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GEOLOGY AND GEOCHEMISTRY OF SOME QUEENSLAND TERTIARY OIL SHALES

By

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INTRODUCTION

Oil shale was first recognized almost a century ago in Queensland. The flammable rock aroused some interest for a number of years but the first serious attempt to assess the resource did not take place until World War II. Typically, the Queensland Tertiary oil shales are sparsely exposed and deeply weathered. The distribution and extent of the oil shale has to be determined by drilling.

Southern Pacific Petroleum and Central Pacific Minerals commenced exploration for oil shale in 1974 and defined the Rundle deposit in the Narrows Graben (Figure 1). The search has since been extended to other basins which hold the attraction of proximity to infrastructure facilities and population centers along Queensland's central coast. In five deposits under review, the indicated in situ shale oil resource exceeds 17 billion barrels (at a cut off grade of 50 liters/ton).

The drill core is logged for lithology and bulk density, then split and assayed on 2m intervals. From experience with the Queensland shales, an 80 gm charge is used in the Fischer retort. Half drill-core 2 meter intervals provide from 3 to 5 kg. of sample and the assay rejects together with unused core are retained to provide a sample bank for characterization tests carried out on the oil shale seams.

GEOLOGY OF THE DEPOSITS

During the Paleozoic and much of the Mesozoic, the region now represented by eastern coastal Queensland developed by continental accretion to the Australian Shield. The tectonic grain strikes northwest-southeast. Sedimentary basin remnants and uplifts from this earlier period underlie the oil shale deposits.

At the beginning of the Tertiary Period, rifting began to open the Tasman and Coral Seas and relaxation of the former compressive forces resulted in the formation of a number of grabens within the continent, adjacent to the developing ocean to the east. This appears to be the framework in which the thick, essentially lacustrine sequences containing oil shales accumulated in narrow, linear, fault-bounded basins, in some cases with accompanying igneous activity (1).

The Narrows Graben (Figure 2)

The Rundle Formation (580m) contains the oil shale resource in The Narrows Graben preserved in two structurally defined lobes, the Rundle and Stuart deposits (2). The most prospective interval (the upper 320m) comprises 4 seams (Ramsay Crossing, Brick Kiln, Munduran Creek, Kerosene Creek) of predominantly oil shale, one (Humpy Creek) of carbonaceous shale ranging to lignite and one thick unit of barren claystone (Telegraph Creek unit). The average yield is 99 liters per ton at zero moisture (LTOM) for Rundle and 94 LTOM for Stuart. Average moisture is respectively 21 and 19%, and in situ bulk density 1.75 g/cc. The calculated in situ resource in the graben is 5.16 x 10^9 barrels oil.

The oil shales, clay and silt in grain size, range from massive to finely laminated, and range in color through combinations of brown, grey and green with the greenish hue more evident in thin barren interbeds within the seams and in the Telegraph Creek unit. There are dark colored carbonaceous horizons in all seams. Ostracods and gastropods are widespread and fragments of reptiles, fish and crustaceans have been found in drill cores. Sedimentary structures (breccias, color grading, slumping) are prevalent and repeated; recent detailed mapping in a cut opened in the Ramsay Crossing seam to provide bulk samples has revealed cyclic sedimentation over a frequency of a few meters (3). Thin, discontinuous, dense limestone beds and lenses are present throughout the sequence.

The sequence dips to the west from 4 to 10 degrees and both flanks of the deposit are in fault-contact with basement. A localized alkaline intrusive has invaded the lower seams of the

Rundle Formation and thermally metamorphosed (pyrolized) up to 46m thickness of oil shales. Its minimum age of crystallization has been calculated at 26.8 m.y.

Hillsborough Basin

Prospecting for oil shale has been confined to the west flank of the onshore portion of the Hillsborough Basin where volcanolithic quartz arenites and pelite form economic basement, conformably underlying the Condor deposit. The brown oil shale, the main unit of the Condor deposit is a remarkably monotonous, massive (to slightly laminated) brown, kerogenous mudstone. It ranges from 300-400m in thickness and has been traced for 15 km along strike. About half of the seam has an average yield of 63 LTOM and constitutes the main potential economic zone of the deposit (4). Towards its base, the brown oil shale becomes blackish and at the contact with the basal sandstone, a high yielding (135 LTOM) humic coal and carbonaceous shale occur along much of the strike length of the deposit. The indicated in situ resource is 8.45 x 10^9 barrels of shale oil.

