REPORT TO VINLAND PETROLEUM INC. ON RESOURCE POTENTIAL OF WEST NEWFOUNDLAND EXPLORATION PARCELS 8 AND 9

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Figures And Tables

Summary

This report outlines the geology and petroleum potential of exploration parcels 8 and 9 on the Great Northern Peninsula western Newfoundland for Vinland Petroleum Inc.

Parcel 9 is located on the western side of the peninsula and is divisible into three structural blocks by two north-northeast striking faults. Only the western, coastal block contains a significant sequence through potential carbonate reservoir lithologies. No seal is developed within this sequence. A shale-rich lithology underlies the carbonate sequence, however, the oxidized nature of the shale, where exposed in the central and eastern blocks, suggests it is not a suitable source lithology. The petroleum exploration potential of parcel 9 is considered to be poor.

Parcel 8 lies on the eastern side of the Great Northern Peninsula and consists of an imbricate thrust stack of the carbonate cover sequence and overlying sheets of the Hare Bay allochthon. Mid-Paleozoic thrusting has resulted in repetition of potential source, seal and reservoir lithologies, and a large scale hanging-wall anticline is present within the exploration parcel. Although these conditions provide an excellent petroleum exploration prospect, the relatively high metamorphic grade of the rocks suggests that the proposed source lithology (Goose Tickle Group) may be over-mature.

Introduction

This report outlines the geology and petroleum potential of exploration parcels 8 and 9 on the Great Northern Peninsula, western Newfoundland for Vinland Petroleum Inc. (Fig 1). It is based on field work carried out in November 1992 with follow up research in January and February 1993. Parcel 8 is located east of the community of Main Brook, on the northeast side of the peninsula, and Parcel 9 is located south of Plum Point on the northwest side of the peninsula. The report first outlines the geological setting of west Newfoundland and then & discusses specifically the setting of Parcels 8 and 9.

West Newfoundland consists of Precambrian and Paleozoic sedimentary, crystalline and ophiolitic rocks, belonging to the Humber Zone of the Appalachian Orogen (Williams, 1978; 1979) and a number of Late Ordovician to Carboniferous successor basins that lie unconformably upon the Humber Zone (Fig. 1).

Regional Setting

The Newfoundland Humber Zone extends from the western limit of Appalachian deformation, which corresponds approximately with the west coast of the Great Northern Peninsula, eastward to the Baie Verte-Brompton Line (Fig. 1). Rocks of the Humber Zone are divisible into three distinct pre-Late Ordovician elements (Stevens, 1970; Williams and Stevens, 1974): Precambrian crystalline basement, a latest Precambrian to Middle Ordovician cover sequence, deposited unconformably on basement, and a series of thrust sheets which structurally overlie the cover sequence. On the Great Northern Peninsula, the transported rocks comprise the Hare Bay allochthon (Williams and Smyth, 1983).

Precambrian crystalline basement consists of high-grade polydeformed quartzo-feldspathic gneisses of plutonic origin with wispy remnants of supracrustal rocks and lenses of amphibolite (Bostock, 1983; Owen, 1991). Metamorphism and deformation took place during the Grenvillian orogenic cycle (1250-1000 Ma; Owen and Erdmer, 1986). Eocambrian mafic dykes locally intrude this basement sequence. Elements of the rifted Precambrian basement are preserved as a series of inliers, the largest of which, the Long Range Inlier (Fig. 1), forms the backbone of the Great Northern Peninsula.

A simplified stratigraphic column for the cover sequence is shown in Table 1. The sequence is divisible into three distinct lithological associations reflecting a three stage process related to the opening and closing of an ancient ocean, Iapetus. The first stage comprises upper Precambrian to lower Cambrian coarse, commonly non-marine, siliciclastic rocks with local igneous activity, and is related to rifting of Grenville basement. It includes the Bateau and Lighthouse Cove formations and probably the Bradore formation of the lower Labrador Group. The second stage consists of Early to early Middle Cambrian mixed siliciclastics and carbonates succeeded by Middle Cambrian to the Early Ordovician carbonates deposited on an extensive platform. These strata represent prolonged drift stage sedimentation at a trailing (passive) margin, and include the Forteau and Hawke Bay formations of the upper Labrador Group, as well as the Port au Port and St. George groups. By the late Early Ordovician, the margin was affected by oceanic closure and plate convergence. The destruction of the margin and the formation of an elongate foreland basin during the Middle Ordovician marks the last stage of the Wilson cycle. Carbonate rocks accumulated along the margin of the foreland basin as massive quantities of siliciclastic flysch derived, at least in part, from the orogenic hinterland filled the bulk of the basin. Units deposited during this stage of the orogen include the Table Head and Goose Tickle groups.

