Devonian limestone in South Campbell Lake quarry. Karst is filled with rusty clay material.

Figure 21: Karst fill at South Campbell Lake quarry. Fill consists of limestone and siltstone breccia, and is reported to contain Cretaceous fossils.

Discussion

Outcrop work attempted to address:

- The size of likely compartments
- Which faults/fractures are likely to be open and flowing vs impermeable? What fill is associated with each fracture set?
- What are fracture apertures and which fractures are they associated with?
- What is the width of fracture zones?
- Are open fractures around sealing faults? What is the fault zone composed of?
- What is the lateral and vertical extent of subseismic faults/fractures in sands of varying thickness, particularly the A, A1, and B sands?
- What is the spacing of faults/fractures of each orientation? Are they evenly-spaced or clustered?

The consensus among the trip participants is that subseismic normal faults (those with displacements less than 30 m) should not compartmentalize the Kamik C sands, and are not likely to compartmentalize thicker B or A1 sands, primarily because these faults juxtapose sand-on-sand across the fault. Secondly, the deformation zone seen around these faults did not exceed 20 m in width and contained deformation bands and fault-parallel fabrics that should impede gas flow across faults, but not stop it. Thinner A, A1, and B sands may be compartmentalized by juxtaposition of sand against shale. None of the faults were mineralized. We were unable to determine the lateral and vertical extent of small-offset faults. In general, fault spacing was several kilometers in the Richardson Mtns; at Parsons Lake the faults are 1 to 2 km apart. Faults do not appear to be clustered. Fault trends, a function of local tectonics, were dominantly north-south in the Richardson Mtns.

In the larger offset (seismic scale) faults the deformed zone is wide (30 m at Willow River canyon; >100 m at Trevor fault) and the Kamik sandstone is brecciated or has multiple slip surfaces and should be permeable to gas.

Joints appear to extend entirely through the sandstones and die out in the surrounding shales. Joint spacing in the C sands ranged from 0.3 to ~10 m and appears to be proportional to bed thickness. Joint sets are orthogonal, with a dominant north-northeast trend. None of the fracture sets were filled with calcite or quartz veins: they are either open, or have an iron oxide coating. In at least one location (Kamik quarry) surface joints are open to groundwater flow.

Outcrop work will contribute to a simulation model that addresses the questions:

- How is gas recovery (absolute amount and rate) affected by fault and fracture permeability and spacing?
- How will the number of wells be affected by the fault compartments?
- Where should bottom hole locations be established with respect to faults?

Conclusions

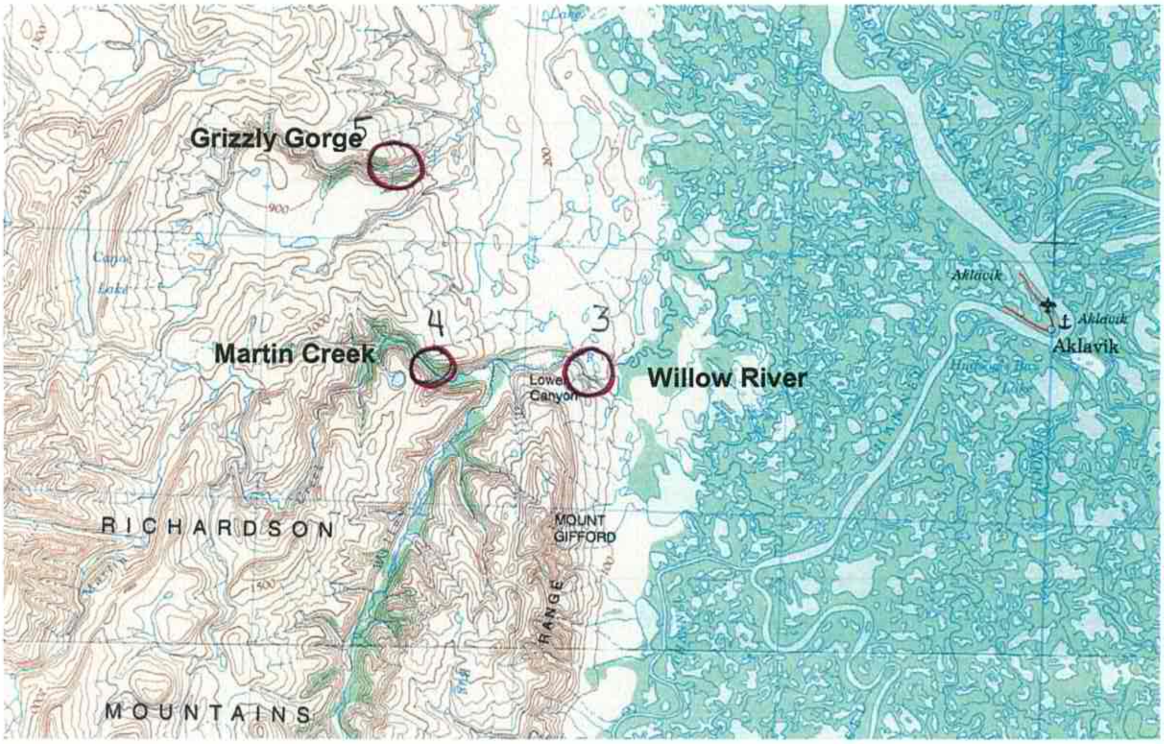
Nothing seen during the field program would suggest we should be concerned about reservoir compartmentalization in the thicker Kamik A1, B, and C sands. We looked at joints, seismic-scale faults, subseismic faults, and deformation bands. At worst, faults in the thicker sands will act as baffles and channel flow parallel to the fracture surface. Deformation zones that impede the movement of gas may also impede the movement of water through the reservoir. At best they will be transparent to flow. Having said that, we did not see an example of shale smear, which may cause faults to seal. Seismic-scale faults in thin A, A1, and B sands may be compartmentalized by juxtaposing sand against shale.

Most of the eastern Kamik outcrops are low strain (gently deformed) sandstones similar to Parsons Lake, even though there is a compressional overprint. Petrographic work shows that porosity in the Richardson Mtns., as at Parsons Lake, is enhanced by dissolution of rock fragments, and that porosity in both areas is occluded to varying degrees by quartz overgrowths. Vitrinite work shows the rocks in both areas were buried to 3500 to 4500 meters. Overall, the Kamik B and C sands seen at Grizzly Gorge, Martin Creek valley, and Willow River valley should be good analogs to the lower Kamik at Parsons Lake field.

