Exploration Targets In the Canadian Rocky Mountain Foothills
Calgary to Moose Mountain, a Helicopter Supported Field Trip

GeoCanada 2000
Field Trip #21 (Post Meeting):

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The popular Moose Mountain Field Trip has now been expanded to include a more general exploration overview of the Canadian Rocky Mountain Foothills play types, along with detailed viewing of structural styles and how they relate to these play types.

Early exploration in the foothills discovered 283 e^9m^3 (10 Tcf) of gas in place, in the first generation of exploration targets up until the 1960's. These were simple prospects consisting of a single thrust sheet (e.g. Jumping Pound West). Subsequently, the second generation of play types contributed 198 e^9m^3 (7 Tcf) of gas in place to the reserve base up until the early 1980's. These were more complex, and consisted of multiple thrust sheets (e.g. Moose Mountain).

Since the eighties, exploration has focused on the search for the third generation exploration targets largely consisting of detachment folds on multiple or single thrust sheets. An example would be the Husky Benjamin 16-28-28-8W5M well that has produced 566 e^6m^3 (20 Bcf) of raw gas at rates of 566 e^3m^3 (20 mmcf/d). Because of the way these detachment folds develop, fractures play a significant role in enhancing primary reservoir characteristics. To date these plays have contributed about 113 e^9m^3 (4 Tcf) of gas in place to the reserves.

Acknowledgments

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Introduction

Moose Mountain, located 50 kilometers southwest of the city of Calgary, is a major topographic feature in the Foothills of the Canadian Rocky Mountain Overthrust Belt (Diagram No. 1). It is 2,440 meters in elevation at its highest point. Surface geology consists of Mississippian age carbonate rocks of the Mount Head, Turner Valley, Shunda, Pekisko and Banff formations; which are surrounded by the Jurassic and Lower Cretaceous age clastic rocks of the Fernie Formation, and Kootenay and Blairmore groups.

Numerous underlying thrust fault repeats of Mississippian, Devonian and Cambrian age rocks developed during the Laramide Orogeny control the domal character at surface. The structural style of the Moose Mountain field resembles that of several other significant hydrocarbon accumulations in the overthrust belt of the Canadian Rocky Mountains (e.g. Waterton, Coleman, Savanna, and Limestone Mountain fields). All of these pools are producing from reservoirs in the Mississippian and/or Devonian aged rocks. These pools produce from one or more thrust sheets beneath an overlying thrust sheet of Paleozoic or older rocks that is exposed at surface. The Moose Mountain Thrust Sheet (MMTS) is exposed at the surface on Moose Mountain. It is carried on the Moose Mountain Thrust Fault (MMTF). Depending on whether these wells were drilled in the valleys or on the flank of Moose Mountain, the KB elevation ranges between 1,647 meters to 2,135 meters.

Existing production at Moose Mountain is from the Mississippian aged Turner Valley Formation in three separate gas condensate pools (Rundle A, B and C.) and an undesignated oil pool. Each of the pools appears to be in different thrust sheets, which lie below the surface at a depth of approximately 2,500 meters (-500 meters). As of December 1999 4,106 e^6m^3 (145 Bcf) of raw liquid rich gas and 47 e^3m^3 (300,000 bbls) of 881 kg/m^3 (38 API) oil have been produced from seven wells in these pools. Drilling since 1993 on the northwest side of the existing production has added significant oil and gas reserves in five wells, two of which have been on production for a year. These wells have been partially included in the Alberta Energy and Utilities Board (AEUB) reserve estimates since 1998 as the Rundle C pool.

Section One

1a. Historical Overview of Moose Mountain

The history of the exploration and development of Moose Mountain is a long one. The first well drilled was Moose Oils #1, 16-29-22-6 W5M which drilled into the Moose Mountain Thrust Sheet (MMTS) in 1929, it tested "some" gas and condensate (Diagram No.2). Moose Oils #2, 8-29-22-6 W5M was drilled in 1935 and produced 1,587 m^3 (10,000 bbls) of 881 kg/m^3 (38 API) oil. These wells were drilled to depths 864 meters (+715 meters) and 519 meters (+1018 meters) respectively. During the following period of 24 years, 7 more shallow wells were drilled with little success. None of them penetrated the Moose Mountain Thrust Fault (MMTF). In 1959 the first 'deep' discovery well was drilled at 16-6-23-6 W5M (Table No. 1). It was the first well to be drilled through the Mississippian, Devonian and Cambrian age rocks of the MMTS to test the Mississippian and Devonian in at least two separate sheets below, to a maximum depth of 4,270 meters (-2,404 meters.). In this well the Mississippian Turner Valley Formation tested 141 e^3m^3 (5 mmcf/d) of gas through perforation from the first thrust sheet underlying the MMTF. During the following 22 years, 4 additional gas wells were drilled at depths ranging between 3,210 meters (-1,255 meters) and 4,752 meters (-3,008 meters). In 1986 the field was tied into the Quirk Creek Gas Plant, located 30 kilometers to the southeast.

After a brief hiatus, drilling recommenced in 1993 with the Husky Rigel Moose 2-23-23-7 W5M location that was completed as a suspended oil well (Table No. 1). It tested 42 m^3 (265 bbls) of 881 kg/m^3 (38 API) oil from a perforated interval in the Turner Valley Formation between 2,628 meters (-671 meters) and 2,715 meters (-759 meters). This well was followed by three other oil wells 10-14-23-7W5, 10-22-23-7W5 and 2-27-23-7 W5M. They all reached TD between 2,685 meters (-804 meters) and 3,094 meters (-1,036 meters). An additional well, 12-12-23-7 W5M, was drilled and is currently a capped gas well. This reached TD at 2,931 meters (-753 meters). All five wells tested hydrocarbons from the Turner Valley Formation in the first thrust sheet below the MMTF.

Section Two

2a. Reserves and Production Summary of the Moose Mountain Area

The Moose Mountain field consists of two parts. The existing production of gas condensate that has been produced by Shell and partners since 1986 from five wells. This is contained in two pools, the Rundle A pool and the Rundle B pool. The oil and gas discoveries in 1993-94 of Husky and Rigel of which two of the five wells drilled during this time have been on production for a year. These wells have proven up another gas condensate pool designated the Rundle C pool. In addition there is an oil pool which has no designation as yet. (Diagram No.3)

The existing production from the Moose Mountain field is from the Mississippian Turner Valley Formation and the Devonian Palliser Formation. (Table No.2 and Diagram No.3). Additional reserves are attributed to the Devonian Palliser (Wabamun) Formation; these are currently being produced in 10-5-23-6W5M as co-mingled production with the Turner Valley. This field produces from multiple thrust sheets with the production from the field ranging between elevations of -271 meters and -876 meters. This suggests a minimum hydrocarbon column of 600 meters in height. However, a good water test from -1100 meters suggests the maximum hydrocarbon column could be in the order of 800 meters in height.

The hydrocarbon reserves for the existing Moose Mountain Rundle A and B pools are 9,940 e^6m^3 (351 Bcf) of gas in place (IGIP), of which 5,324 e^6m^3 (188 Bcf) is sales (AEUB 1998). By the end of 1999, 4,106 e^6m^3 (145 Bcf) of raw gas was produced (Table No. 3 and Diagram No. 3). This is the same as the original marketable gas reserves published by the AEUB for the Rundle A and B pools. Both pools produce gas with an H_2S content of 11-13%.

Enhancement of the Turner Valley reservoir by fracturing has resulted in increased permeability of the dolomitised carbonate. Secondary porosity is also present (see Section 2b). The Rundle A pool consists of four wells into the first sheet under the MMTF (Diagram No. 3). Total production, to the end of 1999, was 3,001 e^6m^3 (106 Bcf), of raw gas at rates of 368 to 141 e^3m^3 (13 to 5 mmcf/d) with no significant water production. According to the AEUB the pay thickness is 25 m, with 6% porosity and an aerial extent of 26 km^2. Reservoir pressure has declined from 12,838 to 7,584 kpa (1,862 to 1,100 psi) between the start of production in 1985 and 1999.

The Rundle B pool consists of one well into the third imbricate of Turner Valley Formation under the MMTF (Diagram No. 3). This well produced 1,132 e^6m^3 (40 Bcf) of liquids rich gas at a maximum rate of 396 e^3m^3 (14 mmcf /d), with no significant water (AEUB 1999). Net pay thickness is 60 meters with 7 % porosity over an area of 0.2 km^2. Reservoir pressure has declined from 15,375 to 8,466 kpa (2230 psi to 1228 psi) between the start of production in 1985 and 1999. The Rundle C pool has only limited public information available as of December 1999.

Although natural gas liquids were reported for the first five years of production, the current values for the Rundle A and B pools cannot be determined. This is due to the post 1990 reserves dropping to less than the ERCB reporting threshold of 800 e^3m^3 (5 million bbls). The initial amount of liquids produced ranged between 307-363 m^3/e^6m^3 (40–45 bbls per mmcf) of sales gas, with remaining reserves of 800 e^3m^3 (5 million bbls) (Table No. 3 and Diagram No. 4).

The four recent wells in the undesignated oil pool have tested 904 kg/m^3 (39 API) oil at rates of 31 to 111 m^3 (200 to 700 bbls) per day from the Turner Valley Formation. Reserve numbers have not been published.

2b. Surface Stratigraphy of the Moose Mountain Area

Exposures on Moose Mountain are primarily of the Mississippian Rundle Group that includes, from top to bottom, the Mount Head, Turner Valley, Shunda and Pekisko formations (Table No. 4, Diagram No. 5). Underlying the Rundle Group is the Banff Formation; it crops out in the in the creek valleys of the Moose Mountain area. Depositional environments are typified by shallow to deep temperature stratified environments. Deep ramp sediments of the Banff Formation shallow up to shelf carbonates (outer to inner ramp deposits) of the Pekisko, Shunda and Turner Valley formations. The Shunda and Mount Head formations exhibit more restricted to sabka characteristics (Diagram Nos.5 and 6; Martindale and Boreen, 1997).

Mount Head Formation: On Moose Mountain the Mount Head Formation is primarily a recessive unit that forms exposures of loose rock. At the base is a distinctive bed of orange-brown ripple laminated, bioturbated cherty siltstone. In Canyon Creek, a very fine grained, five metre thick sandstone constitutes the basal beds (Mundy et. al., 1995). Above this is a brown laminated, silty dolostone and buff to grey microcrystalline dolomite and cherty dolomite. Large boulders and one metre thick beds of solution breccia were noted in the vicinity of the Moose Mountain lookout, probably in the upper Mount Head Formation.

Mundy et al. (1995) also recognized what could be a thin (nine meters thick) Loomis Member in Canyon Creek. It was described as a bioclastic-peloidal grainstone, with grains of echinoderm fragments, bryzoans, foraminifera and ooids. The Loomis Member is about one metre thick where it was recognized on the east limb of the Moose Mountain Anticline, and consists of a lime grainstone.

Discrepancies in the mapping for Moose Mountain in the vicinity of Moose Dome Creek occur between the map presented here and that of Ollerenshaw and Bamber presented by Bamber et.al. (1981). This has been attributed to the inclusion of the thick units of skeletal lime grainstone, packstone, and cherty dolomite into the Mount Head which Newson and Sanderson (1994) mapped as the upper unit of the Turner Valley Formation. Mundy et.al. (1995-page 76) also placed the contact of the Mount Head higher than Bamber et al. (1981-stop 3).

The upper part of this formation has been eroded on Moose Mountain; therefore thickness can only be estimated as greater than 80 meters. Reported thickness of the Mount Head in Canyon Creek ranges between 105 and 140 meters.

Turner Valley Formation: For the purposes of mapping, the Turner Valley was subdivided into three subunits, an upper and lower more resistant unit, and an intervening recessive unit. It is likely that these correspond to the upper porous, middle dense and lower porous described in Canyon Creek and elsewhere in the subsurface (Diagram No. 7a,b). The Turner Valley is the primary reservoir unit. In the subsurface, it is characterized by porous dolomitized grainstones with pinpoint, intercrystalline, and vuggy type porosity. Fractures are common throughout, and are locally well developed. Dolostone, with a secondary porosity resulting from dissolution of calcite forming moldic and intercrystalline porosity is also common in the muddier intervals. Matrix porosities are on the order of 3-8%, where enhanced by fractures, permeabilities can reach as high as 100 md. Generally, permeabilities range between 1 and 10 md.

The lower unit of the Turner Valley on Moose Mountain consists of light grey to buff crinoidal and fossiliferous grainstone that forms resistant bands, and minor dolomitized packstone and wackestone. This is overlain by the middle unit; a laminated, chert banded and burrowed dolomitic limestone, and silty brown-orange weathering dolomite. The cherty portions of this unit can be cliff forming in the northern Moose Mountain area, where it is also thicker. The upper unit is characterized by grey-brown bioclastic, pelloidal to oolitic grainstone, with well developed cross-bedding; skeletal wackestone to packstone occurs near the base of the upper unit in Canyon Creek (Mundy et. al., 1995). Coral bed(s) consisting of *Syringopora* and lithostotionids occur in the uppermost unit, and are correlative with a bed in the hanging wall of the PMTF as described in Canyon Creek (ibid). Bed B, as initially mapped by Newson and Sanderson (1994), is included in the upper unit.

Thickness estimated for the Turner Valley on Moose Mountain ranges between 135 and 170 meters , and in Canyon Creek the reported thickness is 125 meters .

Shunda Formation: Primarily a recessive unit on Moose Mountain, the Shunda Formation is characterized by red-brown weathering, ripple laminated, silty dolostone and lime wackestone to mudstone, with minor amounts of solution breccia. In Canyon Creek this unit is reported to include floatstones of solitary (rugose) corals (Mundy et. al., 1995).