The Taconian allochthons consist of lower slices of sedimentary rock beneath higher slices of volcanic and ophiolitic rock. These rocks are coeval with the cover sequence on Grenville basement and are interpreted as the outboard equivalent of this sequence which were incorporated into the allochthon during emplacement of the ophiolites onto the continental margin. The same threefold lithologic association recognised in the cover sequence is also seen in the rocks of the allochthons. Only the rift facies rocks of the Maiden Point formation are well preserved in the Hare Bay allochthon. Higher structural slices of the allochthons consist of volcanic and ophiolitic rocks and belong to the St. Anthony Complex in the Hare Bay Allochthon. The allochthons were assembled as a stack of thrust slices separated by melanges which consist of scaly shales with sedimentary, volcanic and plutonic blocks. Shale matrix to the melange locally contains Arenigian fossils (Tuke, 1968).

Post-Middle Ordovician successor basin strata on the Great Northern Peninsula are represented by the St. Julian Island Formation of inferred Silurian age and the Lower Carboniferous Crouse and Cape Rouge Formations. Both these groupings of strata probably represent the isolated remnants of more extensive time equivalent sequences exposed in the White Bay and Deer Lake regions, along strike to the south.

Metamorphism And Deformation
West Newfoundland underwent deformation and metamorphism during at least three orogenic episodes. These are the early Paleozoic Taconian orogeny, the mid-Paleozoic Acadian orogeny and the late Paleozoic Alleghanian orogeny.

Taconian deformation established the gross structural style of the Humber Zone. This involved assembly and emplacement of the Taconian allochthons (Williams and Stevens, 1974). Thrusting was dispersed through incompetent, shale-dominated sequences resulting in widespread development of melange (Stevens, 1970). Taconian thrusting and penetrative deformation are restricted to the uppermost crustal levels and only involve the transported slices of the allochthon. Underlying shelf and crystalline basement are largely undeformed. Folding associated with Taconian thrusting is characteristically west-directed recumbent structures.

Acadian deformation is characterized by an overall pattern of west-directed thrusting (Cawood, in press; Cawood and Williams, 1988; Cawood et al., 1988). Greenville basement is thrust above its carbonate cover sequence, and both are locally thrust over the Taconian allochthons. Metamorphism accompanying deformation reaches upper greenschist to lower amphibolite facies. West Newfoundland hes at, or near, the Acadian orogenic front. The intensity of deformation and metamorphism decrease and die out westward.

Alleghanian deformation is relatively mild and concentrated along the Cabot Fault System (Fig. 1), which runs from west of Cape Ray northeast to White Bay. The fault lies at, or near, the eastern side of the Humber Zone and has reactivated and largely overprinted the Baie Verte-Brompton Line. Dextral strike-slip movements occurred along the fault in the Early Carboniferous and controlled sedimentation in the Deer Lake and Bay St. George basins (Bradley, 1982, Knight, 1983; Hyde et al., 1988). Carboniferous strata outside the zone of the Cabot Fault system are essentially undeformed and unmetmorphosed (Williams and Cawood 1989).

Description Of Rock Units
Table 1 provides a simplified stratigraphic column of rock units in and around Parcels 8 and 9, and summarises lithology, thickness and age data for each of the principal units within these regions. A detailed description of the units is given in Knight and Cawood (1991), Knight (1991), Bostock (1983), Cumming (1983), and Williams and Smyth (1983), and will not be repeated here, other than to note any distinctive features present in the exploration parcels. Outcrop of bedrock units is generally poor with

extensive glacial outwash across lowlands (e.g. Grant, 1992).

