APPENDIX A

A REVIEW OF THE EUB REGIONAL GEOLOGICAL STUDY

N.C.Wardlaw,

Wardlaw Petroleum Consulting Ltd.,

1221-17A St. N.W., Calgary, T2N 2E8, Alberta

16/12/03

EXECUTIVE SUMMARY

The major objective of the EUB Regional Geological Study (RGS) is to determine if gas pools have the potential to be in pressure communication with underlying commercial bitumen either directly or through an intervening water zone. Where such communication exists, the pressure in the gas zone or underlying water zone could limit the pressure attainable in the steam chamber of a SAGD operation following steam breakthrough. The Board has concluded that such situations present high risk to future bitumen recovery and associated gas wells are subject to shut-in.

On the other hand, where it can be shown that there is low risk of pressure communication between gas and bitumen zones, wells could be exempted from shut in. For example, where a regional mudstone barrier separates bitumen from gas.

The question of pressure communication between a potential zone of bitumen production and an overlying gas zone requires definition of:

- Regions with potentially commercial bitumen
- Gas zones and underlying water zones through which pressure could be communicated
- Mudstones or other low permeability deposits that could act as pressure barriers isolating bitumen from gas zones.

The RGS gives priority to providing a stratigraphic framework in which the above requirements can be assessed.

The RGS included examination and analysis of:

- ~4500 well logs
- >10,000 meters of core
- Pressure and production data from gas zones.

The project was completed in a four-month period.

Gas zones in the McMurray-Wabiskaw interval are significantly depleted creating urgency for decisions.

The basis for the stratigraphic study is the one-dimensional occurrence of lithologic units, gas zones, water zones and bitumen zones identified using well logs and core. These data are extended to three-dimensional space and the risk of pressure communication amongst units is interpreted.

Several thin mudstone/shale units, recognized from well logs and core, are areally extensive in the McMurray-Wabiskaw interval, and are important in regional correlation within the Athabasca deposit. These markers are used to provide a stratigraphic framework within which other lithofacies are mapped. Regional sands typically overlie the mudstone/shale units in upward coarsening sequences that are <10 m thick. These sands are too thin to meet criteria for commercial SAGD operations.

Channel sands and valley fill cut both the regional sands and mudstone/shale units locally and, where this occurs, sand thickness commonly is much greater than 10 m. These deposits, along with channel sands in the basal McMurray, are the major potential commercial sites for SAGD operations.

The McMurray-Wabiskaw stratigraphy is complex because channels originate from the tops of all of the McMurray sands and cut through variable thicknesses of underlying sediment. Also, the channels themselves are internally complex.

The Board believes that the regional mudstones/shales act as barriers to vertical pressure communication between underlying and overlying sands with contained gas and bitumen zones, provided they are thick enough, i.e., >0.5 m for the D Shale. (EUB, Decision 2003-023).

The inferred presence of one of these regional marine mudstones/shales, separating a gas zone from a recoverable bitumen zone, would be evidence for exempting the gas zone from shut in. It is for this reason that mapping of mudstone/shale continuity is a critically important aspect of the study.

The mapping of mudstone/shale units, regional sands and channel sands has been accomplished and integrated in the RGS with thoroughness and care. In particular, the extensive examination of core and matching of core lithology and well log response has reduced possibilities for errors in correlation.

However, I do not believe that questions of pressure communication amongst lithologic units or between gas and bitumen zones can be answered definitively by stratigraphic analysis and mapping alone.

One reason is that well spacing and availability of well logs and core place inherent limitations on the precision with which predictions can be made concerning the distribution and properties of lithologic units and the degree of communication amongst these units.

Also, the relatively thin (<2 m) regional, marine mudstones/shales, that are thought to be effective permeability barriers where they separate gas zones from bitumen, could be breached by faults on scales that are not detectable using available well-log and core data.

Furthermore, these mudstones have been truncated or removed by erosion in local regions that are difficult to predict precisely.

Faulting and jointing associated with salt-solution collapse and with Laramide tectonics, after deposition of McMurray-Wabiskaw sediments and emplacement of bitumen, is highly probable. The extent of such faulting is unknown but has the potential to breach thin mudstones that are considered as barriers to pressure communication. There is the added risk that faults in bitumen could contribute to accelerated steam breakthrough from a SAGD chamber to an overlying water or gas zone.

In principle, questions of pressure communication could be answered most directly by using appropriate pressure data. In practice, the volume and quality of pressure data combined with the difficulties of measuring pressure in deposits of solid bitumen make it impossible to meet the objectives of the study with pressure data alone.