Overlying the brown oil shale are thinly interbedded and laminated oil shales and siltstones, a unit transitional to the youngest horizon (upper unit). A uniform and regular dip to the northeast of 14° takes the top of the brown oil shale to a depth of 500m at the downdip limit of prospecting.

The oil shale at Condor is a tougher, more competent rock than the other Tertiary oil shales and also possesses a lower moisture content (9% by weight). The brown oil shale unit contains scattered collophane nodules and buddingtonite occurs persistently in the unit, comprising almost 10% of the rock (5).

Duaringa Basin

In contrast to other deposits, the Tertiary sequence in the Duaringa Basin has positive relief, standing as steep-sided tablelands up to 100m above surrounding low lying-country and is underlain by Permian rocks of the Bowen Basin.

"Fence line" drill holes across the basin revealed that oil shale occurs at two horizons (Units B and D) above the base of the tablelands and although lying subhorizontally and continuous, is relatively thin. The oil shales are soft, moist, greenish grey mudstones. Traces of oil shale also occur deeper (from 250 to 800 meters below the surface) in the basin. A stratigraphic core hole drilled by the Geological Survey of Queensland (Duaringa 1-2R) proved a depth of 1200 meters of Tertiary sediments, mostly bioturbated silty and sandy, mottled, oxidized claystones, underlain by 180m+ of basalt (Noon, pers. comm.). Basalts also occur interbedded with the shallow oil shale layers in the southern end of the basin. A distinctive and ubiquitous sanidine-rich ash bed of centimeters thickness occurs near the base of Unit B.

The resource is estimated to contain 3.72 x 10^9 barrels of shale oil.

Byfield

At Byfield, oil shale is contained in a small graben 2 km wide and about 5 km along the western flank of the Water Park Creek Basin. Two oil shale units (TW2, 4) overlie carbonaceous and pale colored claystones and sandstones (TW1) and are separated by about 120m of kerogen-bearing mudstone (TW3). Unit TW2 is 120 m thick of which 50m has an average grade of 58 LTOM with a low (9.5%) moisture and has superficial similarities to the brown oil shale at Condor. At the top of the sequence Unit TW4 (up to 110m) consists of dark brown to black carbonaceous shale - lignitic coal, with interbedded sandstone and siltstone. The shale oil yield is relatively high (up to 100 LTOM) for the appearance of the rock, but averages 77 LTOM for a net 50m. Some of the assay-produced oils contain a tarry fraction, with S.G. >1.0.

COMPOSITION OF THE OIL SHALES

In their study of Queensland Tertiary alginites (exinite material largely of algal origin), Hutton et al. (6) found that they were able to distinguish between accumulations of discrete algal bodies (typical of high grade oil shales, like torbanite and kukersite) and finely banded, lamellar alginite in intimate association with mineral matter (typical Queensland Tertiary alginites). As a result of the study Hutton et al. proposed the terms "Alginite A" and "Alginite B" (or lamosite) as modifications of conventional oil shale maceral terminology. Green algae were shown to be precursors of alginite A, and blue-green algae the precursor of alginite B. Both alginite forms produce Type I kerogen (7).

The Queensland Tertiary lamosites are high moisture, with an organic carbon content rarely exceeding 20% by weight. Pyrite is usually present in trace quantities. An association of silt and clay sized silica and silicate-rich minerals dominates the inorganic constituents. However, generalizations have to be kept in perspective. For example, assaying of the oil has been consistently carried out over two meter intervals and while over this interval, the organic carbon content may rarely exceed 20%, over centimeters within this interval, the range may vary enormously.

Yet, distinctive grade patterns over multiples of the two meter assay interval commonly persist throughout the preserved areal dimension of a deposit, coincident with other lithologic characters of the rock. Thus, the seam classification at Rundle applies also at Stuart, throughout the 28 km length of The Narrows Graben. Likewise, the 10 and 20 m seams (units D and B) at Duaringa persist over a distance of 130 km in the erosional remnants in that basin; and vertical grade changes through the 300 m thick brown oil shale unit at Condor persist for at least 15 km along strike.