Geology of Parcel 9

A simplified geologic map for Parcel 9 and environs is presented in Figure 2 and cross section in Figure 3 (in back pocket). Construction of the cross-section was based on stratigraphic thickness outlined in Table 1 and made with the assumption that the basement cover interface represents a relatively smooth surface. Regional mapping within the Humber Zone indicates that this assumption is probably wrong. Knight and Cawood (1991) and Williams and Hiscott (1987) outline evidence for irregularities along the interface related to rifting of the Laurentian margin at the initiation of the Appalachian orogenic cycle. However, there is no way to accurately predict the position of these basement-cover interface irregularities, so for simplicity they are ignored.

Parcel 9 and the surrounding areas are divided into three structural blocks by two major north northeast striking faults, the Long Range thrust in the east and the Ten Mile Lake Thrust fault in the west (Fig. 4). The eastern block, lying to the east of the Long Range Thrust, consists of Grenvillian basement, marking the northern extent of the Long Range Inlier (Fig. 1), unconformably overlain to the north by arkosic sandstone of the Brador Formation and shale and well-bedded limestone of the Forteau Formation. Northeast of the exploration parcel, this sequences passes up through a complete succession of the cover sequence with the Forteau Formation stratigraphically overlain by clastics of the upper Labrador Group which in turn pass up into units of the Port au Port, St. George, Table Head and Goose Tickle groups (Knight, 1986b; Stouge and Godfrey, ?1982). The central block, sandwiched between the Long Range and Ten Mile Lake thrusts, shows a similar stratigraphic succession as the eastern block, with Grenville basement gneisses, stratigraphically overlain by the Brador (Fig. 5), Forteau (Fig. 6) and Hawke Bay formations of the Labrador Group. The western block, extends west from the Ten Mile Lake Thrust to the coast. Rock units exposed within the block in the vicinity of the exploration parcel are carbonates and minor shale from the Petit Jardin, Boat Harbour and Watts Bight formations of the upper Port au Port and the lower St. George groups (Fig. 2). North of the parcel, rocks as old as Hawke Bay Formation are exposed within the block (Knight, 1986a). In the vicinity of Plum Point (Fig. 2), a fault running parallel to the coast, and termed the St. Margaret Bay thrust by Grenier and Cawood (1987) cuts through the carbonate sequence. This fault dies out south of Plum Point and does not cut through the carbonates on the New Ferolle Peninsula.

Bedding is gently dipping throughout the region (Figs. 2 and 3), with dips of generally 10o or less, except adjacent to the major north-northeast striking fractures where dips as steep as 45o are locally observed. The consistent east-side up sense of movement on the Long Range, Ten Mile Lake and St. Margaret Bay fractures, results in the oldest rocks within each block being exposed immediately east of these structures. For the eastern and central blocks, this lithology is Grenville gneiss, and for the western block it is Hawke Bay Formation, which occurs immediately east of the St. Margaret Bay fault in the region west of Eddies Cove (Grenier and Cawood, 1987). Bedding within the three structural blocks also dips toward the direction in which the fault bounding the western margin of a each block dies out. Thus, north of Parcel 9, the Long Range thrust dies out and merges with the Ten Mile Lake Thrust with displacement transferred to this latter structure (Grenier and Cawood, 1987). This decrease in displacement to the north results in basement of the Long Range Wier plunging north beneath a northwest dipping cover sequence, with progressively higher stratigraphic units exposed in the immediate hanging-wall to the thrust (Fig. 2). An alternative, and possibly complimentary explanation for this pattern of northward plunging rock units is the presence of a lateral ramp beneath the northern Long Range Inlier. The western block shows a similar relationship between bedding and faulting. The dying out of the St. Margaret Bay Thrust south of Plum Point is accommodated in the hanging-wall to the east by folding of the Watts Bight and Petit Jardin formations into a broad South-southwest plunging anticline. The axis of the anticline lies within the exploration parcel west of the Great Northern Peninsula Highway. The crest of the fold is relatively broad and is highlighted by the east-west strike of the Petit Jardin-Watts Bight boundary. Closure of this structure must however occur up plunge, to the north and outside the exploration parcel. A series of small scale macroscopic anticlines with subvertical axial planes and subhorizontal fold axes occur further west on the tip of the Ferolle Peninsula (Figs. 2 and 3). These structures have wavelengths of approximately

500 m to 1 km and amplitudes of up to a few 10's m.