The study integrates pressure, production and stratigraphic data to estimate the extent of regions of influence associated with gas zones and the risk of pressure communication between gas and bitumen zones.

Pressure data come primarily from gas pools. In the RGS, the stratigraphic units in which gas pools occur, within the McMurray-Wabiskaw interval, have been identified, on a regional basis to a higher level of detail than previously. This is necessary for comparison of pressures amongst pools and amongst stratigraphic units.

The RGS concludes with a statement as to whether gas is or is not associated with bitumen, in each of the stratigraphic zones. The criteria are stratigraphic and patterned on those used in the Chard-Leismer area (EUB, Decision 2003-023, Appendix 13)

In conclusion, my opinion is that the RGS is based on sound geologic principles that are reasonable and defendable. The final product is a stratigraphic framework that provides a basis for decisions about pressure communication between gas zones and bitumen zones. It also provides the necessary context for all future geological, hydrological and engineering analysis within the McMurray-Wabiskaw sequence.

Future work should include structural analysis of faults, joints and salt-solution collapse structures and should be fully integrated with the stratgraphic framework of the RGS. This would supplement stratigraphic analysis in assessing risk of pressure communication between gas zones and bitumen.

However, I do not believe that questions of pressure communication can be answered by stratigraphic-structural analysis and mapping alone. Pressure and potentiometric data should be used more extensively to provide independent evidence of pressure communication amongst units and between gas and bitumen zones within the McMurray-Wabiskaw interval.

1 INTRODUCTION

This review includes:

- The objectives, methods, scope and results of the EUB Regional Geological Study (RGS)

- My understanding of, and opinions about, the RGS.

- Recommendations for future work.

1.1 Objective and Rationale

The major objective of the regional geological study is to determine if gas pools have the potential to be in pressure communication with underlying commercial bitumen either directly or through an intervening water zone. Where such communication exists, the pressure in the gas zone or underlying water zone could limit the pressure attainable in the steam chamber of a SAGD operation following steam breakthrough. Reduced operating pressure in a steam zone reduces operating temperature and affects economics through reduced bitumen recovery rates and, perhaps, bitumen recovery efficiency. Additional lifting costs also are possible.

Based on these factors, the Board has concluded: "where gas is associated with bitumen, gas zone depressuring should be minimized to better ensure successful SAGD operations in terms of resource recovery and minimizing the technical difficulties of lifting SAGD fluids" (EUB, Decision 2003-023, Executive Summary, p. 6). Consistent with this, gas wells in such situations are subject to shut in.

On the other hand, where it can be shown that there is low risk of pressure communication between gas and bitumen zones, wells could be exempted from shut in. For example, where a regional mudstone barrier separates bitumen from gas.

The question of pressure communication between a potential zone of bitumen production and an overlying gas zone requires definition of:

- Regions with commercial bitumen
- Gas zones and underlying water zones through which pressure could be communicated
- Mudstones or other low permeability deposits that could act as pressure barriers isolating bitumen from gas zones.

The project was completed in a four-month period.

Gas zones in the McMurray-Wabiskaw interval are significantly depleted creating urgency for decisions.

1.2 Methods

Priority has been given to providing a stratigraphic framework. My opinion is that this approach is the necessary first requirement in meeting the purpose of the study. However, I do not believe that questions of pressure communication amongst lithologic units or between gas and bitumen zones can be answered definitively by stratigraphic analysis and mapping alone.

One reason for this is that well spacing and availability of well logs and core place inherent limitations on the precision with which predictions can be made concerning the distribution and properties of lithologic units and the degree of communication amongst these units. Also, the relatively thin (<2 m) regional, marine mudstones/shales, that are thought to be effective permeability barriers where they separate gas zones from bitumen, could be breached by faults on scales that are not detectable using available well-log and core data. This is discussed in following sections (2.2 Regional Mudstones/Shales as Pressure Seals and 3. Structure). Furthermore, these mudstones have been truncated or removed by erosion in local regions that are difficult to predict precisely.

In principle, questions of pressure communication could be answered most directly by using appropriate pressure data. In practice, the volume and quality of pressure data combined with the difficulties of measuring pressure in deposits of solid bitumen make it impossible to meet the objectives of the study with pressure data alone.

The intent of the study is to integrate pressure and production data with stratigraphic analysis to assess whether gas zones are, or are not, associated (ie. in pressure communication) with bitumen zones. Pressure data are discussed further in a subsequent section (4. Pressure Data).

Pressure data come primarily from gas pools. In the RGS, the stratigraphic units in which gas pools occur, within the McMurray-Wabiskaw interval, have been identified for the first time. This is necessary for comparison of pressures amongst pools and amongst stratigraphic units. These data are required to resolve questions of risk of pressure communication with bitumen zones.

