SEISMIC MODELLING OF POROSITY WITHIN THE JURASSIC AGED CARBONATE BANK, OFFSHORE NOVA SCOTIA

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ABSTRACT

Four drillable plays associated with the Abenaki carbonate bank offshore Nova Scotia are discussed in relation to their geological setting, geological characteristics and geophysical expression. Interpreted seismic sections are incorporated to illustrate the plays. The main emphasis is on porosity development within the carbonate bank, which occurs along its seaward edge and has been encountered in a number of wells drilled there. For example, the carbonates in Shell Demascota G-32 have significance as potential reservoir units due to dolomitization. Testing showed these intervals to be water-bearing. Given the extensive porosity development within the dolomite in Demascota and its encasement in higher velocity limestone, the necessary ingredients are present for seismically mapping these types of drillable, potential hydrocarbon-bearing prospects in this area. A porosity modelling study indicates that zones of 11 to 14 percent porosity, with a minimum thickness of 10 m, can be detected. The tuning thickness of the porous zones was determined to be 50 m. Since minor shows of gas were encountered while the well was being drilled, amplitude-versus-offset (AVO) effects of the Demascota porosity were studied and demonstrate that the porosity zones, in the presence of gas, should be detectable using this technique. A high-amplitude event adjacent to the well was observed on two seismic lines in what may be considered an updip gas-filled porous reservoir. These identifiable seismic events could provide future drilable targets when carefully mapped. The three other plays discussed in this paper are also very important in fully recognizing the hydrocarbon potential of the carbonate bank.

INTRODUCTION

This paper is the result of the authors' work on the exploration play potential of the Abenaki carbonate bank offshore Nova Scotia. Eliuk (1978) provides an excellent reference for the depositional and diagenetic history of the bank utilizing well and seismic data available to the end of 1976. The current paper reviews four different play types associated with the Abenaki bank, concentrating on the porous reservoirs encountered by several bank-edge wells, for which a geophysical modelling study was undertaken. Geological models and interpreted seismic sections are used to illustrate the play types.

The first three plays discussed can be detected using current seismic data. However, closer spaced lines or more detailed mapping are required to enable successful exploitation of these plays on the Scotian shelf and slope. Although the fourth play, namely, porosity development in the carbonate bank, has been confirmed by well control as being present, it has yet to be determined whether such porosity can be observed and mapped directly from seismic data. Numerous papers are available outlining the successful seismic detection of primary and secondary porosity within limestone reefs. Analogies to Nova Scotia's bank porosity can be drawn from case histories of porosity detection in other areas of the world. However, the only indisputable technical evidence for seismic detection is demonstrated by modelling studies which utilize geological and geophysical data specific to that area. Hence, a modelling study of the offshore Nova Scotia area was undertaken using synthetic models generated from the Shell Demascota G-32 well. This well was selected as a template since it encountered 168 m of secondary porosity, over several zones, encased in higher-velocity limestones that could account for significant potential reservoir units. The models generated were altered to observe the seismic response of various thicknesses and ranges of porosity of a porous dolomite encased in limestone. Normal incidence and offset traces, up to 4115 m distance, were generated by varying different reservoir parameters. A simplified carbonate-bank porosity model was

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The carbonate bank study discussed in this paper is available on request by contacting the authors at the Department of Mines and Energy in Halifax, Nova Scotia.
also generated using the Demascota well which demonstrated the various seismic responses of different bank facies, including the seismic response of the porous zones.

This paper discusses the results of this study and describes a potential play generated by applying the study results to seismic data through the Demascota well.

**GEOLOGICAL SETTING**

The eastern North American margin is a classic pull-apart margin which was initiated during the breakup of Pangaea during the late Triassic period (Figure 1). The Abenaki Formation carbonate complex was formed during the mid-Jurassic period shortly after the onset of sea floor spreading and continued through late Jurassic time, creating thick deposits along the ancient shelf edge.

The Abenaki Formation is made up of three members which, in ascending order, are named Scatarie, Misaim and Baccaro (Figure 2). The lowermost Scatarie Member is the most extensive of the three units. It is primarily an oolitic, oncocylic limestone that displays a deepening-upward transgressive cyclicity. It forms a wedge-shaped unit, thickening seaward, exhibiting a ramp type of profile and generating a very distinct seismic reflection. The middle unit is the Misaine Member, a transgressive shale which reflects the drowning of the shallow-water Scatarie facies. It, too, is a good seismic reflector, as it is sandwiched between the two thick carbonate units, namely, the underlying Scatarie and overlying Baccaro Formation.