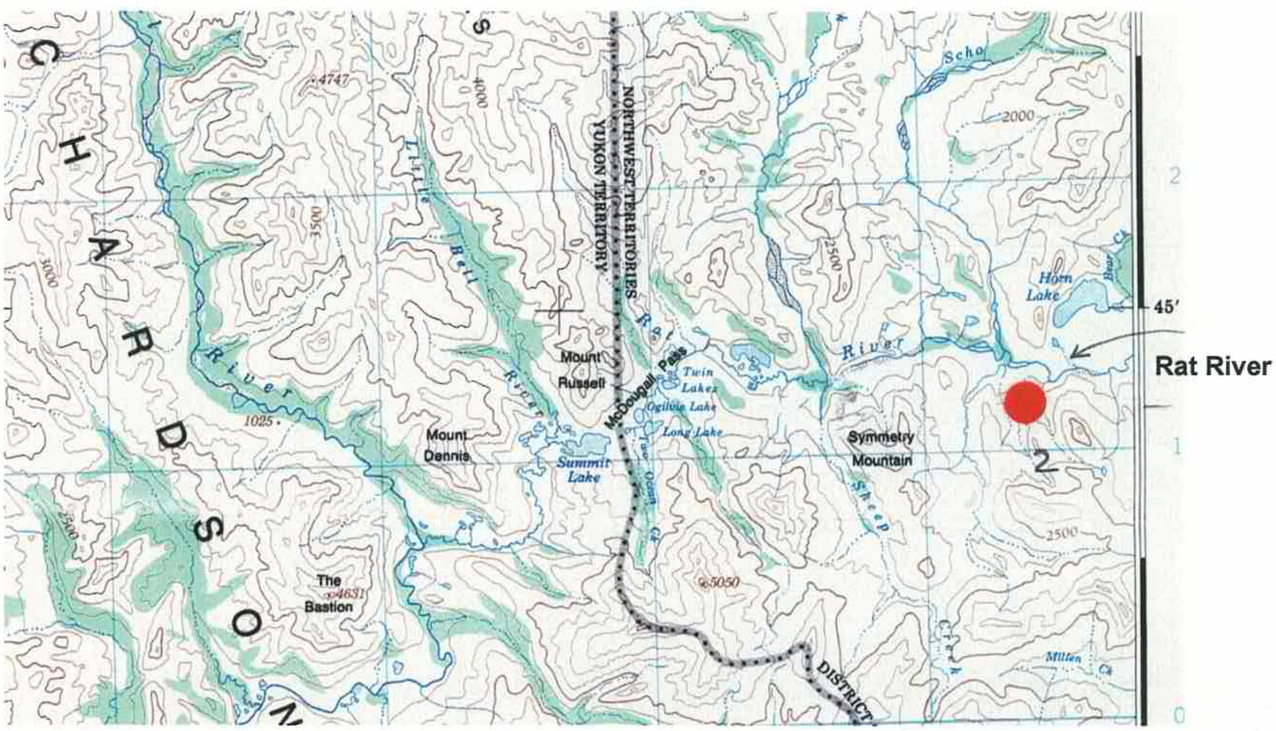
The Devonian outcrops reveal that fracturing is present, that fractures are often open, and that they influenced karst development. An environmental interpretation suggests the limestones were deposited in an open marine to shallow shelf setting. Fracture, cavernous, moldic, and vuggy porosity was observed, but none of the samples had significant reservoir potential. Whereas the Devonian outcrops are limestones and the Siluro-Ordovician rocks beneath Parsons Lake are shaly and cherty dolomite and limestone (Wielens, 1992), the Devonian samples may be partly analogous (with regard to original fabric) to the carbonates encountered in wells at Parsons Lake (65-80 km away) since they were deposited in a similar setting. The origin of dolomite in the Siluro-Ordovician section is unknown, but diagenetic or hydrothermal dolomites tend to have more porosity than limestones.

References

Wielens, J.B.W., 1992, The pre-Mesozoic Stratigraphy and Structure of the Tuktoyaktuk Peninsula: Geological Survey of Canada Paper 90-22, p. 1-78.

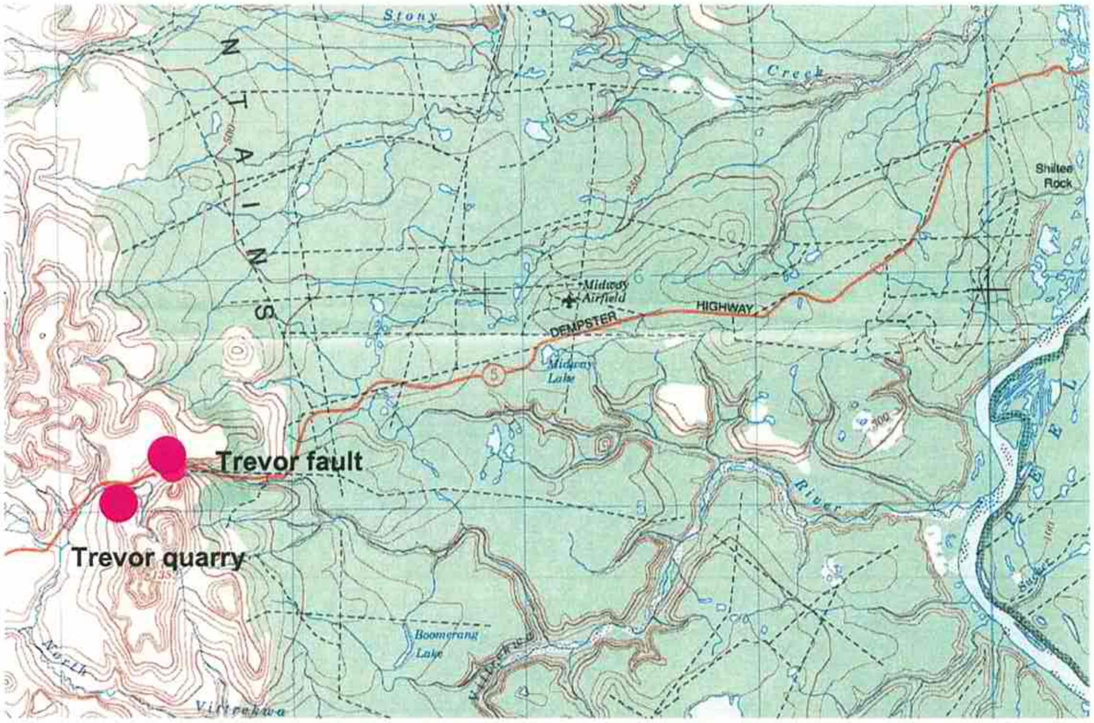


Map 1: Aklavik 1:250,000 sheet (107B) showing Grizzly Gorge, Martin Creek canyon, and Willow River canyon sites.

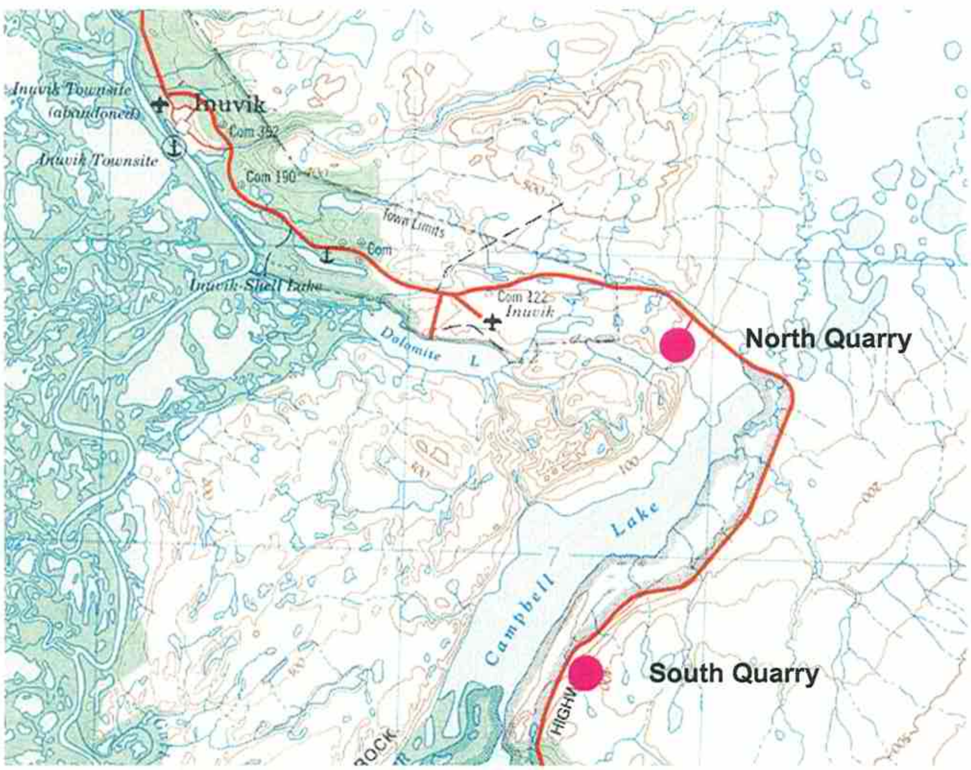


Map 2: Bell River 1:250,000 sheet (116 P) showing the Rat River site.