Seismic data are not included in the RGS because they are not available publicly.

1.3 Scope

The study area lies within an area defined by Townships 70 to 101 and by Ranges 3 to 16 West of 4.

The study included examination and analysis of:

- ~4500 well logs
- >10,000 meters of core
- Pressure and production data from gas zones.

Twenty-four geologists, half from government and half from industry sources, worked in six teams with each team assigned to one of six areas within the Athabasca deposit. There was extensive interaction within and amongst teams to produce an integrated stratigraphic framework for the entire area investigated and mapped. Geologists interacted with a team of six engineers, a supervisory team of both geologists and engineers and with technical support staff and systems analysts.

The project was completed in a four-month period.

1.4 Deliverables

Deliverables include:

- A database with elevations of all stratigraphic units, gas zones, water zones and bitumen zones mapped.
- Structure surface maps and isopach maps on selected stratigraphic surfaces and units and gas pay maps and bitumen maps.
- Maps showing the areal extent of major regional mudstone/shale markers that are considered to be effective permeability barriers.

These data, in combination with other stratigraphic data, pressure and production data, are used to generate a table that identifies whether particular gas zones are associated (ie. in pressure communication) with potentially recoverable bitumen.

2 STRATIGRAPHIC MAPPING

The RGS includes the following priorities:

- Identify and map lithologic units that can be correlated over extensive regions and can be used as approximate time markers (regional marine mudstones/shales). Mudstones/shales are considered to be effective permeability barriers to fluid and pressure transmission.
- Map lithologic units that occur between (regional sands) and transect (channel sands) these regional marine mudstones.
- Where possible, apply a common nomenclature for lithologic units throughout the six geographic areas comprising the study using the “Type Sections” identified in the Chard-Leismer Report (some regional markers could not be identified in parts of Area 4 north of Fort McMurray).
- Identify and map all gas zones and zones with potentially recoverable bitumen (defined as 10 m minimum thickness of bitumen of >6 weight percent bitumen saturation).
- Identify zones of top water.
- Enter into a database the elevations of tops of all units mapped, gas zones, water zones and bitumen zones.
- Construct cross sections, structure contour and isopach maps to illustrate the distribution of major lithologic units and gas and bitumen zones.
- Provide a summary that identifies whether specific gas zones are associated, or not associated, with commercial bitumen.

The emphasis throughout the above is stratigraphic and requires that the one-dimensional occurrence of lithologic units, gas, water and bitumen zones identified in well logs and core be extended to three-dimensional space and that the probability of pressure communication amongst units be interpreted.

The 3-d extent (size, shape and orientation) of particular lithological units (lithofacies) commonly is related to their environment of deposition. For certain lithofacies, there is general agreement concerning the probable environments of deposition but, for others, differences of opinion exist. There are also differences of opinion concerning the complex nature of the stratigraphy and sedimentology of the deposit (Ranger and Pemberton, 1988; Ranger and Pemberton, 1997; Langenberg, et al, 2002; Ranger and Gingras, 2003, Discussion of Langenberg et al. 2002; and Hein and Langenberg, Reply, 2003).

In the RGS, although environments of deposition are inferred, the major emphasis is the correlation and mapping of lithologic units. Changes of opinion about environments of deposition are not likely to affect the results of mapping presented in the RGS.

In the McMurray-Wabiskaw deposits, some changes of lithofaces occur on scales that are small compared with the well spacing, and there are inherent uncertainties concerning the equivalence of certain mapped units and the positions of their boundaries.

2.1 Regional Mudstones/ Shales and Stratigraphic Framework

Four stratigraphic units, recognized from well logs and core, are areally extensive in the McMurray-Wabiskaw interval, and are important in regional correlation within the Athabasca deposit.

These four units, from oldest to youngest, are the McMurray B Mudstone, McMurray A Mudstone, Wabiskaw D Shale and Wabiskaw T-21 Marker. Two additional markers (Wabiskaw C and A Shales) are identified in the Northern Area.

The bases of these mudstone/shale units are interpreted as approximate time surfaces related to major marine transgressions. The origin of the T-21 marker is less clear but is also thought to represent an approximate time surface.

These four markers are used to provide a stratigraphic framework within which other lithofacies are mapped. The T-21 marker is the most widespread geographically and the one that is correlated with the greatest certainty. The McMurray A and B Markers can be mapped with confidence except where the overlying A and B sand sequences are missing or truncated. The sequence overlying the mudstone is necessary in order to identify the mudstone with confidence. These areas of truncation are larger for the McMurray B Mudstone than for the McMurray A Mudstone.