In Canyon Creek, the basal Shunda is recessive over a thin (five metre) interval. This is overlain by dark and medium-dark pelloidal bioclastic grainstone (Mundy et. al., 1995). This grainstone facies was included in the Pekisko Formation by Newson and Sanderson for the purposes of surface mapping; thereby placing the basal contact of the Shunda above the resistant grainstone. The top of the Shunda is characterized by a massively bedded, fine- to cryptocrystalline silty dolomite and dolomitic limestone, with floating recrystallized skeletal debris (?) as irregular pods of less than one centimetre in diametre, some resembles birdseye texture (also noted by Bamber et al., 1981). Bed A, as initially mapped by Newson and Sanderson (1994), is equivalent to this uppermost massive bed

Thickness of the Shunda Formation on Moose Mountain ranges between 50 and 100 meters ; in Canyon Creek the thickness is reported to be 90 meters .

Pekisko Formation: The lower half to two thirds of the Pekisko formation forms a resistant cliff band. This is in contrast to the more recessive upper half. The lower Pekisko (50 or more meters thick) is a very dark grey to black, massively bedded, crinoidal lime grainstone and rudstone, with some packstone. Approximately 30 meters of the uppermost Pekisko consist of a dark grey massively cross-bedded bioclastic (crinoidal), oolitic packstone to wackestone with some grainstone. In Canyon Creek Mundy et. al. (1995) described an increasing oolitic component in the middle Pekisko with thin silty dolostone. Bed P1, as initially mapped by Newson and Sanderson (1994) forms a resistant cliff band approximately 15 meters thick. It is included in the uppermost Pekisko.

Thickness estimates on Moose Mountain range between 100 and 135 meters for the Pekisko Formation, in Canyon Creek the reported thickness is 96 meters.

Banff Formation**:** This unit was mapped in a few poorly exposed locations in the vicinity of Moose Mountain. Based on data available from Canyon Creek, the Banff Formation is a recessive, argillaceous silty lime packstone, wackestone, mudstone, and calcareous shale; overlain by more resistant dark brown-grey, cherty lime packsone and wackestone (Mundy et. al., 1995 and Bamber et. al., 1981). In the upper Banff are lenses of crinoidal grainstone and packstone to rudstone (storm induced event beds commonly referred to as tempestites). The overlying Pekisko forms a resistant cliff above an erosional surface (Richards, 1989). In Canyon Creek, Mundy et. al. (1995) reported two meters of relief at this contact.

2c. Fracture Characteristics

Fracture development in the Mississippian of the Foothills Belt is believed to play a significant role in the productivity of gas pools including the Moose Mountain Field (discussed in Section 2a). Knowledge of the fracture orientations allows for the optimization of horizontal well bore orientations to maximize production. When studying the fracture geometries of an area, consideration must be given to determining which fractures are currently open, and therefore are conduits for hydrocarbons. This usually involves determining the in-situ stress regime in the area of interest.

Fracture intensity is dependent on several factors such as the rock composition, grain size and porosity. In general, increased fracture intensity has been associated with dolomitic or siliceous litholgies, fine grain sizes, and low porosity. Bed thickness and structural position can also influence fracture development, for instance, thinner beds (less than one meter) tend to be fractured on a closer spacing (eg. ten centimeters or less) than thick beds. Zones of high curvature in a structure tend to be more fractured (e.g. the hinge area of a fold).

Fracture orientation, in relation to folds, is best described using the three geometric axes a, b and c (Diagram No. 8). The b axis is equivalent to the fold axis, the c axis is perpendicular to bedding (and the b axis), and the a axis is perpendicular to both the b and c axes and lies within the bedding plane. Fractures are referred to as ac, and bc depending on the plane they occur in. Shear fractures are developed oblique to the ac, bc planes. Each extension fracture can have associated with it two shear fractures (conjugate shears). The term joint is also defined in terms of these three geometric axes, and has been used instead of fracture in the literature (Price, 1967).

Although fracture development was noted in all stratigraphic units at the surface on Moose Mountain, the intensity of fracturing was highly variable. In general, the Mount Head and Shunda formations have more closely spaced fractures than the Turner Valley and Pekisko formations with lithology appearing to be the controlling factor.

A systematic study of fracture development of two folds on Moose Mountain was undertaken in 1998 and 1999. These folds represent two ends of the spectrum in terms of fold styles developed at Moose Mountain. The first is a detachment fold with a hinge width of about 100 meters , west of Moose Mountain Anticline and visible below the lookout. The second is the broad Moose Mountain Anticline visible along the Moose Mountain culmination at surface. This fold was measured at lookout and north ridges.

Characteristics that were included in the study are:

- fracture spacing, aperture width, and length;
- lithological influence; and
- determination of the number of fractures per unit area (density) along with estimates of fracture porosity of a volume of rock (strain).

Preliminary study of the fractures identified the absence of conjugate shear fractures. Although fractures oblique to the structural trend (b axis) exist, they were extensional in nature. Also, there was no clear evidence of an earlier regional fracture system, since the rotation of bedding to horizontal did not change the relationship of fracture sets. (Possibly a case could be made for the oblique sets being pre-folding.) Therefore, the fracture data were analysed with the assumption that fracture development was synonymous with the development of folds.

Results of the study show that the maximum density of fractures (exhibited by the number of fractures per meter) is in the hinge area, regardless of fold geometry (Diagram No. 9). In addition, the highest density fracture set in the hinge area is variable between the transverse ac fractures (<30^o from the c axis), the transverse-oblique fractures (>30^o from the c axis), and the longitudinal bc fractures. In the finer grained facies, consisting of partially dolomitized lime-packstone/wackestone, the spacing between fractures and fracture lengths are less than in the coarser grained facies, consisting of partially dolomitized lime-grainstone. Despite the wider spacing, the calculated fracture porosities for the grainstone facies are higher. This has been attributed to the longer fracture lengths since the finer grained facies exhibit fracture apertures that are in a similar range to that of the coarser grained facies.

Aperture was measured from cemented fractures only, to prevent the incorporation of surface weathering enhancement of open fractures into the measurements. Microscopic work was not performed for the purposes of determining smaller aperture widths less than 0.1 millimeter. Unpublished work by Jamison and Rait (1999) suggests that apertures on the microscopic level do not contribute significantly to fracture porosity.

Detailed fracture studies focussed on morphology and occurrence can be conducted in the subsurface using core. For instance, the work done by Martindale (1995) shows more intense fracturing in the 'upper porous' and 'middle dense' of the Turner Valley Formation than the 'lower porous; this also corresponds with the more dolomitized intervals (Diagram No. 7a,b).

Section Three

3a. Surface structural elements of the Moose Mountain Anticline

Moose Mountain is a surface anticline developed above a subsurface aniformal stack. A number of interesting structural inter-relationships and geometries that could be extrapolated for subsurface interpretation, are visible when traversing the structure from north to south.

From south to north, (see Diagram Nos. 10 and 11) the shortening mechanism changes from primarily thrust faulting on south ridge (south and west of Moose Dome Creek), to folding and minor thrust faulting at lookout ridge, to primarily thrust faulting on north ridge (between Moose Creek and Coxhill Creek).

The detailed map presented in this field guide was based on surface mapping at a scale of 1:20,000. With a surface vertical relief of 400 meters along a strike length of seven kilometers, parallel to the axis of the Moose Mountain Anticline, three-dimensional geometries of the structures could be documented.

Well developed folding, visible beneath Moose Mountain Lookout (Diagram No. 10) highlights the importance of this mechanism in thickening a stratigraphic unit, in this case primarily the Turner Valley Formation. To the north of lookout ridge, folding continues for approximately two kilometers at the same structural level. As well, what was a minor thrust fault increases in stratigraphic displacement to the north, and in the vicinity of north ridge places Shunda Formation onto folded Turner Valley and Mount Head formations in the footwall. These folds are visibly truncated by the thrust fault.

A northerly structural plunge of the Moose Mountain anticline is apparent on the map (Diagram No. 11). The Banff Formation is exposed in the core of the anticline between north and south ridges; north of Coxhill Creek only the Mesozoic aged succession (Jurassic Fernie Formation through Lower Cretaceous Blairmore Group) is present at surface. The disappearance of the Mississippian carbonate succession into the subsurface has been accounted for by the plunge of 15^o towards 310^o of the Moose Mountain Anticline measured at north ridge. At south ridge the plunge is significantly less at 3^o towards 321^o azimuth.

3b. Prairie Mountain Thrust Fault Geometries

On the west flank of the Moose Mountain Anticline is the Prairie Mountain Thrust Fault (PMTF) (Diagram No. 12). Southwest of the Moose Mountain lookout, hanging wall and footwall ramps are developed in the PMTF. Note that the PMTF cuts down-section out of the Turner Valley Formation into the Pekisko Formation in its hanging wall, and cuts down-section out of the Fernie and Kootenay formations into the Mount Head Formation in its footwall. At this location a syncline developed in the Fernie and Kootenay formations is truncated and overridden by the PMTF.

Newson and Sanderson (1994) have interpreted the timing of the PMTF to be syn- to post-deformation in its footwall. This is based on the presence of a well-developed grainstone with *Syringopora* corals at the top of Moose Mountain (near the fire lookout) with Mount Head Formation above and below the grainstone. This unit resembles the upper Turner Valley Formation, particularly that seen in the hanging wall of the Prairie Mountain Thrust Fault (PMTF) to the west, and similar to that described in Canyon Creek for the Turner Valley (Mundy et. al., 1995). Alternatively it could be the Loomis Member, although the presence of large corals makes it unlikely based on nearby exposures of this member.

These relationships suggest that the PMTF is present on the top of Moose Mountain and along the ridge to the north as a small klippe, (Diagram Nos. 11, 12); and that the PMTF has cut down-section in the direction of transport. Although this is not commonly reported in the Southern Alberta Rocky Mountains and Foothills, it is easily explained by deformation of the footwall rocks prior to movement on the PMTF, with the PMTF cutting across already developed or developing structures. On a smaller scale, evidence for a similar structural relationship is present on north ridge, where previously formed folds are truncated by an overriding thrust fault.

3c. Structural Interpretations: their role in the development of the Moose Mountain Field.

The Moose Mountain Field consists of a complex arrangement of fault bend fold style duplex structures, and detachment folds. The Moose Mountain Thrust Sheet (MMTS) consists of Paleozoic and younger rocks and is carried by Moose Mountain Thrust Fault (MMTF). It is folded by an underlying duplex structure developed in the Mississippian through the Cambrian aged succession. Since 1950, several different structural interpretations have been represented by cross sections of this structure. Many of them have used a model similar to the fault bend fold model (Suppe, 1983) to develop the larger scale structural geometries. Recently, the detachment fold model (Groshong and Epard, 1994; Jamison, 1986) has been recognized as important on Moose Mountain in relation to some of the smaller size structures (eg. kilometer or less in amplitude and wavelength), and may impact the future development of the Moose Mountain Oil and Gas field.

These historical structural interpretations illustrate how a structural high beneath the surface sheet, west of the main Moose Mountain culmination, could be present. Drilling later proved this interpretation correct.

In two early cross sections over Moose Mountain by Jones in 1971, and Shell in 1983 (Diagram Nos. 13 and 14), the potential for the crest of the structure of the first sheet under the MMTF to be west of 16-6-23-6W5 or 10-32-22-6W5 was not interpreted. Typically, the Cambrian aged succession is 500 meters thick in this area. Both of these cross sections show the Cambrian on the west flank of the surface anticline (in the surface sheet) to be over 1000 meters thick, with faults cutting through the Cambrian succession. However, the fault displacements are not enough to double the thickness of the Cambrian as shown.

An alternative interpretation by Fitzgerald (1985) (Diagram No. 15) illustrates the presence of a detachment fold in the Cambrian of the surface sheet between the wells 16-6-23-6W5, and 10-5-23-6W5. A detailed look at the geophysical well logs and drill cuttings for the 10-32-22-6W5 well, showed Cambrian strata right way up at 635 meters depth, upside down at 1375 m, and right way up at 1475 meters (Diagram No. 16). These results allow for a structural high in the Mississippian aged rocks of the first sheet under the MMTF, west of the 16-6-23-6W5 well.

A later cross section by Widdowson in 1991 (Diagram No.17) drawn through well location 10-32-23-6W5, also uses the detachment fold model to accommodate a structural high below the MMTF west of 10-32-22-6W5. Fitzgerald's 1985 model was confirmed by the drilling of location 12-12-23-6W5 in 1994. This shows the MMTF to be at -188 m, higher than had previously been identified in the Moose Mountain field. In addition, the structure is showing a northwest plunge at this location. Therefore, up plunge from 12-12-23-6W5, and just west of the 16-6-23-6W5 well, the MMTF could be as high as sea level, proving the presence of a culmination cored by Mississippian strata at this location (Diagram Nos. 16 and 18).

The importance of detachment folding at other structural and stratigraphic levels is also illustrated in the cross section through Moose Mountain (Diagram No. 18). The structurally highest level is exposed at the surface in the Mississippian of the MMTS (Diagram No.11). Seismic interpretation suggests a deeper level of detachment folding forms in the Cambrian in the core of the structure. This is based on using the measured bed length of the Banff Formation (above the Devonian), which is a good seismic marker, to predict the bed lengths of the top of the Devonian and Cambrian aged strata. If this is used in conjunction with a fault bend fold model, an unfilled space results in the core of the structure. This ‘space problem’ can be alleviated by using the same bed lengths but with a detachment fold model.