Map 3: Blow River 1:250,000 sheet (117A) showing location of the Gilbert anticline site.



Map 4: Fort McPherson 1:250,000 sheet (106 M) showing the Trevor fault and Trevor quarry sites.



Map 5: Aklavik 1:250,000 sheet (107B) showing the Campbell Lake north and south quarries.

APPENDIX 1: KAMIK PETROGRAPHY & MERCURY INJECTION WORK

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September 10, 2004

Mr. Peter D'Onfro
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Dear Pete,

The two outcrop samples submitted from the Martin Creek outcrop, Richardson Mountains, NW Territories (see Figure 1) were evaluated using high pressure, mercury injection capillary pressure and thin section petrography. These analyses will document the texture (grain size, sorting), detrital mineralogy, diagenesis and macropore structure of the rock types present, as well as the capillary properties.

Oversized (2" x 3") thin sections were prepared for each sample by impregnating the rock with blue epoxy to highlight pore space, grinding to a thickness of 30 microns and staining to distinguish calcite if present. Scanned images of the entire thin sections are displayed in Plates 1 and 4. Color photomicrographs taken to document important rock properties are shown in Plates 2, 3, 5 and 6.

Mercury injection capillary pressure testing was conducted to quantify the pore structure. The volume of mercury intruded was monitored at 118 pressure points between 1.64 and 59,500 psia, and the data corrected for closure (i.e. mercury conformance to the sample surface). Tabular and graphical data for each sample are contained in the Appendix to this report. Composite plots of the drainage data and pore aperture size distribution can be found in Figures 2 and 3.

Kamik Sample 1 (see Figure 1) is comprised of porous sandstone that is believed to be the host rock, and a shear band containing more compacted sandstone and cataclastic gouge (Plates 1 – 3). The sandstone is comprised mostly of upper fine to medium sand size grains and is considered well near moderately sorted. The average grain size (determined by measuring the long axis of 25 representative quartz grains) is 0.34 mm (medium sand). The observed range is from upper very fine (0.11 mm) to lower very coarse (1.2 mm) sand. A similar grain size and sorting characterizes Kamik Sample 2.

The mineralogy is decidedly quartz-rich with monocrystalline quartz being the dominant grain. Chert and sedimentary rock fragments are the next most abundant grain types. The chert is commonly shaly and several grains contain what appear to be quartz filled fractures (pre deposition). The rock fragments are mostly argillaceous, consisting of clay clasts and shaly siltstone/sandstone. The distribution of these grains is relatively uniform. A very minor amount of quartz overgrowth development is the only evidence for mineral cementation and the porous host rock is moderately friable. There is no indication of clay diagenesis in thin section, and the sandstone appears to be depositionally very clean.

The porous host rock displays an open framework characterized by varying degrees of compaction. The grains in portions of the rock have elongate to slightly sutured contacts and are more efficiently packed leaving minimal intergranular pore space. Intermixed are areas that appear less compacted, where point type grain contacts predominate and there is more intergranular volume. Grain dissolution appears to have been relatively common and may be partially responsible for the open character in some areas.

The shear band in Sample 1 is made up of two different fabrics. The densest rock is along the edges of the band and is made up of crushed grains (down to silt size particles) and interparticle clay (Plate 2a, 2b and 3b). In the central portion of the band the sandstone is much more compacted, compared to the host rock, but there is minimal grain crushing and clay (Plate 3a). Primary intergranular porosity is present, but much more limited, and there is some secondary, leached grain pores. The thinner bands in Sample 2 have a matrix of crushed grains and detrital clay (Plate 5), with the clay content higher than in Sample 1. Areas adjacent to these bands often have compacted fabrics similar to the interior of the thicker band in Sample 1. There are also a few thin organic laminae in the compacted rock that appear to have been drug into the thin shear bands (Plate 6b).

The capillary pressure data (Figures 2 and 3) shows that the porous host rock has a well defined pore structure with a unimodal pore aperture distribution. A sharp intrusion peak occurs at approximately 53 microns (diameter) and the median aperture size is 50 microns. The porosity measured during the mercury injection analysis is 28.2% and the permeability calculated from the data (Swanson equation) is 3455 md. Thin section petrography shows that the total pore volume is a combination of preserved primary pore space and secondary porosity added through grain dissolution. The capillary properties indicate that the two pore systems are well connected and that there is minimal microporosity.

The rock comprising the shear band in Sample 1 was separated from the host rock and analyzed separately. The porosity and, particularly the permeability, are significantly lower at 17.2% and 18.7 md, respectively. The intrusion profile is broad indicating increasing heterogeneity in the pore structure. The initial peak at about 10 microns most likely represents access to the remaining, smaller primary and connected secondary pores. A less developed second peak, located at approximately 3 microns has a broad tail down to about 0.1 microns. The median aperture size is 2.4 microns.

The portion of Sample 2 used for capillary pressure was selected to avoid including small patches of more porous rock. Porosity and permeability increase slightly, compared to the shear band in Sample 1, to 19.5% and 72 md, but remain far below the values in the host rock. The intrusion profile has a relatively sharp initial peak between 10 and 20 microns, again probably related to the remnant intergranular pore system, and appears to be somewhat more homogeneous compared to the shear band. The overall aperture distribution is weakly bimodal and includes a small, very poorly defined peak at 0.5 – 0.6 microns possibly representing pore space associated with the slightly more common matrix clay in the shear bands. This peak is "hidden" by the broad tail exhibited by the Sample 1 shear band. The median aperture size is 5.2 microns, slightly larger than the shear band, but still an order of magnitude smaller that the host rock.

Overall, Kamik Sample 2 and Sample 1 (shear band) have somewhat similar capillary properties, and both are very different from the host rock. Compaction and cataclasis related to the shear bands and faulting reduce the intergranular pore volume and aperture size. These pore structures are much more heterogeneous. The partial preservation of the primary intergranular pore space, except locally in the thin cataclastic layers, limits the seal capacity.

PetroTech has assigned project code PA – 957 to this study. We appreciate the opportunity to provide these services. Please contact us with any comments or questions regarding the data or analytical procedures.

Sincerely,

George Bolger

PLATE 1

Kamik Sample 1

This photograph is a scanned image of the entire thin section (enlargement approximately 4x). The rock is a well sorted, upper fine to medium grained sandstone. Pore space (blue) is common and evenly distributed in the "host" rock (upper and low portions of the sample). Brown grains consist of argillaceous rock fragments and shaly chert.

The lighter colored "band", slightly below center, contains similarly sized sandstone that has a more compacted framework. The edges of the "band" appear less porous and have a matrix of broken grains and clay (cataclastic gouge?).

The rock on either side of the band has 28% porosity and 3455 md permeability (see capillary pressure data), while within the band these values decrease to 17% and 18.7 md, respectively.