The Wabiskaw D Shale is more intermittent and difficult to correlate over wide areas.

Paleontological evidence (e.g. from pollen, spores, dinoflagellates, ostracods, foraminifera, etc.) has the potential to provide independent confirmatory evidence for some of the correlations made in the RGS study. Fossils can be used to interpret both relative age and environment of deposition. Given the complexity of the stratigraphy, this matter could be considered for future attention.

In summary, my opinion is that the lithofacies correlations using the regional mudstones/shales provide the best available stratigraphic framework for the McMurray-Wabiskaw interval and that the correlations have been made with care and attention to both well logs and core data. In particular, the extensive examination of cores and matching with log responses reduces the risk of errors in correlation.

2.2 Regional Mudstones/Shales as Pressure Seals

The regional mudstones/shales are thought to be seals preventing or restricting pressure communication between underlying and overlying sands with contained gas and bitumen zones

The inferred presence of one of these regional marine mudstones/shales, separating a gas zone from a recoverable bitumen zone, would be evidence for exempting the gas zone from shut in. It is for this reason that mudstone/shale continuity is a critically important aspect of the study.

These regional mudstones/shales are thin (generally <1.5 m) and are breached locally by erosion. Where present, they could be offset and breached by faults although no evidence for this is presented in the RGS (see section 3. Structure).

Vertical displacement of 1.5 m would be sufficient to breach a mudstone. Given the typical separation of wells and the accuracy with which elevations of mudstone contacts can be picked (i.e.accuracy of K.B. elevation and mudstone contact resolved from logs or core), faults with offsets of 1.5 m, if present, would not be detected.

In the case of a mudstone offset by a fault, the question of permeability along the fault remains unknown. This could not be determined by structural or stratigraphic observation. Sands underlying and overlying regional mudstones contain bitumen and, in the case of a fault, the extent to which bitumen acts as a seal and restricts pressure communication along the fault is not known.

It has been accepted that, at least in one region pressure transmission from a pressure-depleted gas zone through bitumen occurred (EUB Decision 2000-22: Gulf Canada Resources Ltd., Request for the shut-in of associated gas, Surmont Area, March 2000). This possibility requires confirmation. Also, the role of associated water, within a bitumen zone, in facilitating such pressure transmission requires investigation.

However, if a fault zone were sealed from pressure transmission by bitumen, a question remains concerning the significance of the fault during advance of high-pressure steam in a SAGD steam chamber. A fault plane is a zone of dislocation and structural weakness along which there could be more rapid steam advance and earlier steam breakthrough than otherwise might be the case.

In summary, faulting and jointing associated with salt-solution collapse and with Laramide tectonics, after deposition of McMurray-Wabiskaw sediments and emplacement of bitumen, is highly probable. The extent of such faulting is unknown but has the potential to breach thin mudstones that are considered as barriers to pressure transmission. There is the added risk that faults in bitumen could contribute to accelerated steam breakthrough from a SAGD chamber to an overlying water or gas zone.

Given the difficulties of observing faults directly in the subsurface without high resolution seismic data, it is recommended that regions of extensive post McMurray-Wabiskaw salt-solution collapse be identified and recognized as regions with higher probability of normal faulting. Regions of salt-solution collapse can be interpreted from structure contour and isopach maps for selected surfaces and intervals.

2.3 Stratigraphic Relations of Regional and Channel Sands

Regional sands, typically overlying mudstone/shale in upward cleaning (coarsening) sequences, generally are less than 10 m and are too thin to meet the criteria for commercial bitumen in SAGD operations.

Channel sands and valley fills cut the regional sands and mudstones locally and, where this occurs, sand thickness commonly is much greater than 10 m. These deposits are the major potential sites for SAGD.

The stratigraphy is complex because channels originate from the tops of all of the McMurray sands and incise through variable thickness of underlying sediment. The RGS adopts the nomenclature for channels used in the Chard-Leismer Decision. For example, a channel cutting down from the top of the McMurray B1 Sand is referred to as a McMurray B1 Channel and, similarly, for the other regional sands with incised channels.

The lower portion of the McMurray, referred to as the McMurray C Interval, is comprised largely of channel sands. These are of variable thickness reflecting irregularities of topography on the underlying Paleozoic surface. These irregularities are related, in part, to salt solution collapse.

Any channel cutting through the McMurray B2 Mudstone and penetrating the McMurray C Channel is referred to as a "McMurray Channel". These channels are of major importance because of their large size and volume of contained bitumen compared with, for example, the McMurray A and B Channels.