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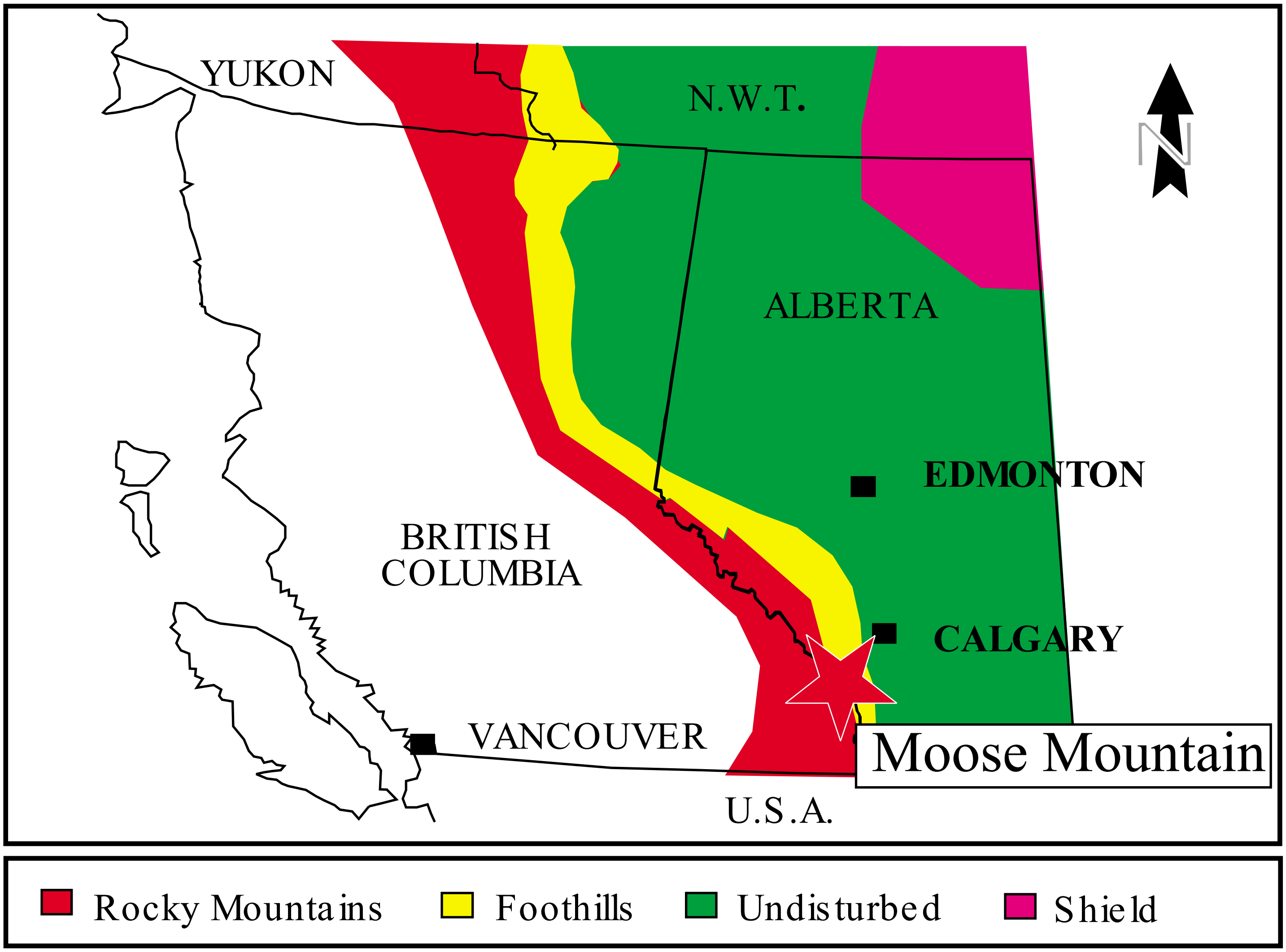
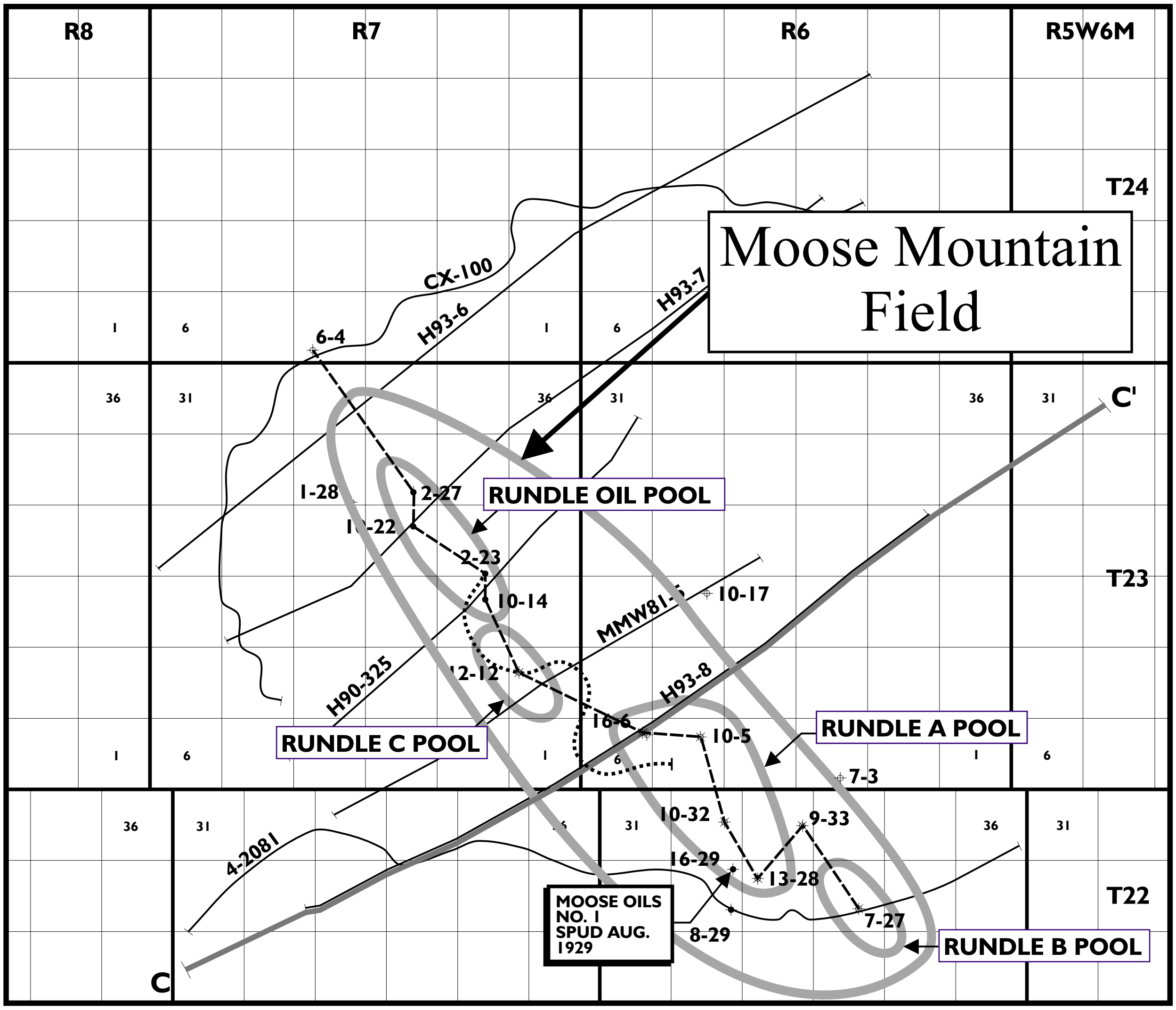
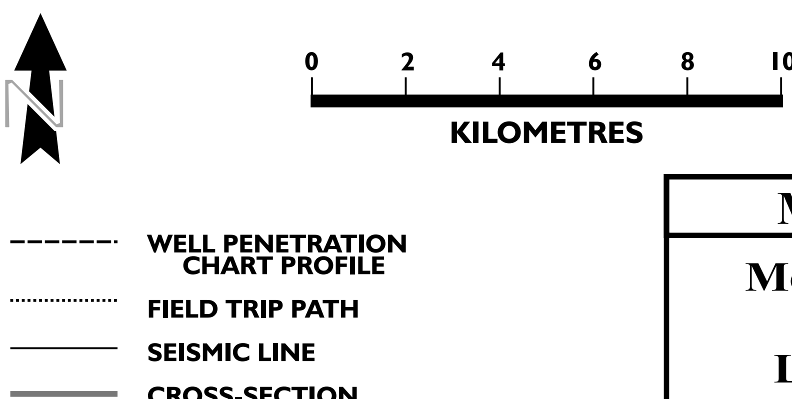
Moose Mountain Location Map



Moose Oils Ltd.		
Moose Mountain Location map		
A.C.Newson	Diagram 1	Revised March 2000

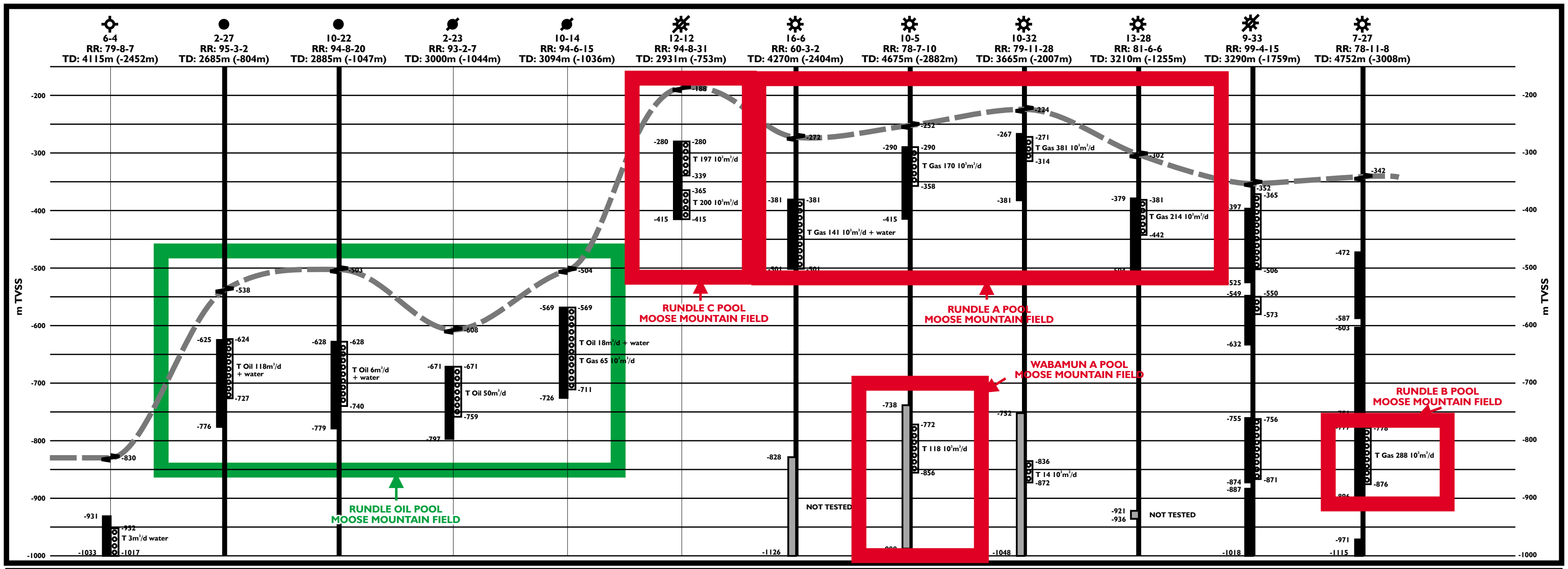




Moose Oils Ltd.

Moose Mountain Field Trip Location Map

A.C.Newson	Diagram 2	Revised March 2000



LEGEND

- * = Rundle A & Wabumun A comingled production as of August 1998
- = MOOSE MTN THRUST FAULT
- = PERFORATIONS
- = TURNER VALLEY FORMATION
- = PALLISER FORMATION
- T = TESTED THROUGH PERFS