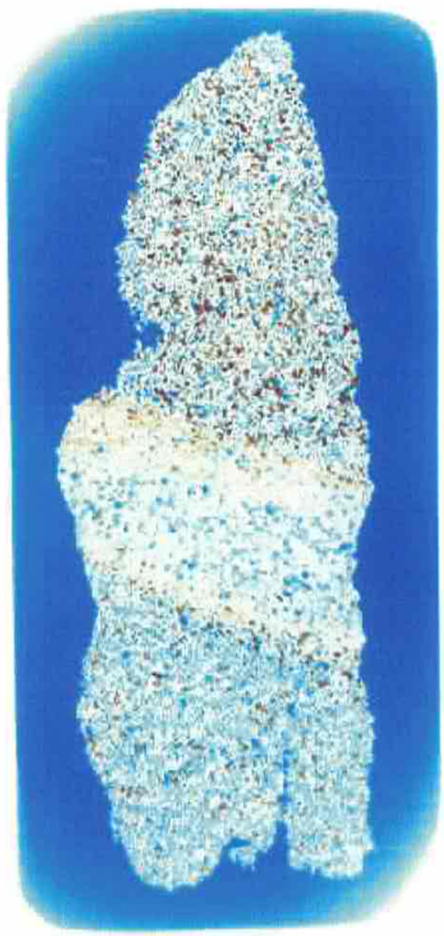


PLATE 2

Kamik Sample 1

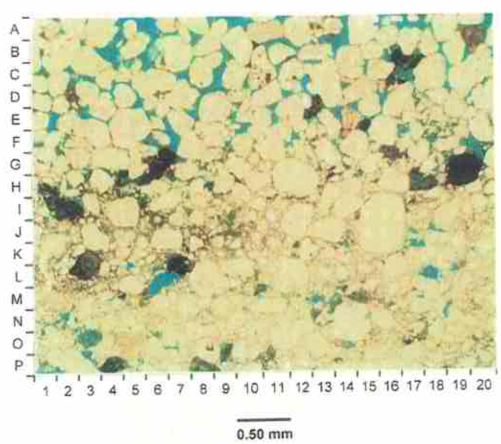
Photomicrograph A shows the boundary between the porous rock (top part of photomicrograph) and the cataclastic band visible in Plate 1. The lower portion of the photomicrographs contains the denser part of the cataclastic gouge. Dark grains visible in both areas are argillaceous rock fragments (clay clasts) and shaly chert. These ductile grains exhibit varying degrees of plastic deformation and dissolution.

The area shown in Photomicrograph B is centered at I19 in Photomicrograph A. This higher magnification view shows that there is a “matrix” of small (mostly silt size) particles of quartz packed between the larger grains. Detrital clay is mixed with the fine particles and occupies the interparticle pore space. The clay generally appears microporous and may represent clay-rich grains entrained in the gouge. There is some open intergranular pore space (blue) and larger leached grain pores (L6, O3 in Photomicrograph A) preserved with the cataclastic gouge.

A-25x B125x

Martin Creek Outcrop
Kamik Sample 1

A



B

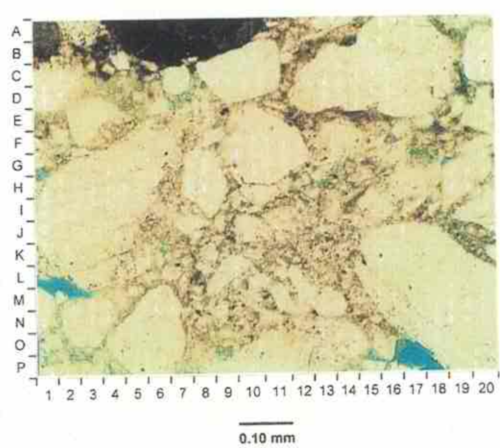


Plate 3

Kamik Sample 1

Photomicrograph A shows the porous sandstone that appears to be the host rock and is adjacent to the cataclastic band. The sandstone is well to moderately sorted, with grains ranging in size from very fine to occasionally coarse sand. The granular framework does not appear to be evenly compacted. In some areas the grains are tightly packed and have elongate to slightly sutured contacts (F12, J7, K13, N14); whereas, in others point type contacts are common and the fabric is more open (C18, D3, F4). White grains are mostly quartz, with darker grains including shaly chert (H9, K20) argillaceous rock fragments (D17, K3) and silty claystone (H5, K11). The chert grains often have quartz cemented fractures (white lines). Pore space (blue) is very common and consists of preserved primary pores and larger leached grain secondary pores (C9, D16, F10, O3). Intergranular cement is minimal.

Photomicrograph B provides an additional view of the cataclastic band. The grains are much more compacted, with little visible primary pore space. Ductile, argillaceous grains are deformed (D6, H7, L19). Silt-size grain fragments increase toward the outer edge of the band (rows J-M). A small amount of the porous host rock is visible along the lower edge of the photomicrograph.

A-25x B-25x

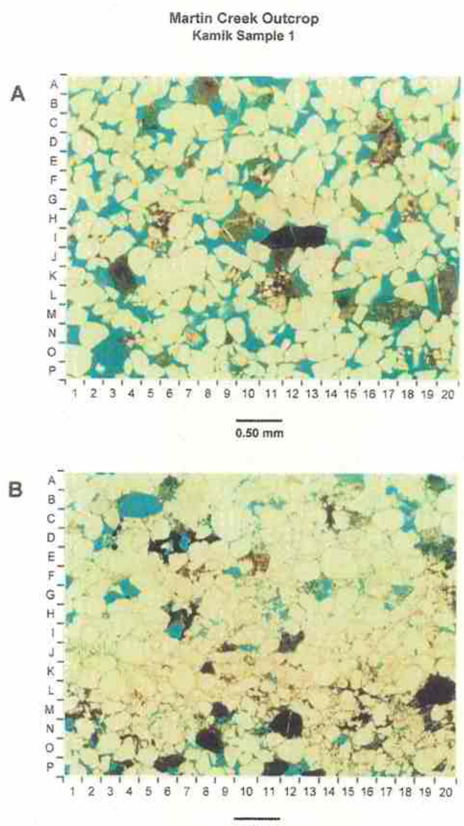


PLATE 4

Kamik Sample 2

This plate displays a scanned image of the whole thin section prepared from the second sample (Fault rock). Magnification is approximately 4x. The sample contains numerous, thin cataclastic bands (light streaks) that are generally parallel. The intervening more porous rock is fine to medium grained sandstone. Grain composition is similar to the previous sample and the brown colored grains are clay-rich chert and rock fragments. Porosity and permeability from capillary pressure is 19.5% and 72 md, respectively.