2.4 Regional and Channel Sands and Producible Bitumen

The McMurray C Interval and the McMurray Channel Sands, for reasons of thickness, areal extent and grade, have the best potential to contain commercial bitumen for a SAGD operation.

The Wabiskaw D Valley Fill meets the thickness criteria but is very shaly in the upper portions.

Sands in the McMurray A and B Sequences are generally less than 10 m thick and generally do not meet the thickness cutoff for commercial bitumen.

A and B Channel Sands are of smaller size, thickness and number making them less significant in terms of volume of bitumen in place.

2.5 Gas Zones

In the Athabasca deposit, there is evidence that biodegradation of oil may have contributed to the generation of biogenic gas by methanogenesis during the transformation of light oil to bitumen (Head, et al, 2003; Dimitrakopoulos, et al,1987; Barson, et al, 2001). That is, the gases are of biogenic origin and derived from bitumen.

In this case, gas is likely to have been present before the deformation of the bitumen-water contact caused by salt-solution collapse and Laramide tectonics. It follows that any associated faulting also could have affected gas zones.

It is possible that faulting occurred before, during or after gas emplacement. Faulting after gas emplacement could have fragmented once larger gas pools with attendant changes in elevation of water-gas contacts. Since most gas pools have maximum gas thickness of three or four meters, small fault displacements would be sufficient to offset a gas zone.

Given the possibility that both regional mudstone permeability barriers and sands containing gas zones could have been displaced and breached by faults, independent evidence is required to resolve questions of gas pool size and communication between gas pools and commercial deposits of bitumen.

Appropriate pressure measurements, possibly combined with production data, could provide evidence of degree of pressure communication.

2.6 Water Zones

Water overlying and underlying bitumen may cause constraints on SAGD.

Water in coarse-grained, high-permeability sands locally overlies bitumen. It has been mapped in the RGS because of its possible effects in transmitting pressure decline from a gas zone to underlying bitumen in situations where there is no intervening mudstone. Rate of pressure transmission can be estimated and a "region of influence" estimated and mapped.

Where water overlies bitumen, following steam breakthrough, there is the possibility of gravity drainage of water into the steam chamber or of steam escape into the water zone with rapid dissipation of heat. It has not been demonstrated in the field that it is possible to match steam chamber pressure to water pressure over long periods of time.

Bottom water was not mapped in the RGS study. Although it is recognized that bottom water may limit applicability of SAGD, it was not essential to the primary objectives of the study.

3 STRUCTURE

The McMurray-Wabiskaw deposits were structurally deformed by Laramide tectonics and by salt solution and collapse of underlying Devonian evaporites. Laramide deformation caused a regional tilt of ~10-20 feet per mile to the west or south-west whereas salt-solution collapse caused more local flexures; both events were accompanied by faulting.

Laramide movements, following biodegradation of light oil to bitumen, tilted the bitumen-water contact. This contact subsequently was unable to re-adjust to horizontal because of high bitumen viscosity and small density difference between bitumen and water.

There is evidence that salt solution and collapse occurred before, during and after deposition of McMurray-Wabiskaw sediments and emplacement of bitumen.

Salt-solution collapse in Pre-McMurray time created topographic lows on the Paleozoic surface that became the sites of thick channel deposits in McMurray time.

Later, following emplacement of bitumen, further salt-solution collapse deformed the bitumen-water contact and McMurray-Wabiskaw deposits. Normal faulting probably accompanied salt-solution collapse although there appear to be limited published data from mine sites, outcrops or the subsurface concerning faulting of the bitumen deposits either by Laramide tectonics or by salt-solution collapse.

There also is the possibility that faulting occurred during differential compaction where topographic relief caused variations in sediment types and thickness.

Faulting could have breached or dislocated both the regional marine mudstones and the sands containing gas zones, or the gas zones themselves. The Board agreed with Nexen that late changes in structure related to salt-solution collapse caused vertical displacement of the stratigraphic section that resulted in varying water/bitumen contacts within the same pool (EUB Decision 2003-023: Chard Area and Leismer Field Athabasca Oil Sands Area, Applications for the production and Shut-in of Gas, March 18, 2003).

Structure has received little attention in the RGS because of time constraints. With the well spacing over much of the Athabasca deposit, it would be possible to resolve only faults with large displacement. It is probably safe to speculate that, as well spacing decreases, interpretation of both structural and stratigraphic complexity will increase markedly.

A review of published structural information from the Athabasca deposit is not attempted in the RGS or in this Review.

In summary, faults and joints, if present, could breach mudstone/shale units that, otherwise, might be permeability barriers. Also, the determination of fault trends, if present, could be important to optimum placement of horizontal wells and to risk assessment for SAGD operations.