The Baccaro Member, which is the focus of this paper, will be discussed in much greater detail than the other members. An important aspect of this member is that it is the thickest member within the Abenaki Formation and occurs as an outer-shelf, carbonate-bank facies, attaining thicknesses in excess of 1300 m. It varies from about 12 to 25 km in width. The member is drowned by the Sable Island deltaic complex to the northeast and is flanked seaward by the coeval Verrill Canyon shales. The expression of the Baccaro Member is seismically complex and variations are discussed.

**STRATIGRAPHY AND SEISMIC RESPONSE OF THE BACCARO MEMBER**

Seismically, the Baccaro Member is important because it produces a prominent and mappable seismic sequence. As it is overlain by clastics of the Mic Mac and Missisauga Formations, the top of the Baccaro Member generates a high-amplitude, well-developed seismic reflection (Figures 3 and 4). Landward, this strong reflection weakens as the Baccaro limestone interfingers with mixed clastics and argillaceous limestones of the Mic Mac Formation. Basinward, the seismic event from the top of the Baccaro Member weakens in amplitude and finally disappears completely as the member shales out into the Verrill Canyon Formation. In the area of the Demascota G-32 and Shell Mohican I-100 wells (Figure 3), the strong seismic event at the top of the Baccaro Member maintains its character until the edge of the bank is reached, which is generally identified by a transition from gently to steeply dipping reflections (Figures 4 and 21). Beyond this point, all seismic events attributed to the Baccaro Member are truncated by many down-to-basin normal faults situated at the bank front.

The Baccaro-Mic Mac facies complex is comprised of three gross depositional zones – the nearshore clastic ridge, the moat and the offshore bank (Figures 5 and 6). The seismic response of the moat (Figure 7) results in a series of continuous events within the Baccaro Member due to the acoustic impedance contrast between limestones and lower-velocity shales. In the transition zone between the moat and the offshore bank (Figure 6), the Baccaro Member is essentially homogeneous, resulting in very little difference in acoustic impedance throughout the zone. Therefore, the seismic response will be a “dead” zone containing few seismic reflections (Figure 7).

The bank facies is marked by the thickening of the Baccaro unit in the basinal direction. This unit is generally comprised of hard, pelletal limestones with occasional zones of porous dolomite, resulting in a seismic response comprised of numerous, subparallel, discontinuous internal reflections below a high-amplitude, well-developed reflection from the top of the bank.

As mentioned previously, at least four identifiable exploration targets are associated with this bank and these are briefly summarized.

**PLAY TYPE 1: SUBTLE DRAPE IN OVERLYING SANDS**

Early drilling focused on structural highs along the Abenaki carbonate bank. Mobil-Tetco Cohasset D-42 (Figure 8), drilled in 1973, was targeted at the Baccaro Member. The limestones were found to be either tight or wet, but a little serendipity was provided by the subtle drape in the overlying sands of the Logan Canyon. Very high gravity oil
(49° - 52° API), with low GOR (<18 m³/m³), was tested in three separate sands while pay was calculated in a total of ten sands. Flow rates of up to 167 m³/day provided sufficient incentive for Petro-Canada to drill a delineation well in the winter of 1985/86 which resulted in another successful well, Cohasset A-52 (Figure 8).

Having determined that perhaps there was a trend, Shell Canada stepped out to drill the adjacent Panuke structure at Panuke B-90 in the fall of 1986. This was followed by a successful delineation well to this discovery, Panuke F-99, drilled by Petro-Canada, which produced a significant amount of oil from one Lower Cretaceous reservoir. Some 3714 m³ were pumped directly into a tanker during a 6-day test.

The oil discoveries made at Cohasset and Panuke demonstrated that the accumulation of oil in gently flexured sands overlying the Baccaro near the bank edge was a viable play (Figure 9). The traps rely upon simple structural closure. Source rock and maturation studies indicate the most likely source of the oils to be the basinward Verrill Canyon Formation shales (Powell 1982).