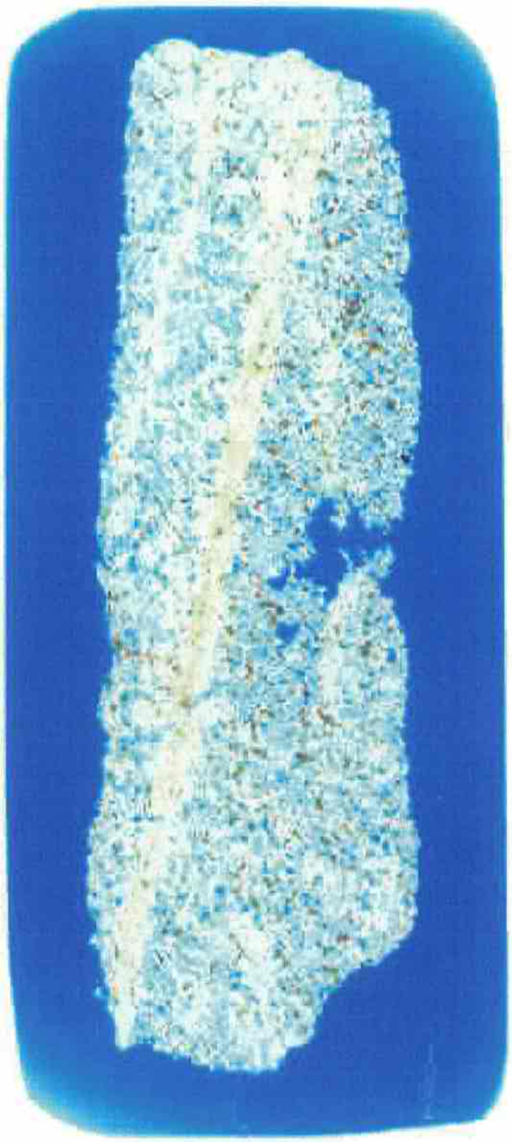


PLATE 5

Kamik Sample 2

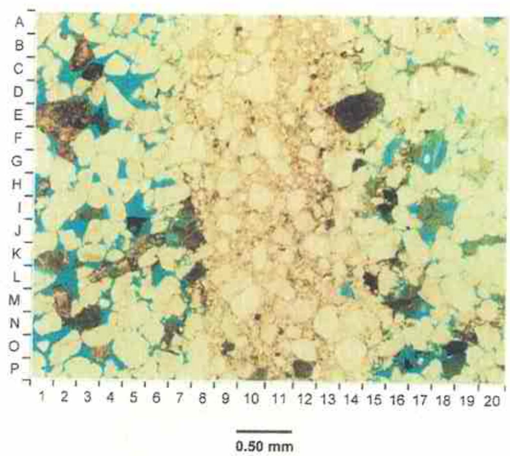
The central portion of Photomicrograph A contains one of the bands visible in Plate 4. The rock to the left is porous sandstone comparable to that of the host rock in Sample 1 (Plate 3A). To the right of the band, the sandstone framework is more compacted and less porous. Dark grains in both areas are clay-rich rock fragments (clay clasts) and shaly chert. Some of these grains have undergone partial to complete dissolution to form the larger secondary pores (F17, I5, I18, O16).

Photomicrograph B shows the center of Photomicrograph A in more detail. The matrix supporting the larger sand grains is comprised of small quartz particles (crushed grains?) and clay. The clay content appears to be higher compared to the cataclastic band in Sample 1.

A-25X B-125X

Martin Creek Outcrop
Kamik Sample 2

A



B

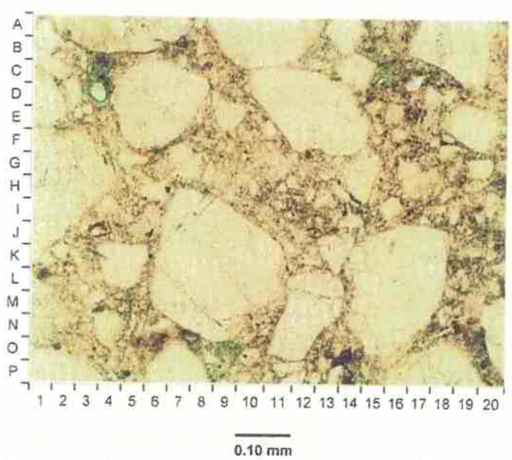


PLATE 6

Kamik Sample 2

A majority of the rock in Photomicrograph A is porous sandstone. The porosity (blue) consists of both primary and larger, leached grain secondary pores (C9, C15, L7, P12). Most of the grains are quartz, but shaly chert (D10), clay clasts (C2, L6) and silty claystone clasts (G6, J13) are scattered throughout. These more ductile grains show evidence of plastic deformation and are squeezed into adjacent pores. The rock along the right (columns 15-20) has a more compacted framework and may be related to a less developed shear band.

The area in Photomicrograph B is mostly comprised of compacted sandstone. Some primary pore space is present (note area around L17), but the pores are much smaller. The larger visible pores are secondary and related to dissolution of chert and rock fragments (A18, F17, I7). The dark, linear feature (D16 to M6) is comprised of compacted organics and appears to have been a laminae that was drug into the cataclastic band visible along the left side of the photomicrograph (Rows 1-3). This band is similar to that highlighted in Plate 5.

A-25x B-25x

Martin Creek Outcrop
Kamik Sample 2

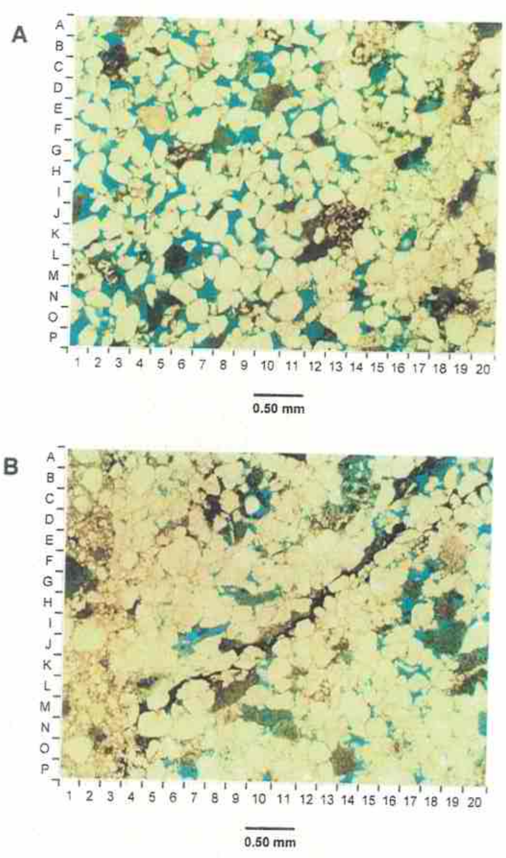
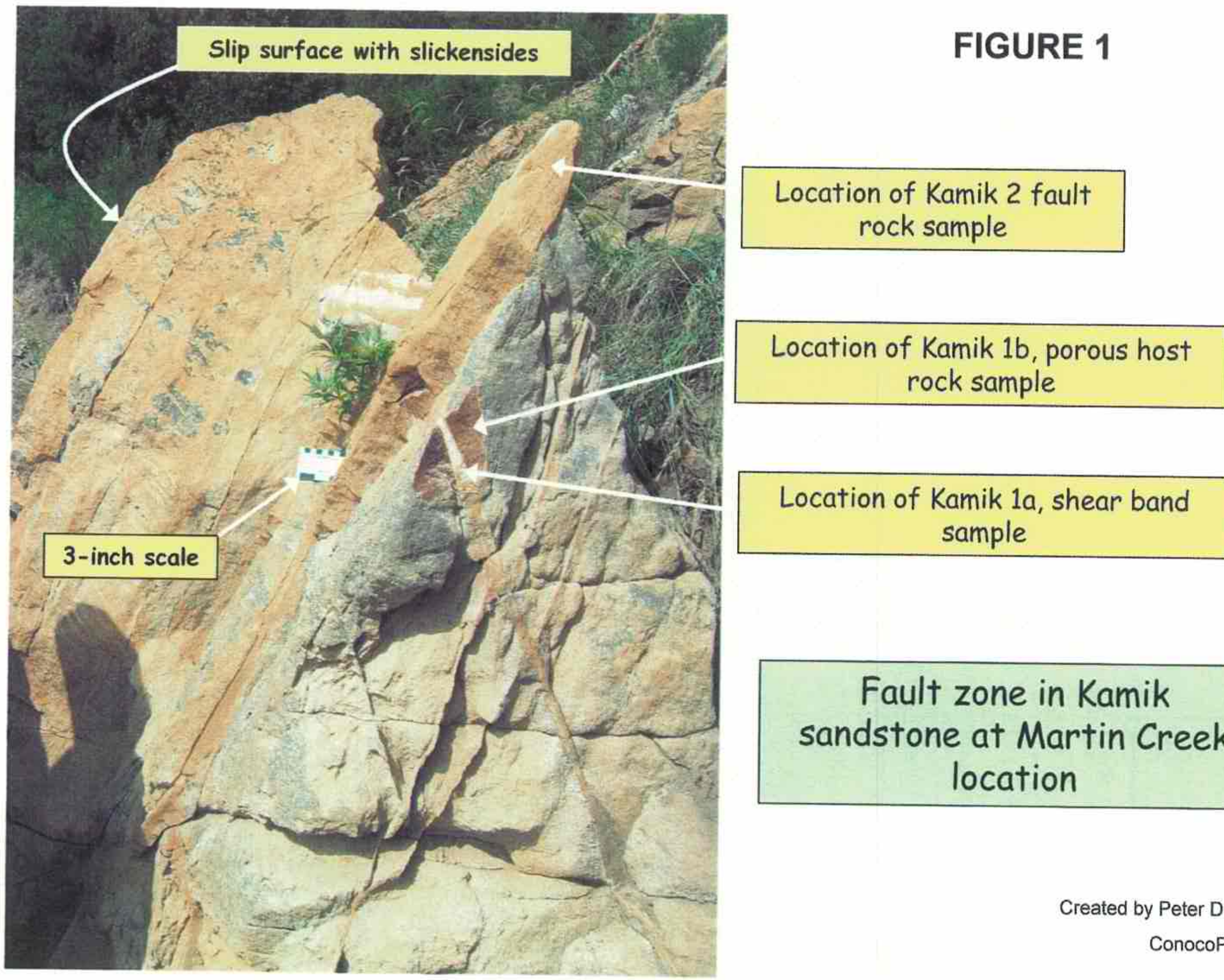