It is possible that regions of post-bitumen salt solution collapse could have more faults and joints and greater associated risks for vertical communication amongst layers.

4 PRESSURE DATA

Appropriate pressure measurements could be used to provide evidence for the degree of pressure communication:

1. between gas zones and bitumen zones; pressure decline, in a bitumen zone associated with an overlying gas zone that is undergoing pressure decline during depletion, could be taken as evidence of pressure communication between gas zone and bitumen zone;
2. between gas zones penetrated by several wells; that is, evaluation of the sizes of gas pools in a particular region; i.e. is there one larger pool or two or more smaller pools?
3. between a gas zone and a water zone overlying bitumen; and define a region of influence.
4. between gas zones in **regional sands** and gas zones **in channel sands** intersecting regional sands.

The primary interest is to determine the risk of pressure communication between gas zones and bitumen zones (1. above). However, measurement of pressure in bitumen zones may not be possible because bitumen is "solid" at reservoir conditions. The other cases (2, 3 and 4) do not require measurement of pressure in bitumen.

4.1 Pressure Communication Between Gas and Bitumen Zones

It has been argued that pressure cannot be transmitted through bitumen because it is "solid" at reservoir conditions. However, bitumen zones also contain liquid water. If the water is at "irreducible" saturation, it is thought to be essentially immobile and not capable of flowing or transmitting pressure. However, if the water saturation is greater than "irreducible", there is the possibility that water could transmit pressure in finite time within a bitumen zone. That is, it is possible that the ability of bitumen zones to transmit pressure could be dependent on water saturation.

If this were the case, the absence of pressure decline measured in a bitumen zone could be related to low water saturation ("irreducible") rather than to the absence of low pressure in a communicating water or gas sand.

Since "irreducible" saturation generally is not defined and water saturation generally is not known at the points of pressure measurement in a bitumen zone, pressure measured in bitumen is of limited use in resolving questions of pressure communication.

Regional mudstones and shales situated between gas zones and bitumen zones could be permeability barriers preventing pressure communication from gas to bitumen. On the other hand, it is recognized that a regional mudstone, although identified in all cores and logs of a given region, could be breached locally between control points by faulting, local erosion or a combination of both.

It is for this reason that the independent evidence of pressure measurements is sought to confirm or deny the presence of pressure communication. However, the lack of certainty as to whether a bitumen zone may or may not transmit pressure means that the apparent lack of pressure response measured in a bitumen zone cannot be used as evidence that a permeability barrier separates bitumen from an overlying pressure-depleted gas zone.

The Board accepted pressure measurements submitted by Gulf Canada at the Surmont hearings as indicative that pressure changes could be transmitted through a bitumen zone. The Board because of other possible interpretations did not accept evidence of pressure change in bitumen submitted at the Chard-Leismer hearing (EUB Decision 2003-023). It may be difficult to determine if pressure is being transmitted through a bulk bitumen zone or if it is an artifact of the pressure measurement technique related to conditions around the well-bore or to other causes.

The limited amount of pressure data measured in bitumen zones and uncertainties associated with these data limit their reliability and usefulness for purposes of interpreting the presence or absence of pressure communication with overlying water or gas zones.

A further indirect line of evidence can be cited for pressure communication between gas and bitumen zones. There is evidence that, in the Athabasca deposits, gas was derived from oil by microbial methanogenesis during bitumen formation (Head, I.M., Jones, M. and Larter, S., 2003). If this were the case, it follows, at least at the time of gas migration, that there was communication to allow passage of gas from bitumen to gas zones. The distance and rate of this migration, of course, remains unknown.

4.2 Pressure Communication Between Gas Zone and Gas Zone or Gas Zone and Water Zone

The problems of pressure measurement encountered in bitumen zones, discussed in the previous section, do not apply in the case of gas and water saturated zones.

It is presumed that if initial pressures and pressures measured during depletion of a gas zone of one well match those of a similar gas zone in an adjacent well, that both wells are in pressure communication and are from the same gas pool. Alternatively, differences between two wells in initial and subsequent pressures could indicate a lack of pressure communication and the presence of separate gas pools.

Similarly, the presence or absence of pressure communication between gas and water zones could be determined by using appropriate pressure measurements.