**GEOPHYSICAL RESPONSE OF PLAY TYPE 1**

As can be seen on the seismic section (Figure 11), the features are subtle but distinguishable, with approximately 10 msec of drape being apparent on line DD' (Figure 10). Mapping along the length of the bank edge shows the presence of other similar, undrilled drape features at the same horizon.

Due to the drape of the sediments over and around the Baccaro carbonate bank edge, this type of play displays structurally positive relief at the top of the Baccaro, elongated parallel to the bank edge. The relief of the shallower strata becomes more subtle, particularly on a time section. Generally, the structural relief on these drape features is slight and, for detailed mapping, it is crucial that the time structure maps should be converted to depth in order to correct for the effect of the dramatic change in water depth.
at the shelf/slope break which overlies these anomalies along the western part of the Scotian Shelf.

**Play Type 2: Reef Talus**

Listric faults along the paleoshelf margin facilitated the slumping of large quantities of bank-edge material. These natural debris piles could form a reservoir system for entrapment of hydrocarbons migrating from the basinward Verrill Canyon shales. The well-developed system of listric faults may have provided convenient conduits for migration. World-wide analogues are documented, such as the Tamabra Limestone of the Pozo Rico trend in the western Gulf of Mexico, which is credited with reserves in excess of 366 million m$^3$ (Enos, 1977).

Such features have considerable size and they are identifiable seismically. However, to date, none of these reef-talus plays has been drilled offshore Nova Scotia.

**Geophysical Response of Play Type 2**

Reef-talus material in front of the carbonate bank is shown schematically in Figure 12. An example of a seismic section and interpretation of this type of play is illustrated in Figure 13, for profile CC'.

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![Map showing the Abenaki carbonate bank, offshore Nova Scotia and the location of three regional seismic lines (Figures 4, 7 and 13).](image)

**Fig. 3.** Map showing the Abenaki carbonate bank, offshore Nova Scotia and the location of three regional seismic lines (Figures 4, 7 and 13).

![Seismic section AA' showing the seismic response of the Baccaro Member in the area of the Mohican I-100 and Demascota G-32 wells.](image)

**Fig. 4.** Seismic section AA' showing the seismic response of the Baccaro Member in the area of the Mohican I-100 and Demascota G-32 wells.
Fig. 5. Growth of the Baccaro carbonate bank and the "moat" zone during periods of low water (after Eliuk, 1978).

Fig. 6. Growth of the Baccaro carbonate bank and the "moat" zone during periods of high water (after Eliuk, 1978).
Fig. 7. Seismic section BB' through the Oneida 0-25 well, illustrating the seismic response of the three gross depositional zones of the Baccaro-Mic Mac facies complex and their location relative to the bank front.

Fig. 8. The carbonate bank edge along its ancestral seaward edge is shown in the vicinity of Sable Island. Wells and field names are shown.
The reef-talus accumulations are interpreted to be comprised of variously sized allochthonous blocks of Baccaro carbonate, including possible reefal material dislodged during storms, and intermingled with finer calcarenite and back-bank sediments which were carried to the bank edge by tidal and storm activity. The facies appears on the seismic interpretation (Figure 13) as a wedge of sedimentary material extending seawards of the bank toe. The top and bottom of this sequence produce generally well-defined seismic reflections due to the acoustic impedance contrast between the encasing basinal elastics and intervening carbonates. Reflections within the debris-wedge sequence vary from strong to weak continuous events.

Fig. 9. Schematic diagram showing the subtle drape of strata which overlie the Jurassic carbonate and the deep listric fault system in front of the bank.

Fig. 10. Map showing the Cohasset and Panuke fields and the Demascota G-32 well in relation to the Abenaki carbonate bank. The locations of seismic lines DD', EE' and FF' are also shown (Figures 11, 17 and 21).

Fig. 11. Final migrated stacked dip section DD' from the Como P-21 well through the Panuke F-99 well that illustrates the geophysical response of: (a) the Como structure (play type 3); (b) the Panuke field (play type 1).
Fig. 12. Schematic diagram showing an example of the talus-debris pile in front of the Jurassic carbonate edge. This example is directly interpreted from a seismic profile.