Although the Long Range, Ten Mile Lake and St. Margaret Bay fractures are interpreted as thrusts (e.g. Williams and Cawood, 1989; Grenier and Cawood, 1987; Grenier, 1990), within the vicinity of the exploration parcel their surface dip is relatively steep. Hence, movement across the structures in predominantly vertical with little lateral transport (Fig. 3). Estimated throw across the Long Range and Ten Mile Lake structures in the vicinity of cross-section A-B (Fig. 3) is approximately 1.75 km and 0.8-0.9 km respectively. Throw across the former was estimated by extrapolating the basement cover interface at the northern end on the Long Range Inlier with a uniform 10o dip to a position along section A-B. The inferred steep dip of the faults in the region is based on their rectilinear surface trace, and exposure of the Ten Mile Lake structure further south in the Port Saunders region (Knight, 1991). The merging of the Long Range and Ten Mile Lake faults just north of Ten Mile Lake and the known low dip of the former structure in the region of Gros Morne (Cawood and Williams, 1986; Cawood et al., 1987; Williams et al., 1986) suggests that they form part of a linked fault system that may flatten at depth into a sub-horizontal detachment.

There are no direct constraints on timing of deformation within the area, other than deformation must post-date the youngest deformed lower Paleozoic carbonates. Regional correlations outlined in Cawood and Williams (1988) and Cawood (in press) suggest faulting and associated folding are mid-Paleozoic features.

Petroleum Potential - Parcel 9

Petroleum potential of Block 9 is poor. Rocks with suitable reservoir characteristics may be present in the carbonates of the western block but no area of suitable closure was identified, nor are an appropriate seal or source rock present. Carbonates of the Port au Port and St. George groups range from massive bedded dolostones and limestones to brecciated dolostone of both primary and secondary origin (Figs. 7 to 12). High porosities are restricted to lithologies with a secondary dolomitic spar, notably in the Boat Harbour formation. Although these carbonates have a weak hydrogen sulphide odour (sour gas), no evidence for any bituminous residue was observed in any of these vugs. The secondary porosity is sporadically distributed and shows no obvious correlation with structural position (i.e. fold hinge). In addition, this spar may locally infill all available vugs and pores producing a relatively tight carbonate (Fig. 11).

The only potential source rock exposed within the area, or likely to be present in the subsurface, is the Forteau Formation. This unit is shale rich, particularly in the lower stratigraphic sections of the unit. The Forteau is well exposed along the forestry track east of Squid Cove, and in a gravel pit at the Mount St. Margaret quarry. The shale dominated sequence of the formation is at least 30 m thick and Knight (1991) notes that in the poorly outcropping low ground overlying the Grenville gneisses east of the Ten Mile Lake Thrust may be several 100 m's thick. Forteau shale in the vicinity of the Highlands of St. John are interbedded with limestone ranging from micrite to oolitic grainstone. Both the shale and limestone are strongly bioturbated, with both horizontal and vertical feeding trails. The Mount St. Margaret quarry section consists of a uniform section of shale some 38 m thick. It is friable green, grey shale with scattered trilobite fragments on bedding parallel parting planes. Bioturbation is less pronounced than in the region east of Squid Cove or in the shale rich sections exposed north of the exploration parcel in the Ten Mile Lake region. The cross bedded character of the grainstones, the locally strongly bioturbated nature of the entire formation, and the green colour of the shales even where not strongly bioturbated, indicate that the shales accumulated in an oxidizing environment and have little potential as a petroleum source.

The sedimentary section in the exploration parcel is relatively thin and only rock units from the lower St. George Group and below are present. The finer grained units from the upper cover sequence are traditionally invoked as a seal to any potential traps. The absence of these units in parcel 9 means that any oil which could have accumulated in the region would have been lost.