Although simple in principle, these determinations of presence or absence of pressure communication between gas and gas or gas and water zones commonly are difficult to make in practice. The following are factors contributing to the difficulties:

- Most of the pressure data are from gas zones; few data, if any, are available from associated water zones.
- In order to resolve questions of pressure communication in shallow wells, it is necessary to be able to detect pressure differences as small as ~100 kPa; accuracy of pressure measurement is a key requirement and, for some pressure data, this requirement is not met.
- To evaluate pressure decline, depletion and, therefore, the size of a gas pool, it is necessary to have pressure measurements prior to production (initial pressures) as well as subsequently; if initial pressure is not measured, there is no method to obtain it subsequently; not all gas wells have initial pressure measurements; in some regions, there is wide variance of recorded initial pressures.
- To evaluate pressure communication amongst gas pools, it may be necessary to have virgin pressures (pressures measured prior to man's intervention) in addition to initial pressures. There are limited numbers of virgin pressure measurements from any given stratigraphic zone..
- Only surface pressures are available for some wells and, in these cases, pressures have to be converted to bottom hole pressures; this conversion requires information about fluids (gas and/or water) filling the wellbore and, in some cases, this information is not available (eg. acoustic logs not available).
- For many wells, pressure data are limited to an initial pressure and one or two subsequent pressure measurements; this information is minimal for purposes of defining pressure decline with time.
- Observation wells, that is wells dedicated for pressure measurement over time, have the potential to define pressure and pressure change with the necessary accuracy but such wells are few in number. The Board does not require observation wells.
- There are cases where accurate pressure measurements are available but difficult to interpret because of co-mingling of gas from more than one zone. Also, interpretation of gas-zone continuity using pressure data can be affected by imposed back-pressures associated with gathering systems for gas; if wells in separate gas pools have the same gathering system and similar back-pressures, they could, over time, develop similar

pressures even though virgin pressures were different. Misinterpretations are possible where virgin pressures are not available.

In some cases, interpretation of the size of a gas pool and questions of gas continuity amongst several wells can be aided by the use of production data in combination with pressure data in material balance calculations. However, the material balance equation is one equation with many terms and can be solved only for one unknown.

4.3 Communication Between Gas Zones in Regional Sands and Gas Zones in Channel Sands that Intersect Regional Sands

Gas zones occur in both regional sands and channel sands. Bitumen deposits of thickness and quality suitable for SAGD are confined mainly to the channel sands.

In the Chard-Leismer area, evidence has been presented that, in at least four cases, there was no effective pressure communication between gas zones in regional sands and those in laterally offsetting channel sands. This is an important observation because it could provide reason for exemption from shut-in. However, in other areas, evidence of pressure communication between regional sands and channel sands is present.

In addition to pressure data, the elevations of gas-water contacts are useful in making decisions concerning the continuity and pressure communication of gas zones in proximity to, and within, channels. However, differences in contact elevation for gas occurrences within and outside channel sands may not indicate lack of gas continuity if the gas zone is bottom sealed.

4.4 Conclusions from Pressure Data

The question of pressure communication between gas zones and underlying bitumen zones cannot be answered directly with existing pressure data measured in bitumen zones and associated gas zones. This is because of the limited amount of pressure data available from bitumen zones and difficulties of interpretation concerning the ability of solid bitumen to transmit pressure and to register pressure changes occurring in overlying gas or water zones. Also, the role of variable water saturation on rate of pressure transmission through bitumen is not known.

It should be noted that, in one case, the Board accepted pressure data measured in a bitumen zone as indicative of pressure decline occurring within that bitumen zone related to depletion of an overlying gas zone (EUB Decision 2000-22: Gulf Canada Resources Ltd., Request for the shut-in of associated gas, Surmont Area, March 2000).

A full analysis of all available pressure data from the Athabasca deposit has yet to be done. Virgin pressures are particularly important. These data have the potential to provide independent evidence concerning the presumption that the McMurray A and B Mudstones, or other mudstone/shale markers, where present, act as barriers to vertical pressure transmission.

5 RECOMMENDED FUTURE WORK

The following, in an order of decreasing priority, are recommended for future work

5.1 Pressure Data

- Review all available pressure data for purposes of providing evidence about communication between gas and gas, gas and water and gas and bitumen zones. For the most part, pressure data were not measured with this use in mind. If the amount and quality of existing pressure data are insufficient, the possibility of obtaining additional data should be considered.
- Determine if pressure data support the opinion that mudstone/shale barriers are seals to vertical pressure communication.
- Review data, obtained from core, concerning water saturations in bitumen zones. Is "irreducible" water saturation a useful concept in relation to pressure transmission and is its value known for sediments in bitumen zones? Are there any experimental or other data concerning effects of water saturation on rates of pressure transmission in bitumen deposits? Is water necessary for pressure transmission through bitumen in finite time?