Fig. 13. Final migrated stacked dip section CC' through the Bonnet P-23 well, which shows the seismic character of a reef talus-debris pile (play type 2).
PLAY TYPE 3: BACK-BANK BUILD-UPS

Another feature that is visible on seismic sections is a build-up in the back-bank area which appears rooted at the Scatarie level. Whether this may be basement-related due to oolitic shoals, or biologic in origin, is as yet unknown. This play has not yet been tested by drilling. An example of such a feature appears to underlie the Como prospect (Figures 11 and 14). The Petro-Canada et al. Como P-21 well (Figure 10) was drilled to test the extent of the drape features in the Cretaceous and not to evaluate this potential carbonate build-up.

The build-up at the Scatarie level is readily identified and has the makings of a potential trap (Figure 11). Closure has been identified and the overlying thick Misaine shale would provide an adequate seal. There is the suggestion that hydrocarbons could possibly be sourced locally within the Scatarie. In addition, marine organic accumulations in deeper portions of the shelf region may have created sufficiently rich source rocks to have provided hydrocarbons to source these features (Tissot and Welte, 1978; Jansa, 1981).

GEOPHYSICAL RESPONSE OF PLAY TYPE 3

Carbonate build-ups can be identified from seismic data using criteria which include observing seismic parameters that directly outline the build-up or infer its presence (Figure 11). A specific reflection configuration generally defines the build-up. Reflections develop from the sides and the top of the build-up and overlying reflections onlap onto it. Drape due to differential compaction can be observed in the reflections overlying the build-up and in the enveloping strata. This positive relief diminishes upwards. Also, the edges of a build-up often appear to be marked by a termination of reflections from surrounding beds and abrupt changes in internal bedding geometry.

PLAY TYPE 4: BACCARO BANK POROSITY

The massive Baccaro Member exhibits a variety of facies (Figure 15) which reflect depositional controls such as water depth (and therefore energy). Pelletial muds, oolitic shoals and banks, and skeletal and reefal build-ups are recorded in well cuttings and cores. Morphologically, the Baccaro is a platform or rimmed shelf deposit (Eliuk, 1978), and in modern depositional conditions and sediment type an analogy is drawn to the Great Bahama Bank (Jansa, 1984). This feature is comprised predominantly of nonskeletal carbonates except for the coral facies and reefal facies located along the bank edge.

The reefal bank region during Baccaro time was separated from the shoreline by a sea of normal marine salinity. The shelf region was termed "moat" by Eliuk (1978) and was dominated by seas of neritic depths, although deeper water facies have been indicated in several wells within this region. The Demascota well (Figures 6 and 8), drilled in 1974 to a total depth of 4672 m, encountered some 1100 m of Baccaro section. This well, with the several cores cut in the Baccaro, provides a significant benchmark in understanding the Baccaro Member and its facies variations.

Both shallow and deep water carbonate environments are represented by cores and cuttings, or are inferred to be present. Important among these is the development of reefal facies (i.e., skeletal rich limestones which are comprised of 10 percent hexacorals, stromatoporids and/or sponges). These organisms have the potential to form bioherms or biostromes. Because of the significant number of framebuilders identified in core, and since a majority of them are in a growth position, a reefal interpretation has been postulated by Eliuk (1978). In the Demascota well alone, the upper Baccaro is interpreted to contain at least three reefal zones.

It is within these reefal facies that porosity has been noted and accounts for significant reservoir potential. In the Demascota well, some 168 m of porous dolomites were present.
encountered, with the porosity due to secondary dolomitization. The formation of dolomite coincides with interpreted periods of emergence of the reef. Eliuk (1978) suggests that the preferred diagenetic model involves the periodic establishment of thick, freshwater lenses beneath the exposed paleohighs. The dolomitization is secondary, occurring at the base of the lenses where it mixes with marine water. Thus, periodic subaerial exposure is a requisite to dolomitization and, therefore, porosity development.

During the deposition of the Baccaro facies, it would appear that there were four periods of shallowing and deepening. The shallowing phase produced the conditions which allowed for reefal growth at the bank edge and for the diagenetic effects that produced the porosity. Note that during deeper water deposition the moat zone expanded, and with shallowing water the moat zone shrank while the bank expanded. Within the record of holes drilled there is evidence that certain diagenetic products, including porosity and dolomite, occur in a vertical sequence. In the Demascota well, four periods of shallowing are recorded (Figure 16) and the accompanying porosity development prompted a modelling study.