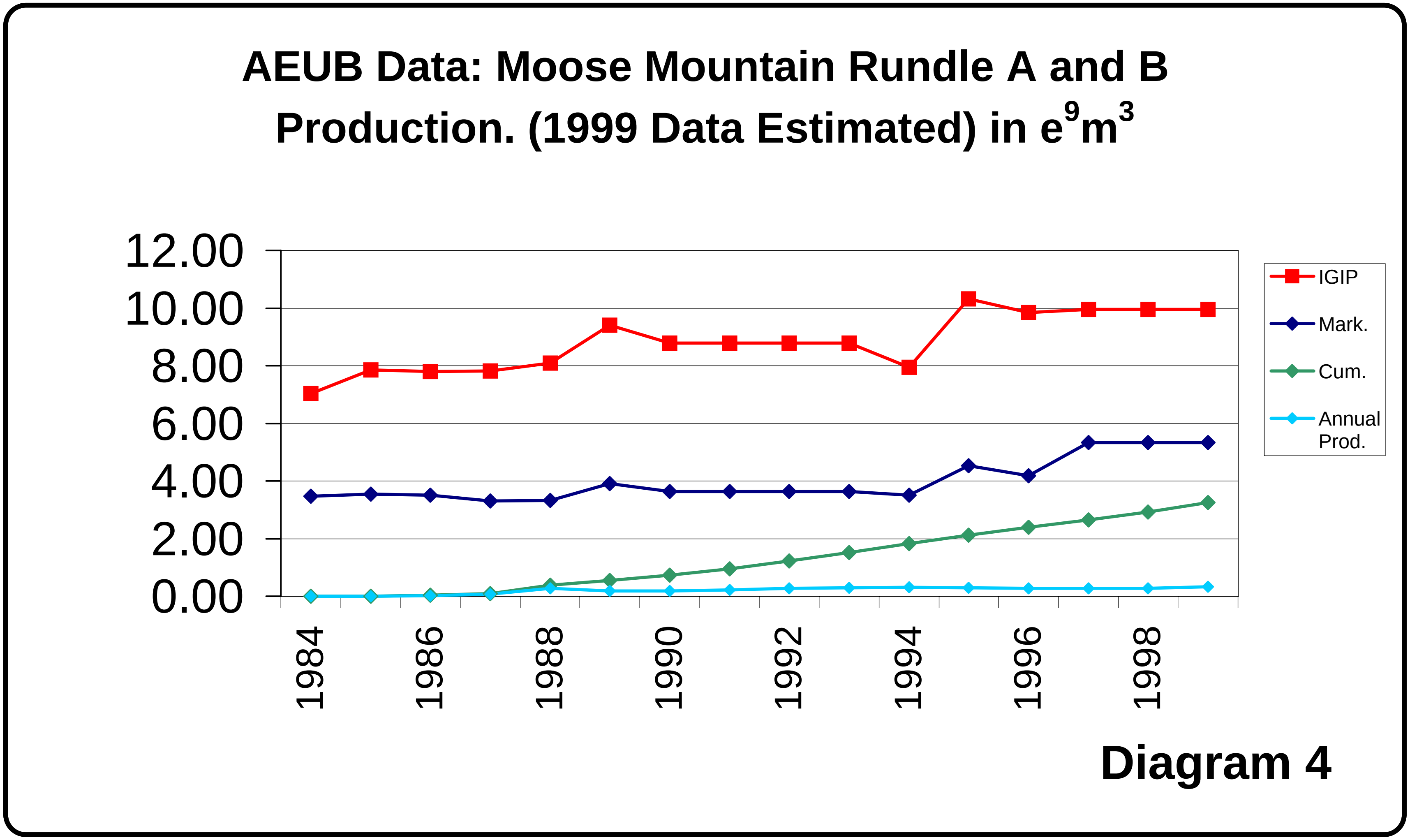
Production as of February 2000	2-27		10-22			6-16	10-5 *	10-32	13-28		7-27	Production as of February 2000
Raw Reserves	Gas 10^6 m^3	Oil 10^3 m^3	Gas 10^6 m^3	Oil 10^3 m^3		Gas 10^6 m^3	Gas 10^6 m^3	Gas 10^6 m^3	Gas 10^6 m^3		Gas 10^6 m^3	Raw Reserves
Cumulative Production	14	32	16	27		228	988	1045	678		1130	Cumulative Production
	10^3 m^3	m^3	10^3 m^3	m^3		10^3 m^3	10^3 m^3	10^3 m^3	10^3 m^3		10^3 m^3	
Initial Production	31	71	42	63		73	210	90	98		290	Initial Production
Current Production	39	73	50	63		45	240	240	180		152	Current Production

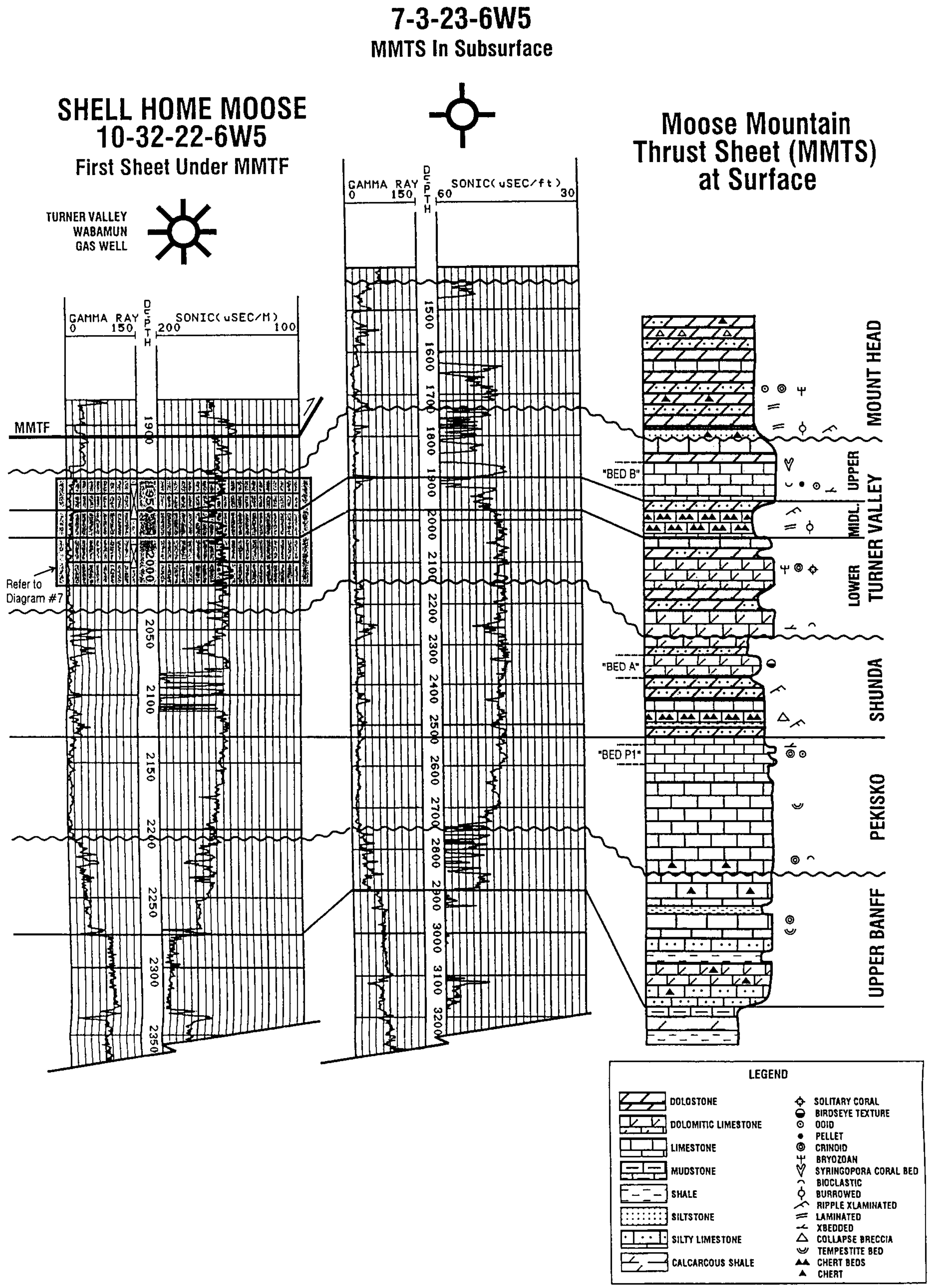
Moose Oils Ltd.

Well Penetration Chart

A.C.Newson | Diagram 3 | Revised May 2000

well_pen_chart


AEUB Data: Moose Mountain Rundle A and B Production. (1999 Data Estimated) in e9m3
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1984
1986
1988
1990
1992
1994
1996
1998
IGIP
Mark.
Cum.
Annual Prod.
Diagram 4