Geology Of Parcel 8

A simplified geologic map & Parcel 8 and environs is presented in Figure 13 and cross section in Figure 14 (in back pocket). Construction of the cross-section was based on stratigraphic thickness outlined in Table 1 and, as for the section from parcel 9, was made with the assumption that the basement cover interface represents a relatively smooth surface.

Rock units exposed within the area consist predominantly of latest Precambrian to Ordovician carbonate, siliciclastic and volcanic rocks. Siliciclastic rocks of probable Silurian age are exposed on St. Julian Island (Williams and Smyth, 1983) and may extend offshore east of Croque Harbour (Fig. 13). Carboniferous strata are exposed on the Cape Rouge and Conche peninsulas and are widespread in the offshore (Le Fort and Howarth 1984), probably forming the northern continuation of the strata in the Deer Lake Basin. The region contains a relatively continuous section through the early Paleozoic cover sequence, extending from the Hawke Bay Formation of the Labrador Group up to the Goose Tickle Group with the latter structurally overlain by thrust sheets of the Taconnian Hare Bay allochthon. Both the cover and allochthon sequences are higher repeated by mid-Paleozoic, thrust faulting. Grenville basement and lower units of the Labrador Group are not exposed but are present in the subsurface (Fig. 14). A series of undeformed mafic dykes of possible Devonian age cut through the lower Paleozoic rock units and are well exposed along the coast of Hare Bay east of Big Spring Inlet.

Deformation and metamorphism of the cover sequence prevented easy and accurate differentiation of the individual formations of the Port au Port and St. George groups and no attempt was made to differentiate these units during my research in the area. Port au Port Group strata are represented mainly by dolostones of the Petit Jardin Formation. These are fine grained, laminated, yellow-grey micritic dolostone (Fig. 15). Carbonates of the St. George consist of bioturbated dolomitic limestone, stylo-bedded to stylo-nodular Limestone, and laminated to thin bedded dolostone locally with chert nodules. Bioturbated carbonates are well developed in the upper St. George Group, and are characterized by sandy dolomitic burrows in a limy matrix (Fig. 16). These rocks are characterized by a sour gas smell when broken. The upper St. George Group in this region was informally termed the Southern Arm formation by Stouge and Godfrey (1982). The lower St. George Group (Fig. 17), termed the Brent Island formation by Stouge and Godfrey (1982), is characterized by well developed sponge and stromalite mounds in the reference section on Brent Islands (Stevens and James, 1975). Laminated dolomitic micrites seen near the top of this unit on the Croque Harbour - Main Brook road are similar to lithologies seen in the Boat Harbour Formation of the St. George in Parcel 9 suggesting that with careful work the formal stratigraphic subdivisions of the St. George Group may be recognised in this more deformed eastern region.

The cover sequence is repeated by east-dipping, west-directed thrusts into at least six imbricate slices (Fig. 18). Five of the slices occur within and west of the western half of the area, lying to the west and southwest of Big Spring Inlet. The sixth slice is isolated from the others by a broad band of Maiden Point Formation, and outcrops in the area south of White Arm Pond (Fig. 13). Thrust sheet 4 is the largest of the western sheets. Slices 1-3 occur largely outside the exploration parcel but are likely present in the subsurface below slice 4 (Fig. 19). Slice 4 is folded into regional scale anticline-syncline pair, herein referred to as the Big Spring anticline and the Main Brook syncline (Figs. 13, 14). Both structures plunge gently to the north-northeast and the axis of the anticline can be traced for over 25 km. The half wavelength of the structures is of the order of 2.5 km The syncline/anticline pair lie in the hanging-wall to the thrust fault bounding the western side of the slice and are interpreted to have formed during thrusting. The basal thrust to the slice, termed the Brent Island thrust by Stouge (1981) is itself folded at the northern termination of the underlying slice 3, whereas the basal thrust to slice 3 is not folded. This suggest that the thrust sequence involved movement of slice 4 followed by movement of slice 3, with the latter wedging and further folding the former. This is shown in the cross section (Fig. 14) by the down-plunge projection of slice 3 into the plane of the section. North of the line of the cross-section, the Big Spring anticline is characterized by a long thin nose of St George Group carbonates. These form the exposed crest of the anticline for a distance of some 8.5 km from Big Spring Inlet south almost to the Croque Harbour - Main Brook road. This pronounced thickening of the fold hinge indicates it is a nonparallel fold, although mapping indicates that it is also probably broken by high-angle faulting.