Given that there is porosity development within the bank edge, and that the bank is encased in shale, there is good potential for a hydrocarbon reservoir. One possible source of hydrocarbons would be the Verrill Canyon shales, and Powell (1982) attests to their maturity and potential for output. A convenient conduit is provided by the listric fault system which developed along the front of the carbonate bank.

Interestingly, only 5 wells have been drilled into the Baccaro along the mappable bank edge, which extends some 500 km from the Sable Island area to the beginning of Georges Bank. The geophysical study was aimed at providing better techniques for the prediction of the porosity trend.

**Geophysical Response of Play Type 4**

As mentioned in the previous section, the Baccaro Member at the carbonate bank edge is expressed seismically by many subparallel discontinuous reflections. Because of the porosity encountered in several carbonate bank wells, two

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**Fig. 15.** The spatial distribution of Upper Jurassic facies along the Scotian Shelf with a dominant carbonate bank drowned to the northeast by the Sable Island delta. Landward and seaward facies equivalents are shown (after Wade and MacLean, 1990.)
Previous publications by Eliuk (1978) and Jansa and Wade (1975) were used to establish the paleogeographic setting, the depositional facies and the diagenetic history of the carbonate bank.

As previously mentioned, significant porosity was encountered in the Petro-Canada et al. Bonnet P-23 and Shell Demascota G-32 wells (Figures 8, 13 and 17). Porosity was modelled in both wells, but this paper will focus only on the results from the Demascota well, since the Bonnet modelling results were inconclusive and the Bonnet well requires further detailed work which was beyond the scope of the study.

The initial stages of modelling involved determination of the frequency content of the seismic sections. This was done by matching the seismic data with synthetic seismograms for which the appropriate seismic wavelets were employed. The Demascota G-32 well was modelled with several different wavelets, and it was found that the Ormsby wavelet yielded a better character match to the data than the other wavelets (Figure IX). Subsequently, four Ormsby wavelets were chosen for use on all models generated in this study. These were: 8/12 - 20/30 Hz, 8/12 - 30/40 Hz, 10/15 - 30/35 Hz and 10/15 - 40/45 Hz.

### Geophysical Modelling

A number of one-dimensional models were created for the Demascota well including those where the porous zone was unedited and others where the thickness of the porous zone was varied, including a "no porosity" case (Figure 19). The purpose of these models was to observe the seismic response to the variation in thickness of porosity. A noise factor was added to some models to help determine its effect on the seismic response.

In the unedited case, the porosity zones are interrupted by two tight zones. A low-amplitude trough coincides with the top of the first porous zone. The bottom of each porous zone is not separately resolved, but due to the interference of the tight zones, the response from the bottom of the first porous zone and the top and bottom of the second porous zone tune together to produce a single peak-trough rather

![Fig. 18. Portion of section EE' showing the excellent tie between the synthetic seismogram and the Demascota G-32 well.](image-url)
key questions come to mind regarding these subparallel discontinuous reflections:
1. Can porous reservoirs within the Baccaro Member be detected seismically?
2. Are the seismic events (Figure 17) along strike line EE' (Figure 10) through the Demascota well due to porous dolomite, chaotic internal structure, seismic noise, or multiples?

**Carbonate Bank Study**

In order to better understand the seismic response and implications of this play, a modelling study of porosity was undertaken for the Nova Scotia Department of Mines and Energy by Petrel Robertson Ltd. in April and May of 1989 (MacGregor et al., 1989). This is the first time a geophysical study dealing with Nova Scotia's offshore carbonate bank has been made available to industry. The purpose of the study was to model porosity development within the Baccaro Member to determine the extent to which stratigraphic changes such as lithology and porosity could be identified and mapped from reflection seismic data.

These objectives were achieved through the following means: a) one-dimensional modelling which utilized synthetic seismograms to provide a better understanding of the theoretical seismic response of existing porosity zones and changes in porosity and thickness; and b) two-dimensional modelling to simulate real exploration seismic data in order to determine the subsurface conditions and seismic recording geometry required for porous dolomites to be resolved and mapped.