SURFACE LITHOLOGY AND GEOPHYSICAL LOG CORRELATIONS

Diagram 5	Surface Lithology and Gamma Ray Correlation.	D.A.Sanderson

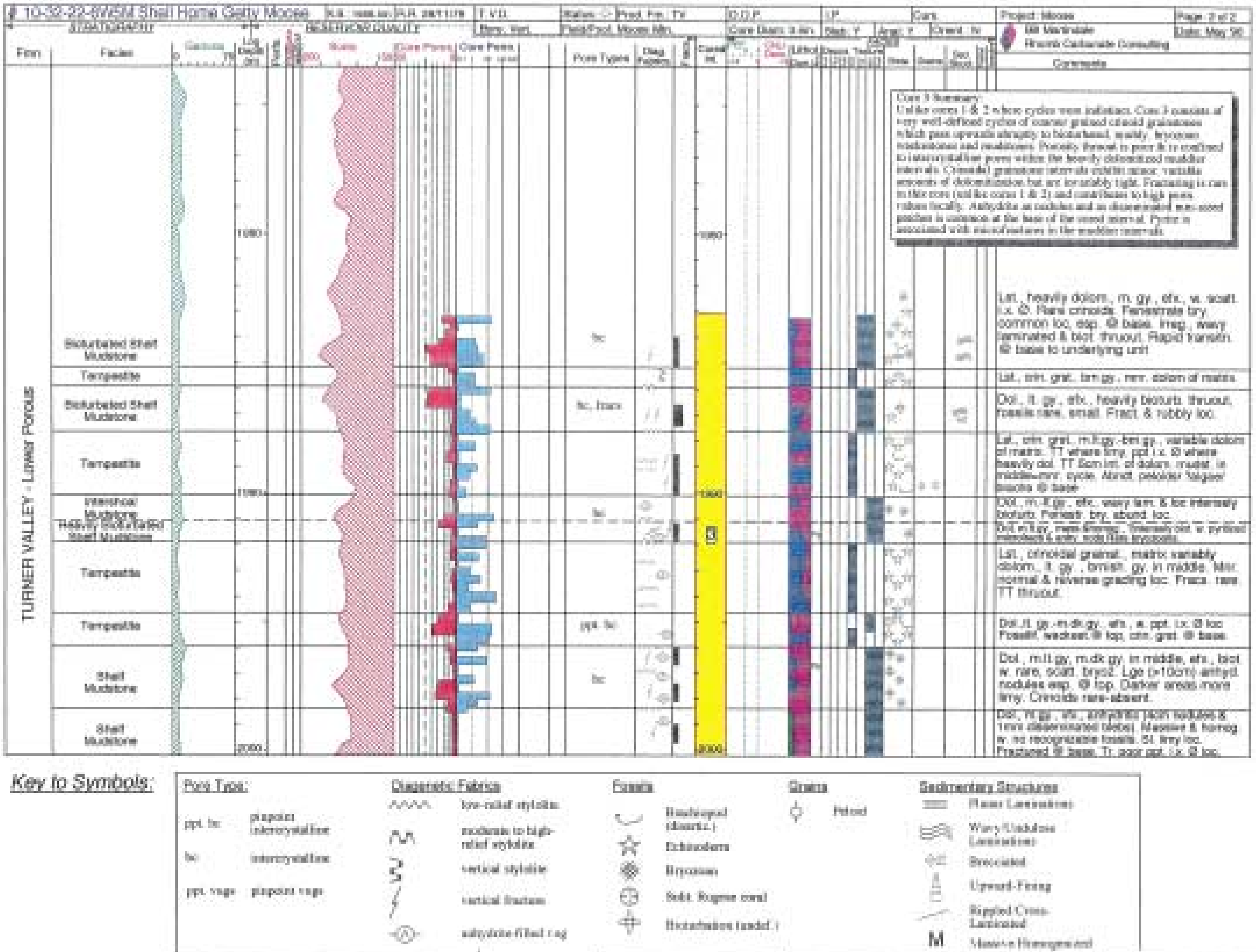


Diagram 7 a	Core Descriptions For 10-32-22-6W5M	B.Martindale

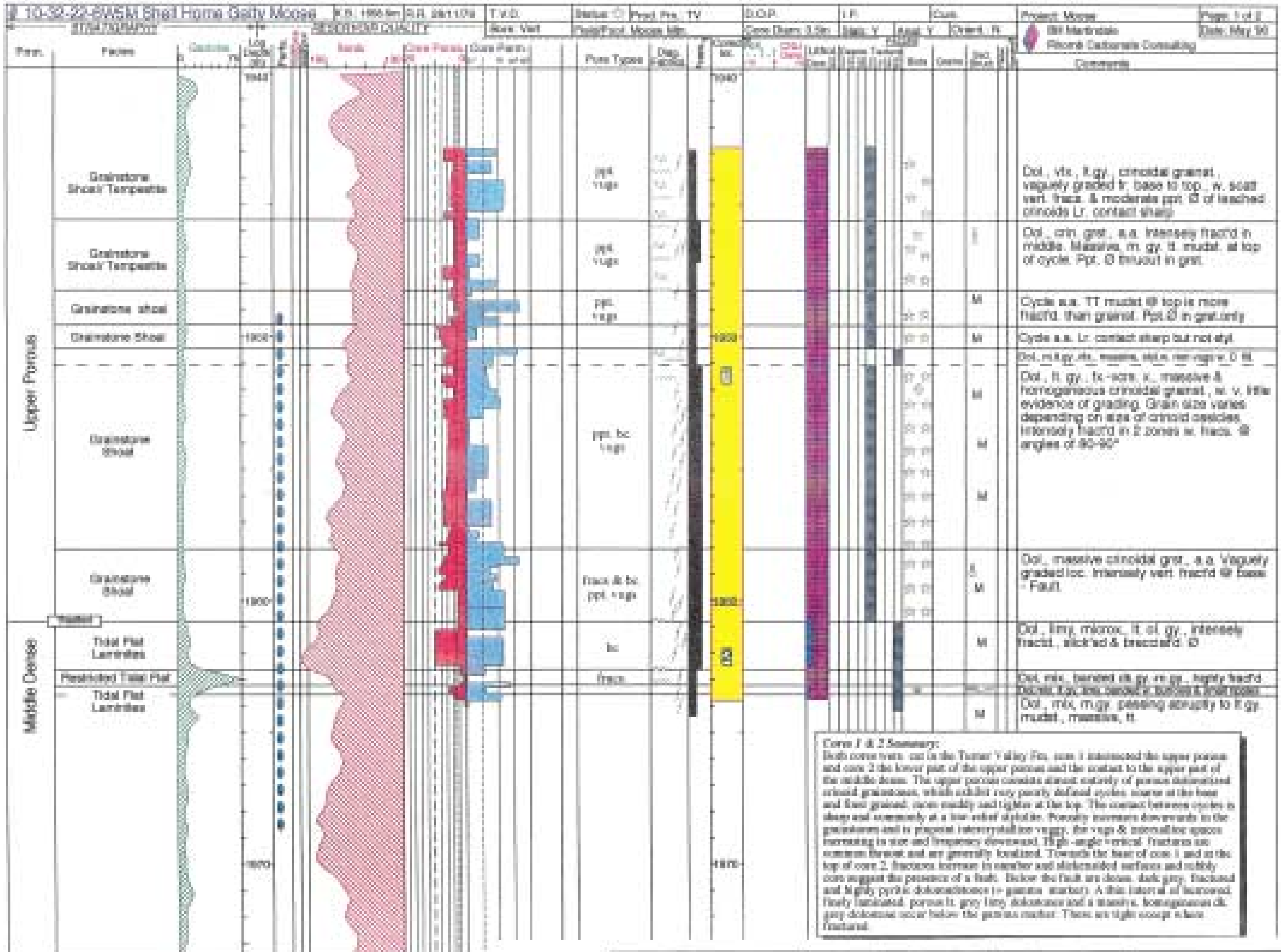
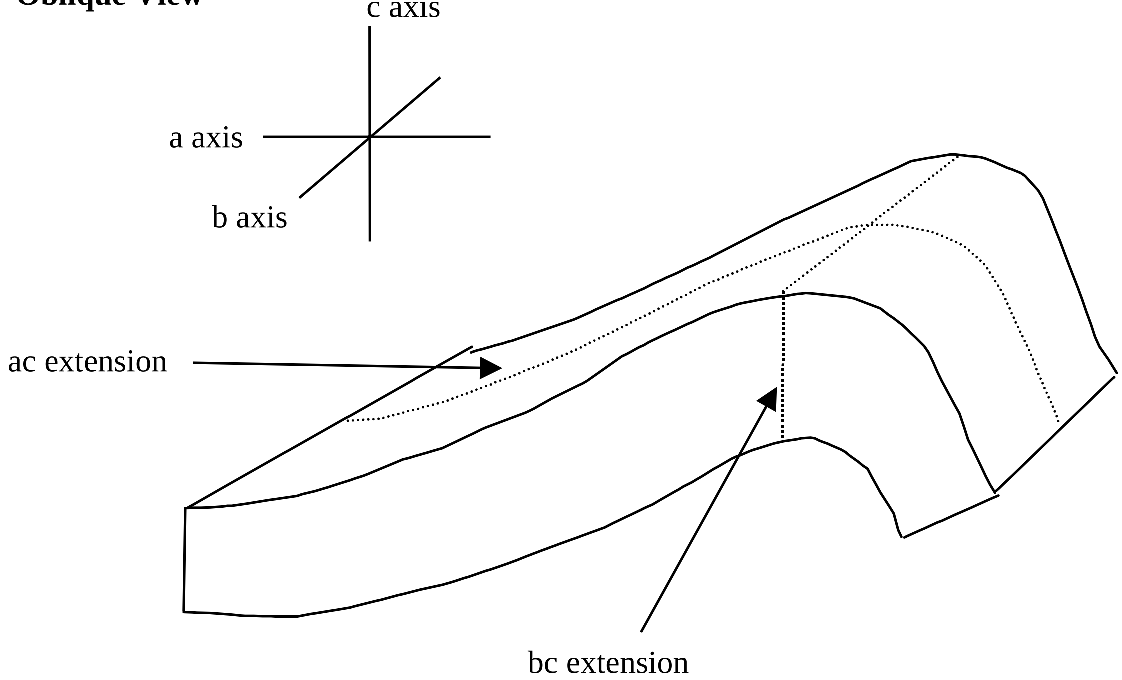
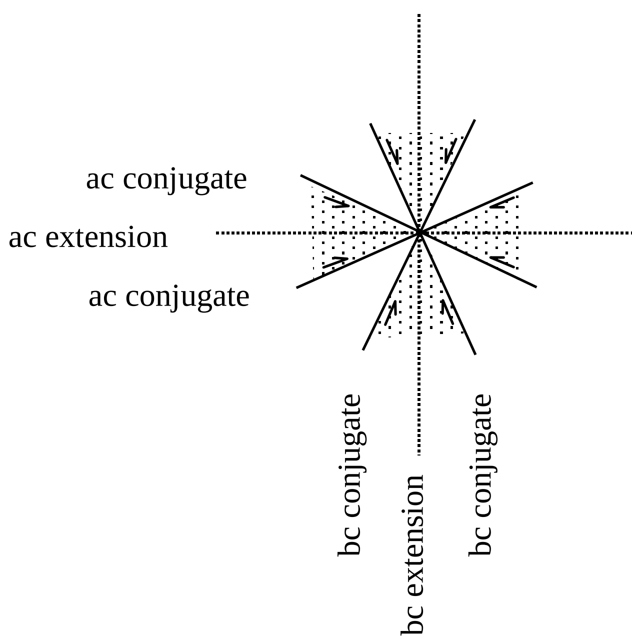


Diagram 7 b	Core Descriptions For 10-32-22-6W5M	B.Martindale

Oblique View

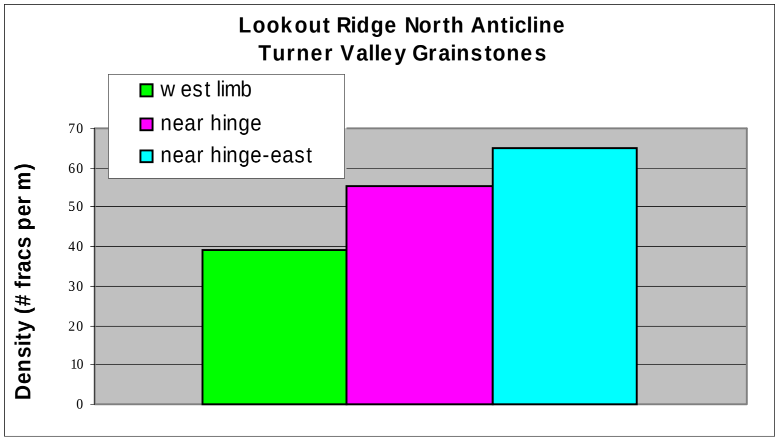


Plan View

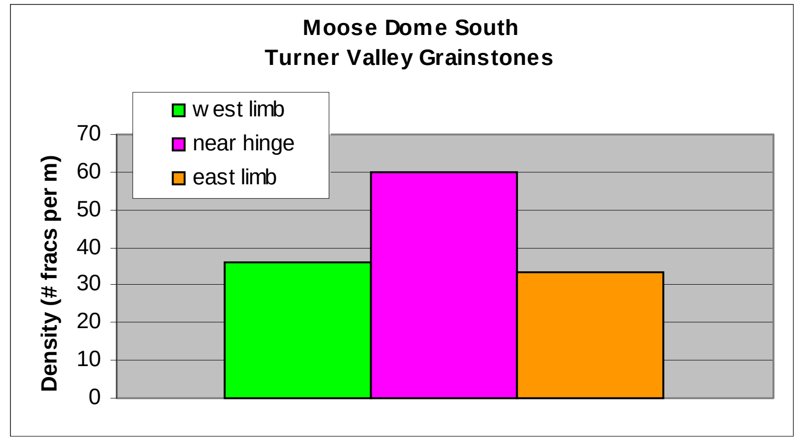


Fract.ppt

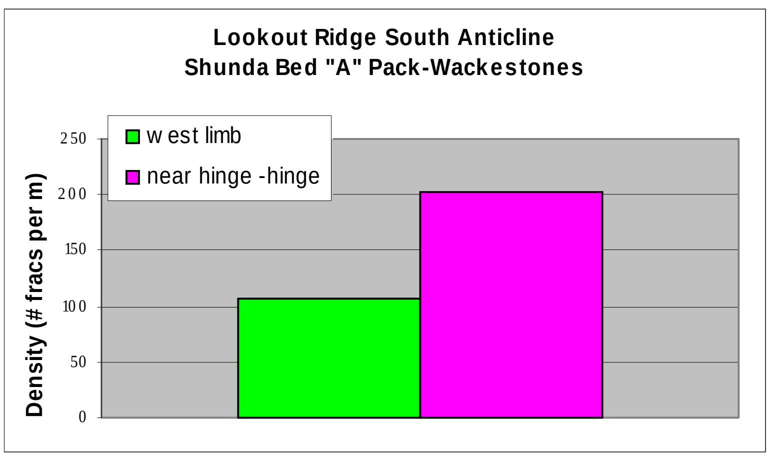
Fracture Description Diagram
Diagram No. 8



a



b

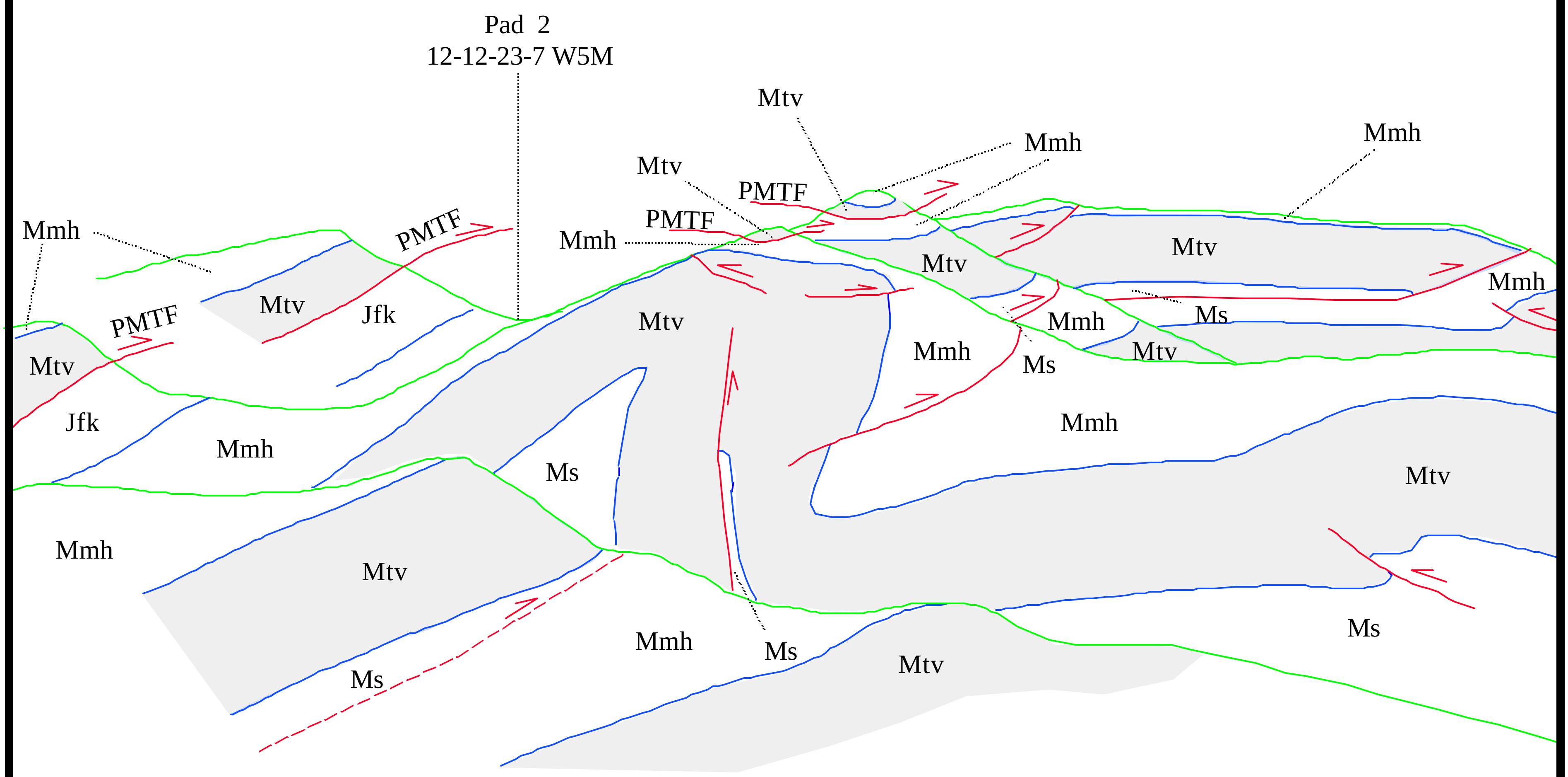


c

Fracture density distribution shown for a detachment fold 9a,b (2 locations along strike) west of Moose Anticline, and the Moose Mountain Anticline 9b. Note that all the maximum densities occur in the hinge area, although the finer grained facies of 9b shows densities that are at least twice that of the coarse grained facies (9a,c).