5.2 Structure

- Compile all publicly available data on structure within the area of the Athabasca deposit; this is not attempted in the RGS or in this Review. It could include surface linears from air photos, faults, joints and structures arising from salt-solution collapse and Laramide tectonics. Is there evidence that fault and joint trends could create permeability anisotropy within bitumen? See, for example, effects of structure in heavy-oil sands of Lloydminster area (Gregor, 1997).
- Possible associations between magnetic anomaly lineaments and known faults or surface photolineaments could be investigated.
- Published information on relative ages, extent and geographic areas of salt solution collapse should be compiled. Areas of collapse post-bitumen emplacement are particularly important because faults could be more frequent in these regions.
- The "tops" for stratigraphic units in the RGS could be used to produce structure surface and isopach maps that could reveal additional information concerning salt-solution collapse events.

5.3 Paleontological Evidence

Paleontological evidence (e.g. from pollen, spores, dinoflagellates, ostracods, foraminifera, etc.) has the potential to provide independent confirmatory evidence for some of the correlations made in the RGS study. Fossils can be used to interpret both relative age and environment of deposition. Given the complexity of the stratigraphy, this matter could be considered for future attention (eg. see Hein and Dolby, 2001; Hein and Langenberg, 2003).

5.4 Salinity of Formation Waters

All available data on the salinity of formation waters within the McMurray-Wabiskaw interval should be compiled and their quality assessed; salinity could be related to structure (faults and joints) and to regions of salt-solution collapse. Salinity affects wettability and could affect interpretation of bitumen saturation from resistivity logs (see Hein, Cotterill and Rottenfusser, 2001).

6 REFERENCES

Barson, D., Bachu, S. and Esslinger, P., 2001, Flow systems in the Manville Group in the east-Central Athabasca Area and implications for steam assisted gravity drainage (SAGD) operations for in situ bitumen production. Bull. Can. Petrol. Geol., Vol. 49, p.376-392.

Dimitrakopoulos, R. and Meulenbachs, K., 1987, Biodegradation of petroleum as a source of C13 enriched carbon dioxide in the formation of carbonate cement. Chem. Geol., Vol. 65, p.283-289.

EUB Decision 2000-22: Gulf Canada Resources Ltd., Request for the shut-in of associated gas, Surmont Area, March 2000.

EUB Decision 2003-023: Chard Area and Leismer Field Athabasca Oil Sands Area, Applications for the production and Shut-in of gas. March 18, 2003.

Gregor, V.A., 1997, Mannville linears in the Lloydminster heavy oil area and their relationship to fractures and fluid flow in the Western Canada Sedimentary Basin. In, S.G Pemberton and D.P.James, Petroleum Geology of the Mannville Group, Western Canada. Can. Soc. Petrol. Geol., Memoir 18. p. 428-474.

Head, I.M., Jones, M. and Larter, S., 2003, Biological activity in the deep subsurface and the origin of heavy oil, Nature, Vol. 426, November Issue, Hydrocarbon Reservoirs, p. 344-352.

Hein, F.J., Cotterill, D.K. and Rottenfusser, B.A., The good the bad and the ugly: reservoir heterogeneity in the Athabasca oil sands, northeast Alberta. Rock the Foundation Conference, June 18-22, 2001, Proceedings Can. Soc. Petrol. Geologists, p. 492-494.

Hein, F.J and Dolby, G., 2001, Regional lithostratigraphy, biostratigraphy and facies models, Athabasca oil sands deposit, northeast Alberta. Rock the Foundation Conference, June 18-22, 2001, Proceedings Can. Soc. Petrol. Geologists, p. 170-171.

Hein, F.J. and Langenberg, C.W., 2003, Reply to discussion by Ranger and Gingras, Seismic modeling of fluvial-estuarine deposits in the Athabasca oil sands using ray-tracing techniques, Steepbank River area, northeastern Alberta. Bull. Can. Petrol. Geol., Vol. 51, p. 354-366.

Langenberg, C.W., Hein, F.J., Lawton, D., and Cunningham, J., 2002, Seismic modeling of fluvial-estuarine deposits in the Athabasca oil sands using ray-tracing techniques, Steepbank River area, northeastern Alberta. Bull. Can. Petrol. Geol., Vol. 50, p.178-204.

Ranger, M. and Gingras, M., 2003, Discussion concerning, Seismic modeling of fluvial-estuarine deposits in the Athabasca oil sands using ray-tracing techniques, Steepbank River area, northeastern Alberta. Bull. Can. Petrol. Geol., Vol. 51.

Ranger, M. and Pemberton, S.G., 1988, A quantitative approach to the geological evaluation of tar sands of South Athabasca. Proceedings of 4th UNITAR/UNDP Conference on Heavy Crude and Tar Sands, Edmonton, Alberta, Paper No. 220, p.1-20.