The following data were utilized in the study: 1) representative seismic lines through study wells, 2) electrical logs from study wells, and 3) well summaries, mud logs and geological strip logs for several wells studied along Baccaro carbonate bank.
than a double peak-trough (Figure 19). Regardless of the problems caused by the tight zones, it appears that a seismic response is being generated that can be correlated with porosity encased in tight limestones. As the porous zone was decreased in thickness from 207 m to 50 m (Figure 19), a similar type of response was observed on the synthetics. It was also determined that porosity is detectable even if the thickness of the porous zone was decreased below 50 m. However, the trough defining the top of the porous zone is now less distinct from the peak defining the bottom of the porous zone. Indications from this model are that 50 m of porosity may be considered the critical tuning thickness for the porous dolomite encountered in the Demascota well. As expected, no reflections within the Baccaro arc generated for the model containing no porosity.

One of the most direct methods of analyzing the effects of variations in porosity and its thickness on the seismic response is to create a wedge model. In this model, porosity was held constant while the porous zone was thinned from 265 m to 0 m over 26 traces. The most encouraging model was that with porosity in the range of 11 to 14 percent, resulting in a marked decrease in acoustic impedance through the porous wedge. Even in the presence of 10 percent noise, the synthetic seismic section shows a distinct trough at the top of the wedge and a peak at the base (Figure 20). It is clear from Figure 20 that 11 to 14 percent porosity over 10 m can be detected but not resolved. Fifty metres of 11 to 14 percent porosity are necessary to resolve both the top and bottom of the porous interval.

Seismic data were examined through the Demascota well, recognizing that the modelling clearly demonstrated that porous dolomite is seismically detectable and resolvable. The Demascota well encountered some 168 m of porous dolomites encased in tight limestones. Also of significance is the fact that minor gas shows were encountered while drilling the upper reefal section of the mid-Baccaro carbonates. On both strike and dip lines (Figures 17 and 21, respectively) a high-amplitude reflection was observed at the mid-Baccaro level with essentially no reflections occurring below this event. If the gas shows in the Demascota well are on the downdip end of a reservoir, and the zone was present and fully gas-filled updip from the well, could the bright peak and weaker trough development in the seismic data be due to a gas-filled dolomite reservoir?

Thus, further modelling was undertaken in an attempt to establish some significance to the mid-Baccaro reflector seen on both strike and dip lines through the Demascota well. A model of the Baccaro carbonate bank was developed using the well logs from the Shell Oneida O-25 and Demascota wells (Figure 22). The porous dolomite was truncated to simulate the geometry of the type of porous lens predicted by Eliuk (1978). The peak generated at the top of the porosity development is at approximately the same time above the Misaite shale event as the peak generated from argillaceous limestones in the Oneida well. However, due to the geographic location of the carbonate bank and the thickening of the Baccaro Member seaward, the seismic response from the porous dolomites can never be mistaken
Fig. 20. Wedge model generated by holding the porosity constant while the porous zone in the Demascota well was thinned from 265 m to 0 m over 26 traces. This model exhibits a high-amplitude trough at the top of the porous wedge and a peak at the base. The acoustic impedance decreases through the porous wedge.

Fig. 21. Final migrated stacked dip section FF’ which runs 1.5 km southwest of the Demascota well. Notice the high-amplitude reflector at 2.6 s which correlates with a high-amplitude reflector observed on section EE’ (Figure 17) that ties the Demascota well. This bright peak and weaker trough may be due to a gas-filled dolomite reservoir.

Fig. 22. Carbonate bank porosity model which was developed using the Onoida O-25 and Demascota G-32 wells. Notice the response generated at the Demascota well which confirms once again that the porosity here should be seismically detectable and resolvable.
for that from the argillaceous limestones. Examination of the model, even with 10 percent noise, indicates that the porosity within the Demascota area should be seismically detectable and resolvable.

Next, consideration was given to the effects on the seismic signature of varying the lithology, the pore fluid content, and of fracturing the possible reservoir updip of the Demascota well. In order to evaluate the effects of these changes, amplitude-versus-offset (AVO) models were generated.

Three separate models were generated from the Demascota well. The first model represents the unmodified Demascota well and has two good porous intervals, the upper zone being gas-filled and the lower zone being water-filled. The second model assumes a fractured, gas-filled reservoir which is dolomitized and encased in limestone, while the third model depicts a nonreservoir, vuggy limestone. The effective porosity for these models was assumed to be intercrystalline caused by dolomitization. The porous reservoirs were assumed to be fractured due to the number of faults in the area and indications from core descriptions (Eliuk, 1978; Jansa and Wade, 1975). This will cause a change in Poisson's ratio of about 0.11 for fractured, carbonate gas-filled reservoirs. Poisson's ratio used for the encasing limestone in the three models was between 0.26 to 0.28.