FRACTURE DENSITY DISTRIBUTION IN FOLDS

Sanderson and Billesberger	Diagram 9	Sept. 1999



Key

Topography	PMTF = Prairie Mountain Thrust Fault
Fm Boundary	Jfk = Jurassic Fernie/ Kootenay Fm
Faults	Mmh = Mount Head Fm
	Mtv = Turner Valley Fm
	Ms = Shunda Fm

Moose Mountain; Oblique View Looking NW.
By
Andrew C. Newson and Deborah A. Sanderson

Diagram No. 10

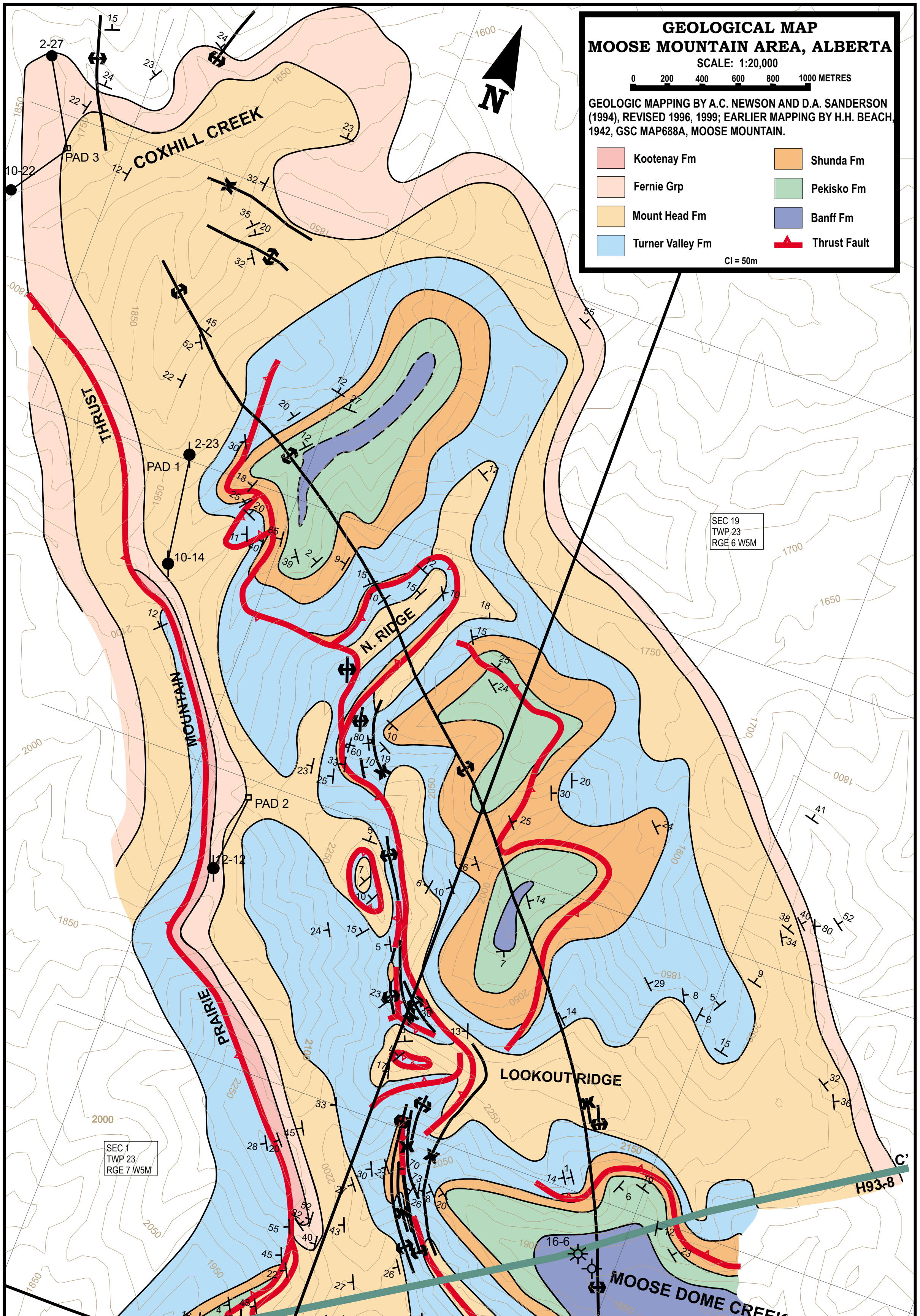
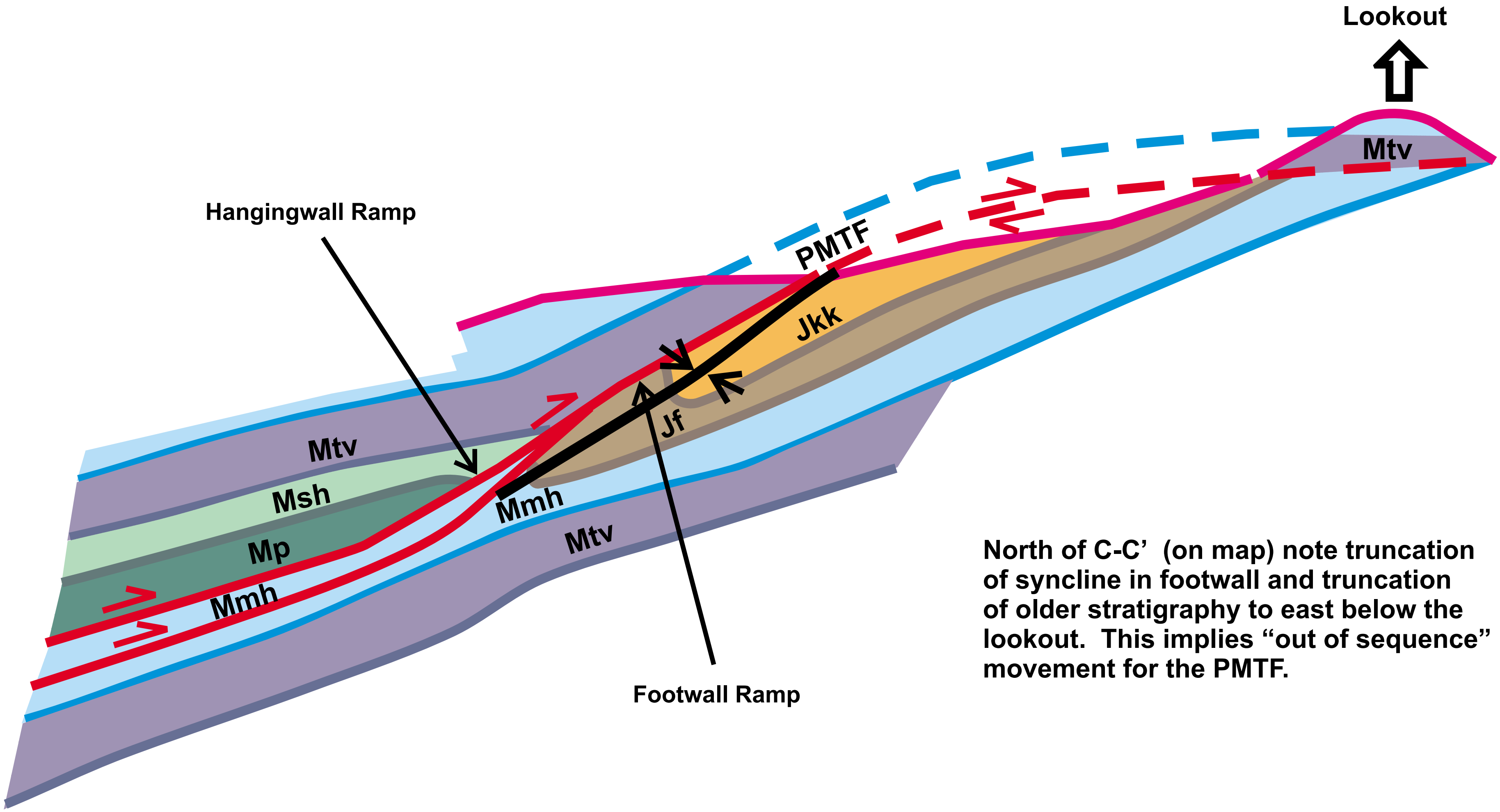

GEOLOGICAL MAP
MOOSE MOUNTAIN AREA, ALBERTA
SCALE: 1:20,000
0 200 400 600 800 1000 METRES
GEOLOGIC MAPPING BY A.C. NEWSON AND D.A. SANDERSON (1994), REVISED 1996, 1999; EARLIER MAPPING BY H.H. BEACH, 1942, GSC MAP688A, MOOSE MOUNTAIN.
Kootenay Fm
Fernie Grp
Mount Head Fm
Turner Valley Fm
Shunda Fm
Pekisko Fm
Banff Fm
Thrust Fault
CI = 50m
COXHILL CREEK
PAD 3
PAD 1
PAD 2
N. RIDGE
LOOKOUT RIDGE
MOOSE DOME CREEK
S. RIDGE
THRUST
MOUNTAIN
PRAIRIE
SEC 19
TWP 23
RGE 6 W5M
SEC 1
TWP 23
RGE 7 W5M
H93-8
C
C'

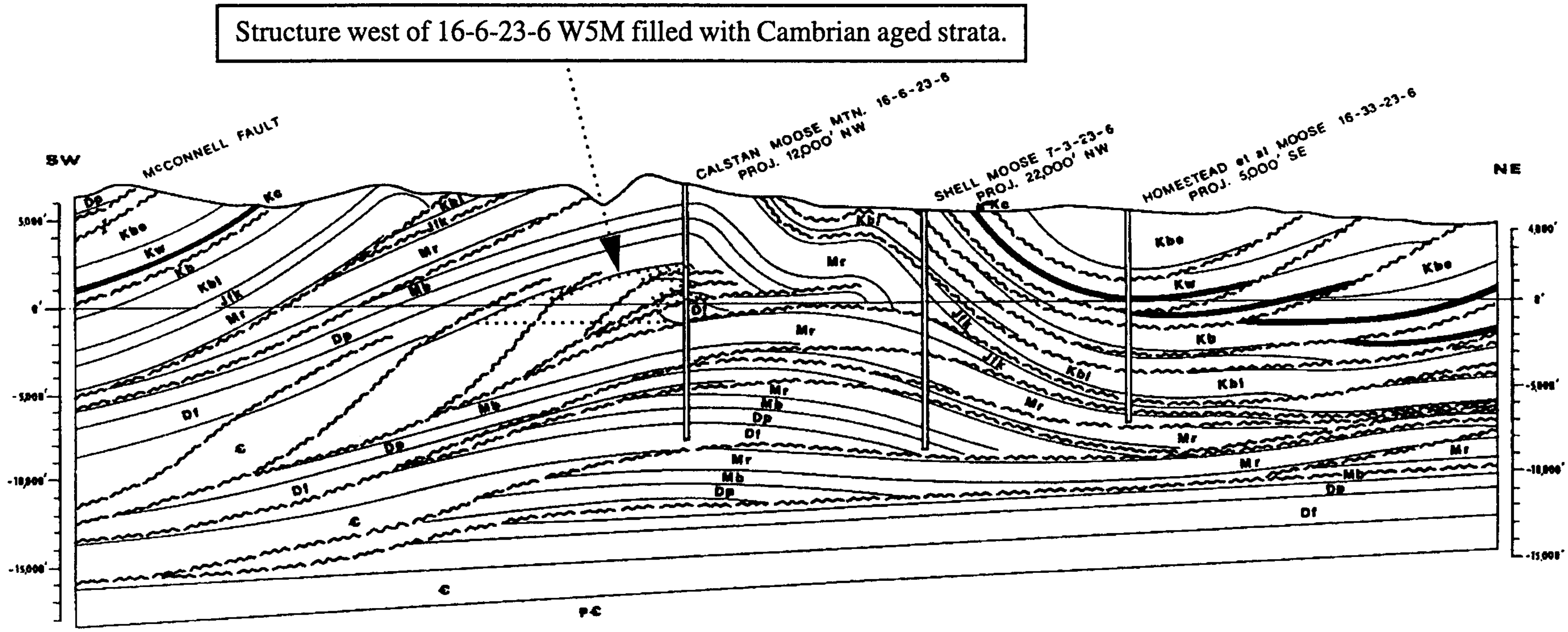
Diagram 11



North of C-C' (on map) note truncation of syncline in footwall and truncation of older stratigraphy to east below the lookout. This implies "out of sequence" movement for the PMTF.

SCHEMATIC OF THE PRAIRIE MOUNTAIN THRUST FAULT, WEST OF MOOSE MOUNTAIN LOOKOUT

Sanderson	Diagram 12	March 2000



0 1
MILE

U. Cretaceous :
Kbe Belly River – Edmonton
Kw Wapiabi
Kc Cardium
Kb Blackstone

L. Cretaceous :
Kbl Blairmore

L. Cretaceous & Jurassic :
Jfk Kootenay & Fernie Undivided

Mississippian :
Mr Rundle
Mb Banff

U. Devonian :
Dp Palliser
Df Alexo & Fairholme

Cambrian :
€ Undivided

Precambrian :
P € Metamorphic Basement

P. JONES
JUNE, 1971

Figure 6 Structural cross-section through Moose Mountain. Line of section is the same as that of section. Q-R on Seebe-Kananaskis Area Map.