FIGURE 1



Fault zone in Kamik sandstone at Martin Creek location

Created by Peter D'Onfro
ConocoPhillips

FIGURE 2
Kamik

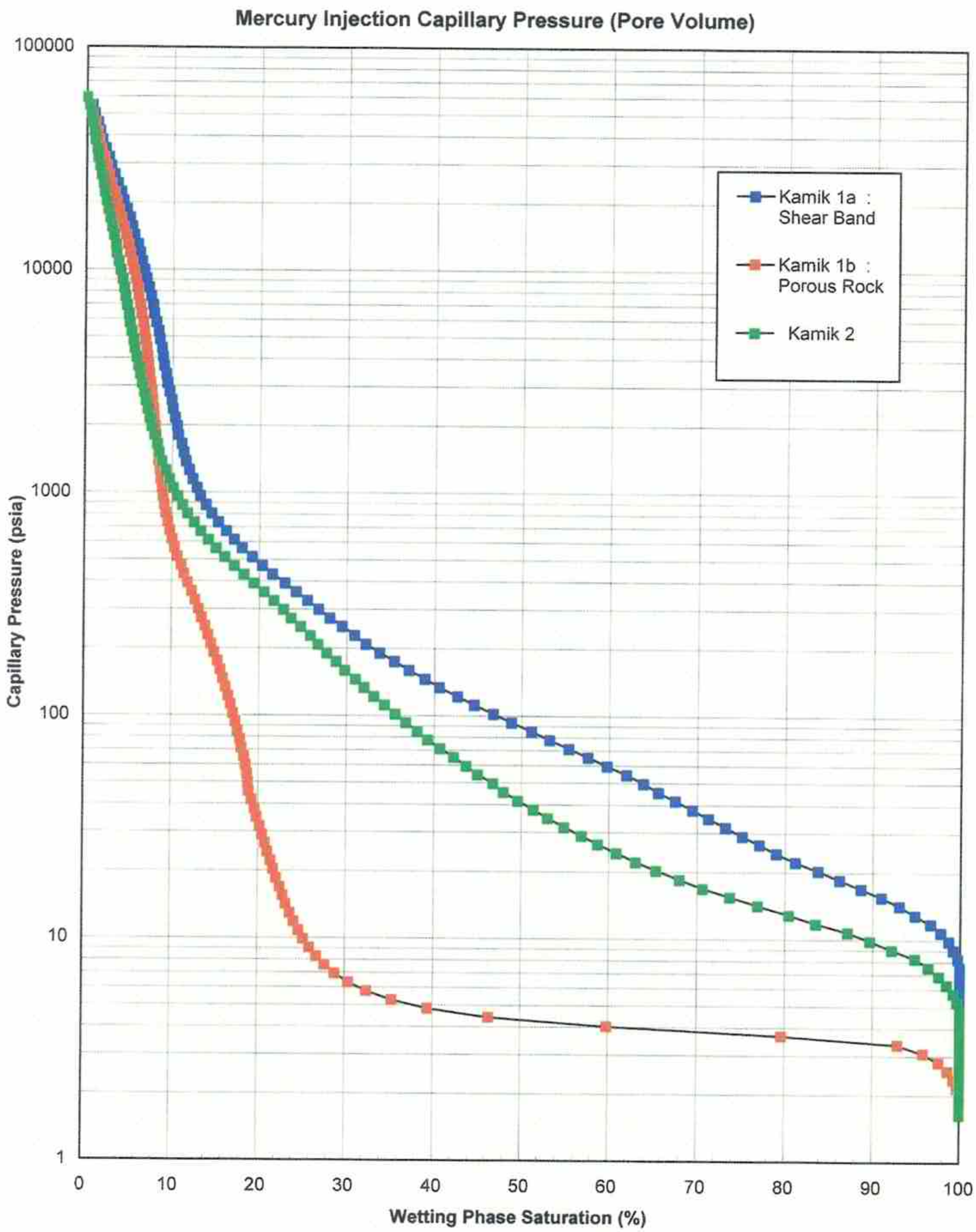
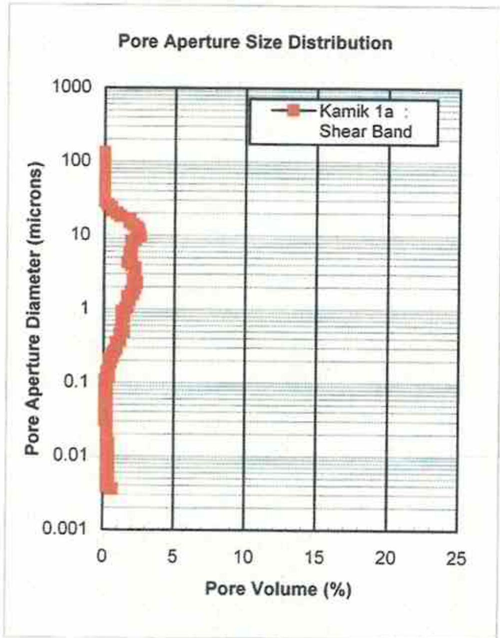
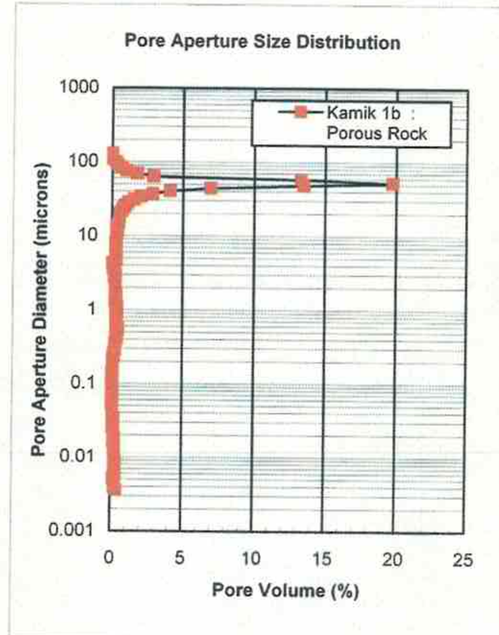
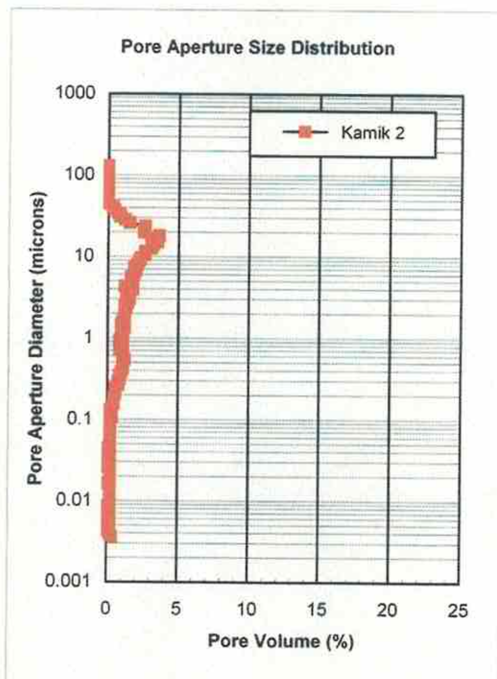