Slice 6 consists of the carbonate cover sequence thrust over siliciclastics of the Maiden Point Formation. The cover sequence is folded into a hanging-wall anticline, herein informally referred to as the White Arm anticline; this structure has previously been referred to as the White Arm window (Williams and Smyth, 1983; Stouge and Godfrey, 1983). Relations along the western side of this structure show it is not a simple symmetrical window marked by folding of a primary Taconian thrust contact, but rather is a hanging-wall anticline to a west-directed Acadian thrust. Evidence for the western contact of slice 6 being an east-dipping late thrust rather than a west-dipping early thrust is seen in exposures along the Main Brook-Croque Harbour road (Fig. 20). The contact is inferred to be parallel the penetrative foliation in the area which dips steeply east-southeast at around 70o. Melange, which is a characteristic feature of Taconian contacts, is absent and the contact cuts through the hanging-wall stratigraphy, such that in the vicinity of the road, the Goose Tickle Group and most of the Table Head Group are cut out. On the eastern limb of the anticline, the contact between the carbonates and the Goose Tickle Group, which has previously been mapped as either a stratigraphic contact (Williams and Smyth 1983) or a thrust fault, is a normal fault: the contact downdrops the Goose Tickle lithologies to the east against carbonates to the west. It could have formed due to collapse of a thrust ramp at depth, perhaps at the termination of mid-Paleozoic compressional deformation (e.g. Fig. 14).

Structural style and metamorphic grade of the early Paleozoic rock units increase across the exploration parcel from west to east. Rocks in the west are gently to moderately dipping, with a weak to moderately developed cleavage. In the east folds become tighter, the cleavage fabric is closer space and better developed, and bedding is generally steeper. The regional distribution of metamorphic grade throughout western Newfoundland is shown in Figure 2 1. Metamorphic grade of parcel 8 is at greenschist grade and the carbonates, particularly those in the east, are altered to marbles. The data base for this conclusion is however, limited and based on conodont colour alteration index (CAI) data published by Stouge (1986) and Nowlen and Barnes (1987). Stouge (1986) does not provide accurate location data for his samples: approximately 5 are located within the exploration parcel; four within the vicinity of thrust slice 4 and the fifth from slice 6. Those from slice 4 have a CAI of 5 and from slice 6 a CAI of 5-6. Nowlan and Barnes (1987) report one conodont CAI sample from the exploration parcel. This sample was located in the Table Head Group of slice 4 at Little Spring Inlet and also gave a CAI of 5. Based on the work of Epstein et al. (1977) a CAI of 5 implies a temperature range of 300-400°C.

Two generations of thrusting are recognised within the area. The first is responsible for emplacement of rock units of the Hare Bay allochthon onto the platform cover sequence, as well as internal deformation and imbrication within the allochthon succession. Deformation associated with this event appears to be largely confined to the allochthon succession. In the cover succession, the effects of this event are limited to subsidence of the platform, the termination of carbonate sedimentation and its replacement by clastics of the Goose Tickle Group (Cawood and Williams, 1988). Contacts between the Goose Tickle Group and the Northwest Arm Formation of the allochthon are marked by scaly shale melange (Williams and Smyth, 1983). The contact between the Maiden Point Formation and Goose Tickle Group is also mapped as a primary Taconian thrust contact, and a considerable proportion of the lithologies shown in Fig. 13 as Goose Tickle Group along this contact zone are deformed into melange. This is clearly seen in the section of 'Goose Tickle Group' exposed along the Croque Harbour - Main Brook road by Tom Roses Pond. However, the contact also shows some evidence for later reactivation. The contact locally cuts down section, removing the Goose Tickle Group and juxtaposing the Maiden Point Formation directly over the Table Head Group. In addition, in the Coles Pond region (Fig. 13), the contact appears to truncate or merge with a later thrust involved in deformation of the cover sequence. Further evidence for reactivation is seen along the contact on the Conche Peninsula road, east of Roddington. Here the Maiden Point Formation is thrust directly over carbonates (?Table Point Formation) with no intervening Goose Tickle Group or melange and the cover sequence in the footwall is intensely thrust imbricated.