Diagram 13	Structural Cross Section Through Moose Mountain	P.Jones 1971

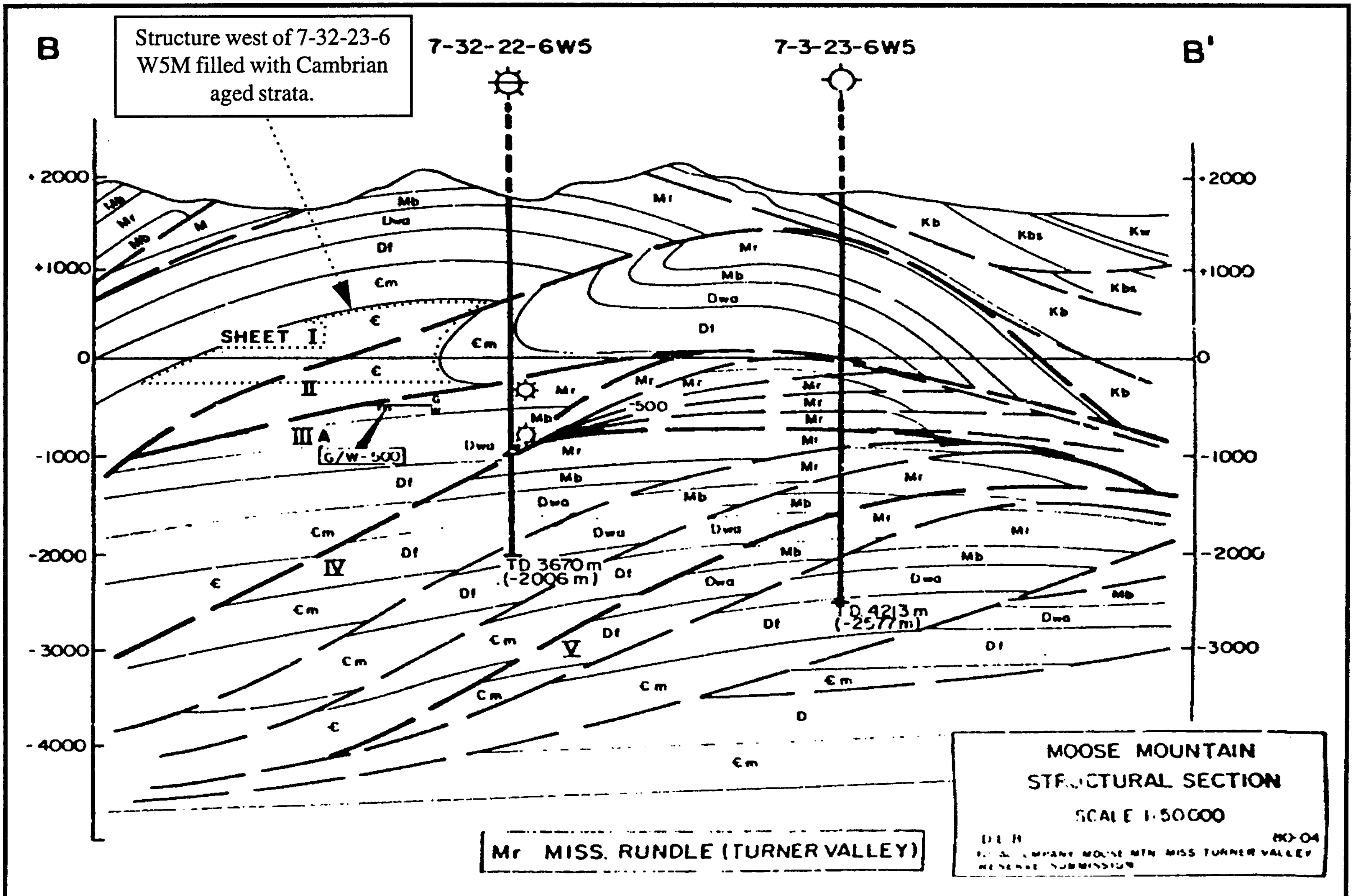


Diagram 14	Structural Cross Section Through Moose Mountain	Shell Canada Ltd., 1983

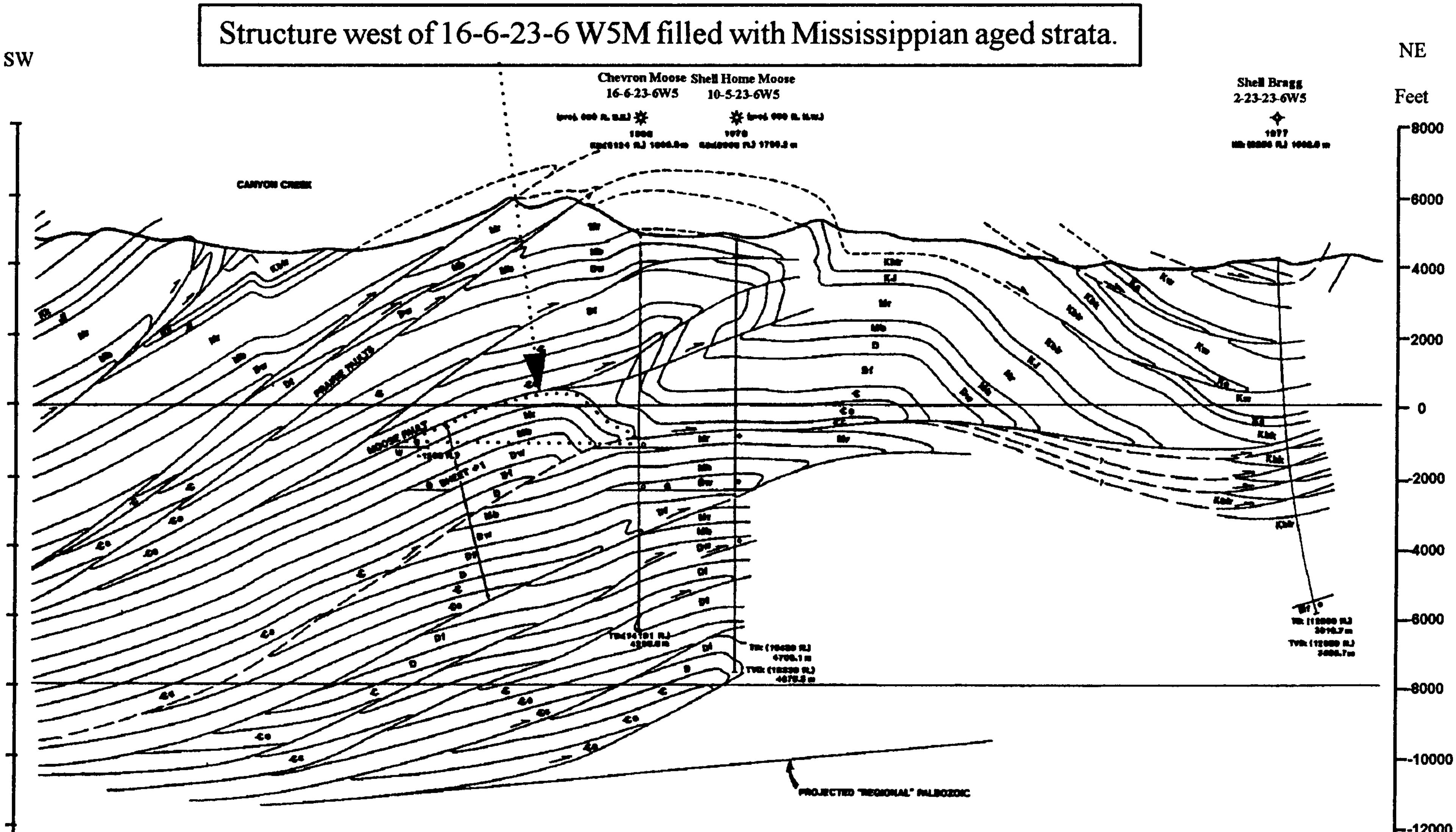
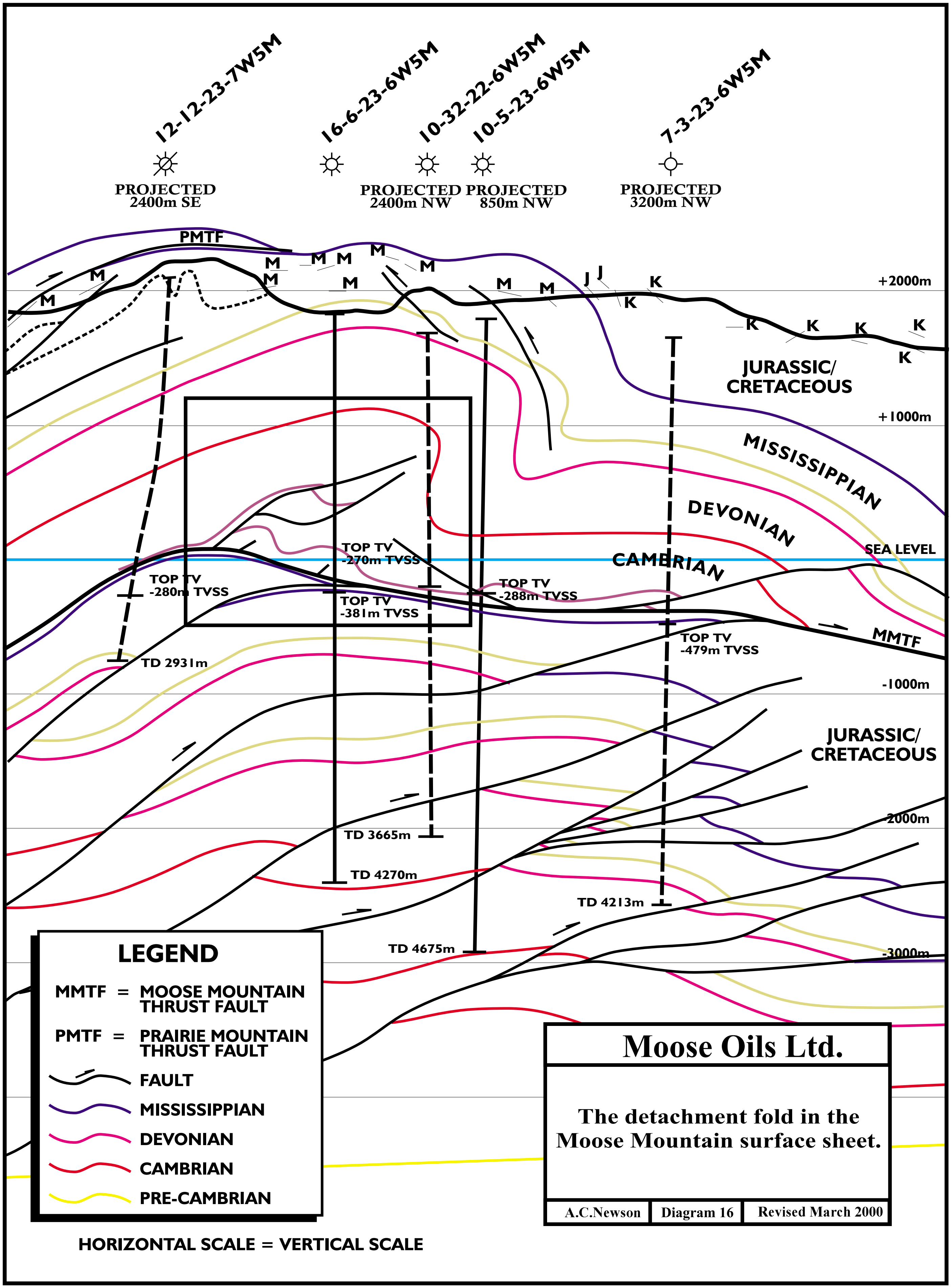


Diagram 15	Structural Cross Section Through Moose Mountain	E.Fitzgerald, 1985


12-12-23-7W5M
PROJECTED 2400m SE
16-6-23-6W5M
10-32-22-6W5M
PROJECTED 2400m NW
10-5-23-6W5M
PROJECTED 850m NW
7-3-23-6W5M
PROJECTED 3200m NW
PMTF
+2000m
+1000m
SEA LEVEL
-1000m
-2000m
-3000m
JURASSIC/ CRETACEOUS
MISSISSIPPIAN
DEVONIAN
CAMBRIAN
MMTF
TOP TV -280m TVSS
TOP TV -270m TVSS
TOP TV -381m TVSS
TOP TV -288m TVSS
TOP TV -479m TVSS
TD 2931m
TD 3665m
TD 4270m
TD 4213m
TD 4675m
LEGEND
MMTF = MOOSE MOUNTAIN THRUST FAULT
PMTF = PRAIRIE MOUNTAIN THRUST FAULT
FAULT
MISSISSIPPIAN
DEVONIAN
CAMBRIAN
PRE-CAMBRIAN
HORIZONTAL SCALE = VERTICAL SCALE
Moose Oils Ltd.
The detachment fold in the Moose Mountain surface sheet.
A.C.Newson
Diagram 16
Revised March 2000