FIGURE 3
Kamik







APPENDIX 2: CARBONATE PETROGRAPHY

Emsian-Eifelian (lower middle Devonian) limestones
North & South Campbell Lake Quarries, NWT, Canada
Technical Work Agreement WBT.CU0382

C. T. Feazel, 10/01/2004

Sample 04-7-21-1a (N. Quarry, adjacent to fracture, low on wall)
Limestone: grain-dominated packstone, skeletal. Abundant crinoid ossicles, fragments of delicate and robust pelecypods and brachiopods (some leached and re-filled, leaving no internal structure other than equant calcite crystals). One articulated bivalve with sparry internal cement. Most skeletal fragments are angular to subangular (broken by predators, not transported). No borings. Rare coral fragments, subrounded. Poorly sorted. Matrix is finely recrystallized calcite. Indistinct outlines of 10-50μ peloids. Subhedral chalcopyrite (or weathered pyrite) in opaque masses 1-100μ across. Porosity (<5% overall) is concentrated along fractures and irregular patches to 1 cm diameter [outcrop photo suggests that these may follow biogenic precursors: ichnofossils or molds of skeletal components], and includes rhombic molds (de-dolomite?) 1-20μ across. Microporosity where fine matrix particles have been leached (and also inside some crinoid ossicles). Crystalline calcite lining fracture contains curved shear lamellae. Some tiny (<1μ) areas inside crinoid fragments appear rhombic to subrhombic – incipient dolomite?

Environmental interpretation: marine shelf

Reservoir potential: very low

Sample 04-7-21-1b (N. Quarry, adjacent to fracture, middle of wall)
Limestone: grain-dominated packstone/wackestone, skeletal. Abundant crinoid ossicles, fragments of delicate and robust pelecypods and brachiopods (some leached and re-filled, leaving no internal structure other than equant calcite crystals). Gastropods, branching stromatoporoids (Amphipora sp?), coral fragments. Several articulated brachiopods. Most bioclasts are angular to subangular, suggesting breakage by predators but little transport abrasion. Subhedral to euhedral chalcopyrite (or weathered pyrite) in opaque irregular masses to >1 cm, some concentrated with bitumen(?) in stylolitic residues. Matrix is indistinctly peloidal. Very poor sorting of bioclasts and peloids. Juxtaposition of packstone and wackestone textures may indicate bioturbation. Minor (<1%) dolomite, as subhedral to euhedral 1-5μ rhombs. Several calcite-healed fractures, including one probably stylolite-associated, filled with optically continuous calcite. No visible porosity, other than recent fractures resulting from sample collection or preparation.

Environmental interpretation: marine shelf downslope from stromatoporoid fore-reef

Reservoir potential: very low

Sample 04-7-21-1c (N. Quarry, adjacent to fracture, high on wall)

Limestone, dolomitic: grain-dominated packstone, skeletal. Whole and broken delicate to robust brachiopod shells to >1 cm, crinoid ossicles, bryozoan fragments, gastropods, very poorly sorted in matrix of fine (<20μ) skeletal debris. Bioclasts are broken, but not abraded. Poorly sorted. Brachiopod shells retain internal structure. Very rare borings into bioclasts. Cylindrical 1 cm burrows filled with wackestone, indistinctly peloidal, or very fine grainstone, peloidal. Stylolitic seams concentrate opaque bituminous residue and scattered 1-10μ anhedral masses of pyrite. Minor chalcopyrite or weathered pyrite scattered through matrix in euhedral to subhedral 1-10μ masses. Abundant calcite-healed subparallel fractures. Dolomite (~5%) is most abundant in and near stylolites, as 1-10μ rhombs. No visible porosity.

Environmental interpretation: marine shelf

Reservoir potential: very low

Sample 04-7-21-1d (N. Quarry, adjacent to fracture)

Limestone: grain-dominated packstone, skeletal. Whole and broken robust and delicate brachiopod shells, crinoid ossicles. Shells have been leached and replaced; no internal structure remains. One articulated brachiopod shell contains infill of coarser crinoidal packstone. Sorting poor: matrix of silt-size bioclastic debris. Opaque bitumen comprises 25% of matrix in some portions. Chalcopyrite (or weathered pyrite) in scattered (<1%) irregular subhedral masses 1-20μ across. No visible porosity, except in fractures resulting from sample preparation. Major fracture along one side of sample [and visible in outcrop photo] healed with sparry calcite crystals several centimeters across. Some crystals have euhedral terminations pointing away from the fracture wall, implying early growth into a void, followed by later precipitation of fracture-occluding cement. Smaller, probably conjugate fractures are also calcite-cemented.

Environmental interpretation: marine shelf

Reservoir potential: very low

Sample 04-7-21-1e (N. Quarry)

Limestone, dolomitic: grain-dominated packstone, peloidal. Coarse-grained and poorly sorted, with bioclasts to several centimeters long. Fragments and spines of robust and delicate brachiopod shells, gastropods, crinoids, and bryozoans. Some bioclasts are bored; others have micritized rims. Most brachiopod shells have been leached and refilled, but some have retained internal structure. Matrix of indistinct 1-20μ peloids and silt-size bioclasts. Shell fragments are broken; some abraded and sub-rounded. Stylolite containing a bryozoan(?) and clays(?) – Photos. Minor fracture porosity; otherwise tight. Dolomite is present (<5%) as 1-10μ rhombs in matrix and inside bioclasts.

Environmental interpretation: shallow marine shelf (photic zone)

Reservoir potential: very low

Samples 04-7-21-1f-1 and -2 (N. Quarry)

-1

Limestone: grain-dominated packstone, skeletal. Poorly sorted mix of bioclasts, many broken and angular, not abraded, some bored. Fragments of crinoids, brachiopods, bryozoans and pelecypods predominate. Rare subangular to rounded quartz silt, concentrated in probable burrow fill 4 mm across. Quartz has been embayed by very finely crystalline calcite matrix. Euhedral to anhedral pyrite, slightly weathered, 1-500µ across, concentrated in probable burrow fill. Microporosity (<1%) in and adjacent to stylolites and in patches several centimeters long (probable burrows).

-2

Limestone, as above, except that pyrite crystals are smaller and more weathered (yellow-brown iron-stained halos surround Subhedral 1-10µ crystals). One edge of sample is recrystallized to <1µ anhedral calcite and contains the most weathered pyrite. Microporosity preferentially occurs in this recrystallized zone.