Each model was output with four separate displays (Figure 23). The first is a CDP gather, the second is a stack of the first four traces (near offsets), the third is a stack of the last four traces (far offsets) and the last is a stack of all the traces (full stack).

Results from the first model (Figure 23) show a slight increase in AVO for the trough at the onset of the partially gas-filled intercrystalline porosity model. However, the porosity in the lower portion of this model is water-filled and the seismic reflection shows no variation in AVO. The Poisson's ratio used for the top gas-filled portion of the model was in the 0.20 to 0.26 range while the lower water-filled portion varied from 0.23 to 0.29.

The second model (Figure 24) utilized a Poisson's ratio of 0.16 and shows the fractured, gas-filled reservoir as having a significant AVO response. The amplitude of the trough at the onset of porosity increases nearly 100 percent. The peak at the base of porosity shows a similar response.

The third model (Figure 25) shows that both the top and bottom events from the vuggy limestone have no variations in AVO, assuming a Poisson's ratio in the order of 0.26 to 0.28 for this zone, i.e., no contrast in Poisson's ratio between the low-velocity limestones and the surrounding country rock.

The AVO modelling suggests that a porous, gas-filled carbonate in the Demascota area will generate a significant AVO effect in seismic data. This anomaly will be strongest where the reservoir is dolomitized, fractured and encased in tight limestone. Fluids in the pore space, other than gas, will yield no AVO anomaly. This is also true for nonreservoir, vuggy limestones. Even with the introduction of a significant amount of random noise, it is felt that the AVO response of the "fractured, gas-filled dolomite", shown by modelling, should be detectable on seismic data. This offset effect should be identifiable on a full stack or on a far-trace, distance-limited, stacked section.

Fig. 23. AVO model in which the upper portion of the model is gas-filled and the lower portion water-filled. The trough at the top shows a slight increase in AVO due to partial gas saturation while the peak represents the water-filled lower portion of the model and shows no variation in AVO.
Fig. 24. AVO model for a fractured gas-filled reservoir. The amplitude of the trough at the top of porosity increases nearly 100 percent between near and far offsets. The peak at the base of porosity shows a similar AVO response.

Fig. 25. AVO model in which the porous zone is completely replaced by a vuggy limestone. No variations in AVO occur at the peak or the trough which represent the top and the base of the vuggy limestone, respectively.
SUMMARY AND CONCLUSIONS

From the study, several interesting conclusions about the detection of porosity in the Demascota area can be drawn. The carbonate bank study has verified that the detection of bank porosity depends upon the lithology (therefore, the density and velocity) of the strata above and below the porous zone. This zone can best be detected if it is isolated in the middle of the Baccaro Member, rather than at the top where there will be interference from the high-amplitude reflection generated by the top of the Baccaro.

Because porous dolomite tends to be encased in tight limestones and the porosity occurs at the mid-Baccaro level in the Demascota area, a dolomite bed with 11 to 14 percent porosity and as thin as 50 m should be resolvable. Reprocessing and reinterpretation of seismic data in an attempt to analyze the AVO effects over the strong peak identified updip from the Demascota well should be undertaken to determine its viability as a future exploration target.

We draw the following conclusions about the carbonate bank and its associated plays:

1. The four plays mentioned are very important in recognizing the hydrocarbon potential of the carbonate bank.
2. The sand-drape play has been established by discoveries at Cohasset and Panuke. Expectations remain high for further pools to be discovered in the trend.
3. The reef-ralus play can be identified at the toe of the bank but additional, detailed mapping of the carbonate bank is required to identify the potential of this type of play.
4. Back-bank build-ups have yet to be tested for hydrocarbon potential, but since this play is definable, it may be an important consideration for further exploration along the carbonate bank.
5. As has been demonstrated, porosity within the bank should be detectable and resolvable. A concentrated effort in evaluating and mapping porosity along the bank’s edge should be considered.

The four plays associated with the carbonate bank deserve much more attention than has been given in the past. Higher frequency content and closer spaced seismic data should be acquired by the explorationist to further evaluate these plays. This should result in the identification of new play trends associated with the carbonate bank, which will in turn help generate a new round of exploration activity.

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