A second phase of thrusting, post-dating allochthon emplacement, resulted in imbrication and repetition of the cover sequence into the six thrust slices outlined above (Fig. 18). Regional considerations suggest this event correlates with the mid-Paleozoic Acadian Orogeny (Cawood, 1989; in press; Cawood and Williams, 1988; Knight and Cawood, 1991). Unlike Taconian contacts, which are marked by melange, the younger Acadian thrust contacts are marked by brittle breccia zones. One of these contacts is well exposed on Marechal Island (also know as Bard Island). Here, along the Brent Island thrust, St. George Group carbonates from thrust slice 4 are thrust westward over the Goose Tickle Group clastic rocks of slice 1. The Goose Tickle Groups dips southeast ($S_o//S_1$dip 66° to 130°/66°). The carbonates are deformed into a hanging-wall anticline immediately adjacent to the thrust. The thrust plane is delineated by a 1 m wide zone of carbonate breccia orientated 135°/70°.

Petroleum Potential - Parcel 8

Parcel 8 contains the necessary elements for petroleum accumulation; reservoir, source and seal are all present. However, the relatively high metamorphic grade of the rock units in the area may negotiate against the preservation of oil if it did originally accumulate within the area.

The dolomitized and locally vuggy carbonates of the upper St. George Group provide a viable reservoir horizon within the cover sequence. These carbonates are a prime exploration target along in the western side of the Great Northern Peninsula and in the offshore Gulf of St. Lawrence. The hydrogen sulphide odour (sour gas) of these carbonates suggests that they my have at one stage contained organic-rich material. Recent work on hydrogen sulphide formation by Machel (1989) suggests that dissolved sulphate species and organic compounds are thermodynamically unstable and at temperatures above 100-135°C they react leading to reduction of the sulphate phases to sulphide (e.g. H_2S) and oxidation of the organic compounds to solid bitumen, bicarbonate and /or carbon dioxide. These reactions are often associated with secondary dolomitization of the sequence (Machel, 1987a, b, 1990).

A potentially excellent structural trap is represented by the Big Spring anticline. Initial structural studies suggest this is a thrust generated anticline related to westward transport on the Brent Island thrust. The anticline is however locally broken by high-angle faults (only a few of which are show on Fig. 13) and the effect of these on the integrity of the trap is unknown. The fine clastics of the Goose Tickle Group, as well as the fine grained carbonate phases of the Table Head Group and upper St. George Group (Aguathuna Formation) could provide a suitable seal.

The black organic rich shales of the Goose Tickle Group provide a likely source material. On the western side of the Great Northern Peninsula, and in the region of the Port au Port Peninsula, these rocks, along with the Table Cove Formation of the Table Head Group, are characterized by a strong petroliferous smell when broken. The initial cross section constructed for the area suggest that although the Big Spring anticline is defined by folding of rock units lying within thrust slice 4, thrust slices 1-3 may be present in the subsurface below the anticline (Figs. 14, 19). This suggests a number of structural levels with the same trap, seal, source combination.

Although Parcel 8 contains the necessary combination of source, trap and seal elements, the fundamental problem in establishing the prospectivity of the parcel is the presence or absence of rocks of suitable thermal maturity within the source area. Metamorphic data outlined above indicate that slices 4 and 6, and presumably the intervening slice 5, have CAI's of 5 or more and hence any source rocks in these slices were heated to temperatures of at least 300oC, well above the window for hydrocarbon generation. Have rocks within slices 1-3 been heated to the same degree? Structural cross-sections indicate that these slices are present in the subsurface below the Big Spring anticline and hence, provide potential source and reservoir horizons for any oil which could accumulate in the anticline. Crucial to resolving this question is the relative timing of thermal and deformational events in the region. If metamorphism predates deformation, then rocks in slices 1-3 could be at a significantly lower thermal state that slices 4-6 and thus suitable for oil generation. If metamorphism post-dates deformation, then slices 1-3 are probably at a similar thermal state to the higher slices and prospectivity of the area is considerably diminished. Harris et al (1981) has shown in the southern Appalachians that eastward-increasing regional thermal patterns existed prior to thrusting, so that during westward movement of thrust sheets thermally mature eastern rocks were placed over less mature western rocks.