Environmental interpretation: marine shelf receiving windblown quartz silt

Reservoir potential: very low

Sample 04-7-21-2a-1 (S. Quarry, float, from karst infill)

Limestone: grain-dominated packstone, skeletal. Angular to rounded bioclasts include fragments of crinoids, echinoids, pelecypods, gastropods, bryozoans, and ostracods. More rounded bioclasts have micritized margins, and a few are bored. Some have been leached and replaced with equant calcite. Matrix of finely broken skeletal fragments, plus some lime mud that in places is peloidal. Well-rounded 5-10µ peloids are preserved inside a gastropod shell despite extensive recrystallization of both the shell and surrounding matrix. Bioturbated fabric. Larger shells have been recrystallized to a finely crystalline mass of 1-10µ anhedral calcite. Fractures in several orientations, with multiple stages of cement, including planar bitumen, containing some pyrite, that has separated from fracture walls and now floats in elongate quartz crystals aligned 10-20 degrees off perpendicular to fracture walls. Also floating in the quartz are clear yellow subhedral 1-10µ crystals of dolomite(?) and several subhedral 50-100µ crystals of ferroan dolomite. Weathering of very fine (1-10µ) subhedral pyrite has stained adjacent calcite crystals yellowish-brown. Fracture porosity (<1%) with bitumen lining.

Environmental interpretation: open marine shelf

Reservoir potential: very low (but bitumen in fractures shows that at one time the potential may have been higher)

Sample 04-7-21-2a-2 (S. Quarry, float, from karst infill)

Limestone host rock with 2 cm thick laminated siliceous crust.

Limestone: grainstone, skeletal, peloidal, intraclasts-rich. Poorly sorted matrix of subrounded to well-rounded and abraded skeletal grains, many with micritized rims, and a range of muddy grains from 10µ peloids to >1 cm intraclasts containing bioclasts and peloids. Skeletal fragments include gastropods, small fragments of brachiopod and pelecypods shells, bryozoans, and ostracods. Mud fill in gastropod shells resembles well-rounded intraclasts where the shells have been recrystallized and are indistinguishable from cement. Many bioclasts have been neomorphosed to very finely crystalline calcite. Others have been leached and replaced by coarse equant calcite. Intergranular cement is blocky equant calcite. Minor (<1%) bitumen in irregular masses and microstylolite residues. Silica-cemented fractures 1-10μ wide, with sub-micron inclusions (esp. at fracture margins) of probable dolomite as in the siliceous crust, oriented parallel to host rock face. Earlier calcite-cemented fracture, <5μ wide, oriented perpendicular to host rock face.

Environmental interpretation: nearshore skeletal sand shoal

Reservoir potential: very low

Crust: Siliceous expansion fabric -- repeatedly spalled 1-20μ layers of the host rock, apparently spread apart by growth of elongate quartz crystals perpendicular to the host rock wall. Intimately intergrown with the quartz are sub-micron crystals of bright yellow dolomite(?). Away from the host rock wall, the crust is layered in millimeter to centimeter thick alternations of lighter and darker siliceous bands, reflecting varying amounts of dark iron-stain or organic matter. Orientation of the elongate (some fibrous) quartz crystals becomes more random with increasing distance from the host rock, with a swirling pattern evident in the outermost layers.

Environmental interpretation: this crust likely represents hydrothermal alteration (filling and spreading) of pre-existing tectonic fractures. Karst processes later exploited this fracture zone (i.e. the crust formed pre-karst).

Reservoir potential: nil

Sample 04-7-21-2b (S. Quarry, float, from host rock)

Limestone: mudstone finely interlaminated on a millimeter scale with wackestone, skeletal. Bioclasts are too small (most 10μ or smaller) to identify with certainty, but include bivalve fragments (possibly ostracods) and calcispheres of unknown affinity. Broken fragments are the norm, with only a few intact but disarticulated shells. Several areas of equant ferroan dolomite with irregular outlines may represent leached and refilled angular bioclasts to 1 mm across. Small (1-5μ) subhedral dolomite in matrix (<5%). Several near-vertical fractures and irregular former cavities contain geopetal infill (finely crystalline calcite below; equant calcite spar above). Weathered pyrite in blocky rectangular masses to 1 mm across. Very minor (<1%) fracture porosity with adjacent microporosity in places. Microporosity also occurs as isolated patches to 1 mm across in matrix.

Environmental interpretation: coastal karst infill by restricted marine (lagoonal) sediment – likely during transgression following karst formation, followed by vadose diagenesis during the next lowstand

Reservoir potential: low in present state, somewhat higher if cavities formed during the initial karsting or the subsequent vadose diagenesis are preserved

NB: this interpretation suggests sample mix-up…sample 2b was thought to be host rock but petrographically more closely resembles karst fill, whereas both samples from 2a appear to represent the host rock, but were collected (or at least labeled) as karst fill.

Appendix 3: Vitrinite reflectance analyses of coals from Kamik Formation, Martin Creek and Trevor Fault Zone, Northwest Territories

for:
Gary Prost
Conoco-Phillips,
Calgary, Ab

by:
L.D. Stasiuk,
Natural Resources Canada, Geological Survey of Canada,Calgary

Natural Resources Canada | Ressources naturelles Canada

Summary

Two outcrop samples of coal from the Lower Cretaceous Kamik Formation, NWT, were analysed for vitrinite reflectance. Coal from Martin Creek Valley has a mean vitrinite reflectance of 0.55 %RoR (sub-bituminous coal rank) whereas vitrinite in coal from the Trevor fault zone has a mean reflectance of 0.84 %RoR, clearly indicating that the later has seen significantly more thermal maturation, either from greater burial, or from a higher geothermal gradient.

Methodology

Whole rock cuttings, core and side-wall core samples were prepared for incident light microscopy and huminite and vitrinite reflectance. The samples were gently crushed into ~ 1-10 mm particulates. The samples were then mounted in an epoxy, after hardening the 'pellets' were then ground using first carborundum and diamond grit and polished on cloth and silk using an alumina-water slurry. Standard procedures for coal petrology were generally followed (Stach et al., 1982). Organic petrography was conducted using incident light microscopes equipped with white and fluorescent light sources, and oil, air and water immersion objectives (up to 2500x magnification). Percent reflectance in oil (%Ro; η_{oil} = 1.518) was measured with the Leitz MPV II and Zeiss UMP systems using plane polarized white light at 546 nm with the polarizer set at 45°. The number of reflectance measurements made on any given maceral within a sample generally varied from 5 to 50; samples were occasionally re-ground and re-polished to increase the number of measurements. Random percent reflectance in oil (%Ro) was measured (n = 50) on telovitrinite macerals. Reflectance was calibrated using glass standards (1.025 and 0.502 %Ro) of known refractive index.

Results

Two outcrop samples of coal from the Lower Cretaceous Kamik Formation, NWT, were analysed for vitrinite reflectance. The results are shown in table 1. Vitrinite in the coal sample from Martin Creek has a mean reflectance of 0.55 %RoR (sub-bituminous coal rank) whereas vitrinite in coal from the Trevor fault zone has a mean reflectance of 0.84 %RoR, clearly indicating that the later has seen significantly more thermal maturation, either from greater burial, or from a higher geothermal gradient.

Table 1. Vitrinite (Org_Type 2) reflectance analyses for Kamik Formation coals from outcrop.

DEPTH	IN	FM	Type	Location Type	PEL #	ORG_TYPE	%Ro_R	SD	N
182.88	m	Kamik	outcrop	Martin creek	**868/04**	2	0.55	0.03	50
750.00	m	Kamik	outcrop	Trevor Fault zone	**869/04**	2	0.84	0.05	50

Based on correlations done between temperature (established from fluid inclusion work and/or modeling) and vitrinite %Ro for lower Cretaceous coals in the Mannville of Alberta portion of the WCSB (Fig. 1), maximum temperatures for the Martin Creek and Trevor fault zone coals were possibly on the order of 90-95 °C and 125-130 °C, respectively.

Figure 1. Correlation between %Ro vitrinite and temperature established for Mannville Formation coals, WCSB.