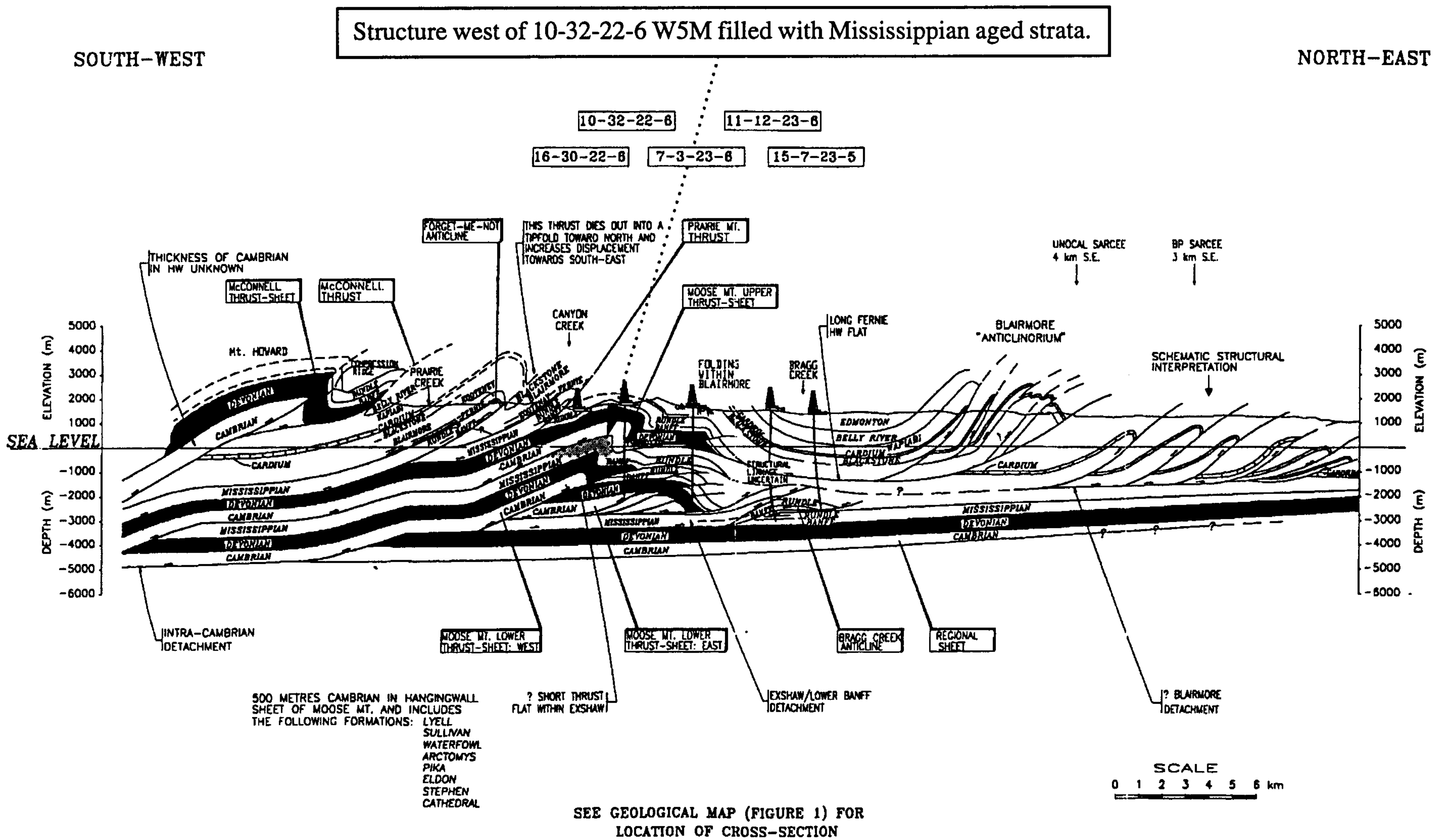
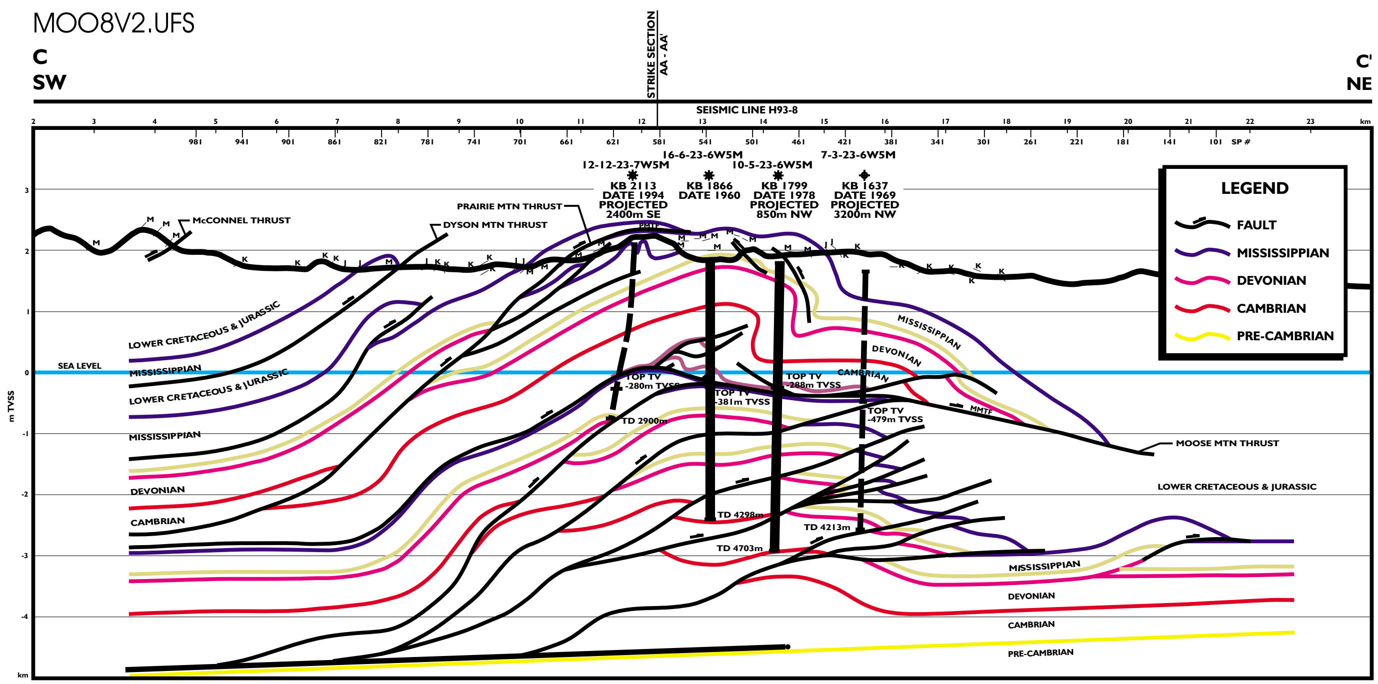
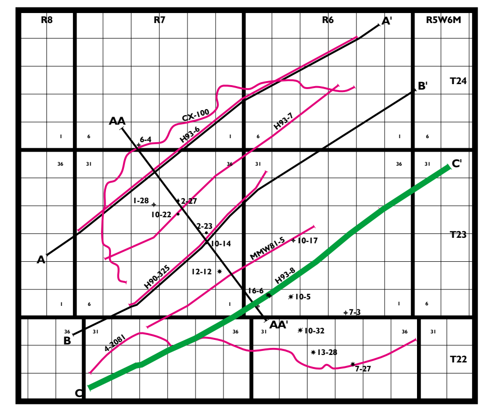


Diagram 17	Structural Cross Section Through Moose Mountain	R.Widdowson 1993





INDEX MAP
(NOT TO SCALE)

PROJECTED OUTCROP AND APPARENT DIP

- K - CRETACEOUS
- J - JURASSIC
- M - MISSISSIPPIAN

Moose Oils Ltd.

Moose Mountain
Dip Section C-C'.
Horizontal = Vertical Scale
1:50,000

A.C.Newson | Diagram 18 | Revised March 2000

TABLE 1 — **Moose Mountain Wells**

Location	Status	Year Drilled	TD Drill Depth (metres)	TD True Vertical Sub Sea Depth (metres)	TD Formation	Top of Turner Valley Formation in Producing Thrust Sheet, Drill Depth (metres)	Top of Turner Valley Formation in Producing Thrust Sheet, True Vertical Sub Sea Depth (metres)
16-06-23-6W5	gas	1960	4270	-2404	Palliser	2253	-381
07-27-22-6W5	gas	1978	4752	-3008	Cooking Lake	2527	(four imbricates) -472, -603, -777, -971
10-05-23-6W5	gas	1978	4675	-2882	Beaver Hill Lake	2087	-290
10-32-22-6W5	gas	1979	3665	-2007	Palliser	1925	-267
6-4-24-7W5	abandoned	1979	4115	-2452	Cambrian	2577	-952
13-28-22-6W5	gas	1981	3210	-1255	Pekisko	2395	-379
2-23-23-7W5	shut in oil	1993	3000	-1044	Pekisko	2628	-671
12-12-23-7W5	shut in gas	1994	2931	-753	Banff	2436	-280
10-14-23-7W5	shut in oil	1994	3094	-1036	Banff	2603	-569
10-22-23-7W5	Oil and gas	1994	2885	-1047	Banff	2435	-628
2-27-23-7W5	Oil and gas	1995	2685	-804	Shunda	2490	-625
9-33-22-6W5M	shut in gas	1999	3290	-1015	Turner Valley	2613	(four imbricates) -397, -549, -755, -887

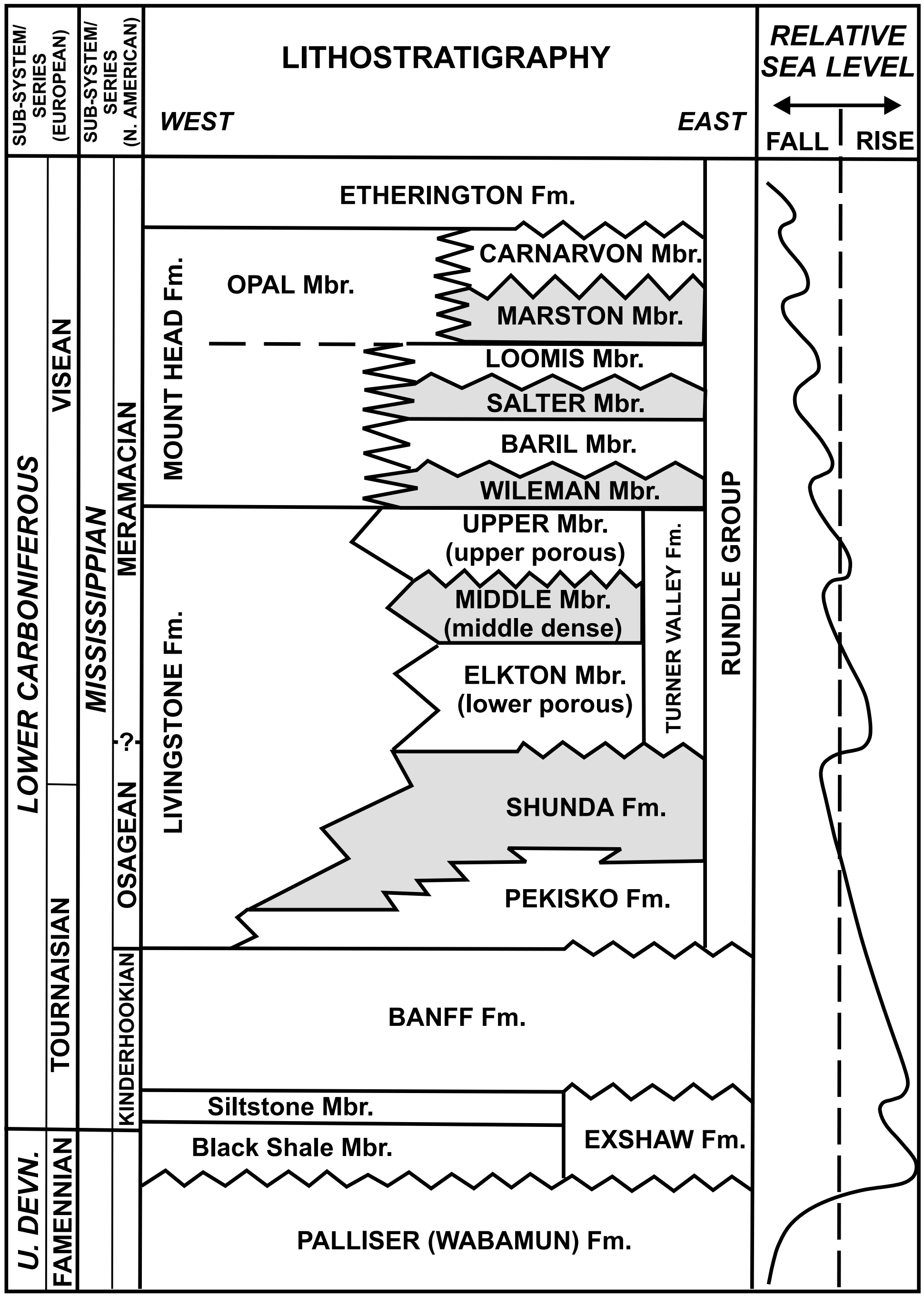
TABLE 2	Moose Mountain Producing Wells (AEUB Figures as of Dec 1999)						
Location	**Pool**	**Date on Production**	**Status**	**Producing Formation**	**Subsea (metres)**	**Cummulative Gas Production (e^6m^3)**	**Cummulative Oil Production (e^6m^3)**
07-27-22-6W5	Rundle B	Jan-86	gas	Turner Valley	-777	1.13	0.00
13-28-22-6W5	Rundle A	Dec-85	gas	Turner Valley	-379	0.68	0.00
10-32-22-6W5	Rundle A	Feb-86	gas	Turner Valley	-267	1.06	0.00
10-05-23-6W5	Rundle A	Dec-85	gas	Turner Valley	-290	0.98	0.00
16-06-23-6W5	Rundle A	Dec-85	gas	Turner Valley	-381	0.23	0.00
2-27-23-7W5M	Rundle C	Nov-98	oil and gas	Turner Valley	-624	0.01	0.03
10-22-23-7W5M	Rundle C	Dec-98	oil and gas	Turner Valley	-628	0.01	0.02
Total						**4.11**	**0.05**

Table 3 Moose Mountain Production

(AEUB 1998 Figures with 1999 estimated)

	IGIP	Mark.	Cum.	Annual Prod.	Remaining Condensate
	e^9m^3	e^9m^3	e^9m^3	e^9m^3	e^6m^3
1984	7.04	3.46	0.00	0.00	0.00
1985	7.86	3.54	0.01	0.01	0.00
1986	7.80	3.51	0.03	0.03	0.00
1987	7.82	3.30	0.10	0.07	0.00
1988	8.10	3.33	0.38	0.28	0.00
1989	9.41	3.90	0.55	0.18	0.00
1990	8.79	3.63	0.73	0.18	0.00
1991	8.79	3.63	0.95	0.22	0.82
1992	8.79	3.63	1.22	0.27	0.95
1993	8.79	3.63	1.51	0.29	0.84
1994	7.94	3.51	1.82	0.31	0.85
1995	10.32	4.52	2.12	0.30	0.85
1996	9.84	4.19	2.38	0.27	0.00
1997	9.95	5.33	2.66	0.27	0.00
1998	9.95	5.33	2.93	0.27	0.00
1999	9.95	5.33	3.26	0.33	0.00

TABLE 4 GENERALIZED STRATIGRAPHY OF MISSISSIPPIAN, SOUTHWESTERN ALBERTA



Intervals are mainly lithostratigraphic units that change facies laterally. Shaded intervals represent unconformity-bounded regressive phases with upward shallowing sequences. The relative sea level curve has been included only to illustrate the overall, second-order regressive nature of Mississippian sediments and associated third-order transgressive-regressive fluctuations. (from Martindale & Boreen, 1997)