Western Newfoundland, like the southern Appalachians shows an increase in metamorphic grade from west to east. Relationships within Parcel 8, as well as regional relationships in west Newfoundland, suggest that although the grade of slice 1-3 is less than that in the higher slices (4-6), it is still too high for oil generation. No marked metamorphic breaks where observed at structural contacts such as the Brent Island thrust. This continuity of metamorphic grade across structural boundaries was only estimated visually and if the grade and thermal patterns across the parcel are to determined accurately further work is needed. In particular samples from thrust sheets 1-3 need to be sampled and analysed. This trend is consistent with the regional patterns outlined in Figure 21 and the results of detailed studies in the Comer Brook region (Cawood and van Gool, 1992).

Figure 21 shows the regional distribution of metamorphic facies in western Newfoundland associated with mid-Paleozoic deformation. Of relevance to the present problem is the continuous belt of greenschist facies rocks along the western side of the Great Northern Peninsula. Because of the overall north-northeastly plunge of rock units off the northern end of the Long Range Inlier this belt of greenschist facies lithologies must cut structurally up section from Canada Bay to Hare Bay. West of Canada Bay the greenschist facies lithologies are in units equivalent to those found in slice 1 immediately to the west of the exploration parcel. Moving north sinclar metamorphic grade is found in progressively higher thrust slices. Detailed work in the region between Corner Brook and Grand Lake shows a sinclar relationship of thermal pattern to deformational state with peak metamorphism post-dating the major DI thrusting event (Cawood and van Gool, 1992). There is however, some continued post-metamorphic west-directed shortening in the Corner Brook region. In summary, available data on thermal patterns suggests rocks in the subsurface below the Big Spring anticline will be over-mature.

Alternative Exploration Play In Parcel 8; ?Carboniferous Source

An additional exploration play for Parcel 8 could be the migration of hydrocarbons from nearby Carboniferous strata into a trap in adjoining Ordovician carbonates. Carboniferous strata occur south of Parcel 8 on the Conche Peninsula. Oil seeps occur near the contact with the Maiden Point Formation. Although the source of this oil is unknown, gas and oil shales do occur within the Carboniferous sequences of the Deer Lake Basin. Figure 13 shows the inferred position of the boundary of the Carboniferous strata directly offshore from Parcel 8 and Figure 14 shows a cross-section across this boundary. For the Carboniferous strata to act as a source for any potential carbonate play in the vicinity of the Whites Arm anticline, requires the downthrow on the bounding fault to be at least 4 km. Given that this fault shows considerably less downthrow on the Conche Peninsula and that there is no evidence for extensive scissors motion on the fault moving north, this play is considered highly unlikely.

Conclusions And Recommendations

Exploration parcels 8 and 9 provide exposure of all the principal rock units found in west Newfoundland and thus allow a good assessment of the potential of this region as a petroleum province. Although potentially suitable reservoir, seal and source lithologies occur on the Great Northern Peninsula, only parcel 8 has these in a combination suitable for petroleum accumulation. In Parcel 8 a large anticline, termed the Big Spring anticline, formed through west-directed mid-Paleozoic Acadian thrusting. A generalized cross-sections across the structure suggest it may overlie a footwall ramp with repetition of potential source, seal and reservoir units. A problem with the structure is the high thermal state of exposed rock units in the area and the potential that metamorphism post-dates deformation such that rock units in the subsurface are at a similar over-mature thermal state.

I would recommend no further work be carried on exploration parcel 9.
Parcel 8 is a potentially promising prospect but before any major work is carried on the area I would recommend resolving the thermal state of the rocks in the parcel.

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