MINERALOGY

The distribution of the major elements (expressed as oxides) in the main oil shale seams in three basins, (The Narrows Graben, Duaringa and Hillsborough Basins) are listed in Table I. The most apparent variations are in the inorganic components of the carbonaceous units (Humpy Creek seam in The Narrows Graben; brown-black oil shale and carbonaceous unit at Condor) when compared to the lamosites. At Condor, the increase in Al_2O_3 at the expense of SiO_2 is very pronounced; whereas in the Humpy Creek seam the distribution is reversed. The other aspect to the Humpy Creek is the relatively higher incidence of Na_2O and lower level of CaO and MgO compared to the rest of the seams in The Narrows Graben. In the lamosites, the values of CaO and MgO are lower in the Duaringa and Condor deposits than in Stuart.

Mineral composition, as determined by X-ray diffraction, shows a dominance of clay minerals, although quartz and opaline silica are persistent as sub-dominant or co-dominant (Table II). The clay minerals are commonly interstratified montmorillonite and illite (in all deposits) with kaolinite or illite appearing as accessory or sub-dominant components. A marked contrast in the dominant clay species occurs between the brown oil shale unit and the two units below it at Condor. In these lower units, kaolinite is in greater abundance than other clays as well as quartz, an aspect already indicated in the variations in Table I.

Feldspar occurs as an accessory or trace mineral in all deposits. At Rundle, Stuart and Duaringa it is a K-feldspar and more rarely, plagioclase, while at Condor it is the unusual ammonium feldspar, buddingtonite (5). The presence of buddingtonite in the Condor sequence coincides with the change from kaolinite to montmorillonite dominance. The feldspars in the deposits may be authigenic. At the base of Unit B oil shale at Duaringa, there is a thin (20± cm), but laterally persistent sanidine - rich marker horizon, considered to be of allogenic origin, probably a volcanic ash.

Apart from recurrent thin limestone beds in The Narrows sequence, carbonates are present in all deposits in only trace or accessory amounts. Siderite occurs in all deposits and is persistent through the sequence at Byfield and Condor, except for the carbonaceous units where its incidence is variable. At Condor, a second, possibly calcian siderite, occurs but only with an identical distribution through the sequence to the buddingtonite. Other evaporites, gypsum, halite and jarosite occur only in trace amounts. The sulfates may be a secondary development. Phosphate mineralization occurs in the transitional and brown oil shale units at Condor; a mineral related to jahnsite (5) and ovoidal collophane nodules up to 5 cm (4). Vivianite is associated with Unit B shale at Duaringa. Barite nodules occur in weathered shale at the surface at Duaringa from about the same horizon in close stratigraphic association with diatomite recorded in that sequence.

Trace element analysis by emission spectroscopy on pyrolized shale has not revealed any concentration of metals in anomalous or unusual amounts even though the provenance for the different basins ranges from sedimentary, through igneous and metamorphic sequences.

KEROGENS

In the course of characterization work, a number of kerogen samples have been isolated from different seams in the various deposits. Their elemental composition (on a mineral free basis) has been incorporated into Table III and atomic ratios plotted on the Van Krevelen diagram, Figure 3. The diagram demonstrates the persistence of Type I kerogen in the lamosites from the Queensland Tertiary deposits. Two of the five kerogens from the Condor brown oil shale show unusually high O/C atomic ratios. The other kerogens from this unit appear to be intermediate between Type I and II.

The Carbonaceous units (Condor, Byfield and Humpy Creek seam at Rundle and Stuart) characteristically fall into Type III kerogens implying a lower algal content or the presence of higher plant material. Higher rank for the Condor Type III is apparent. Maturation due to greater burial might also be assumed for the position in the diagram of Type I Condor and for the older kerogens (Ramsay Crossing and Brick Kiln) in The Narrows Graben.

Elemental analyses together with hydrogen/carbon and oxygen/carbon ratios for shale oils have been listed in Table III. The table shows where analyses have been performed on kerogen and derived shale oil, that the hydrocarbon content and the H/C atomic ratio of the oil are higher than for the parent kerogen.

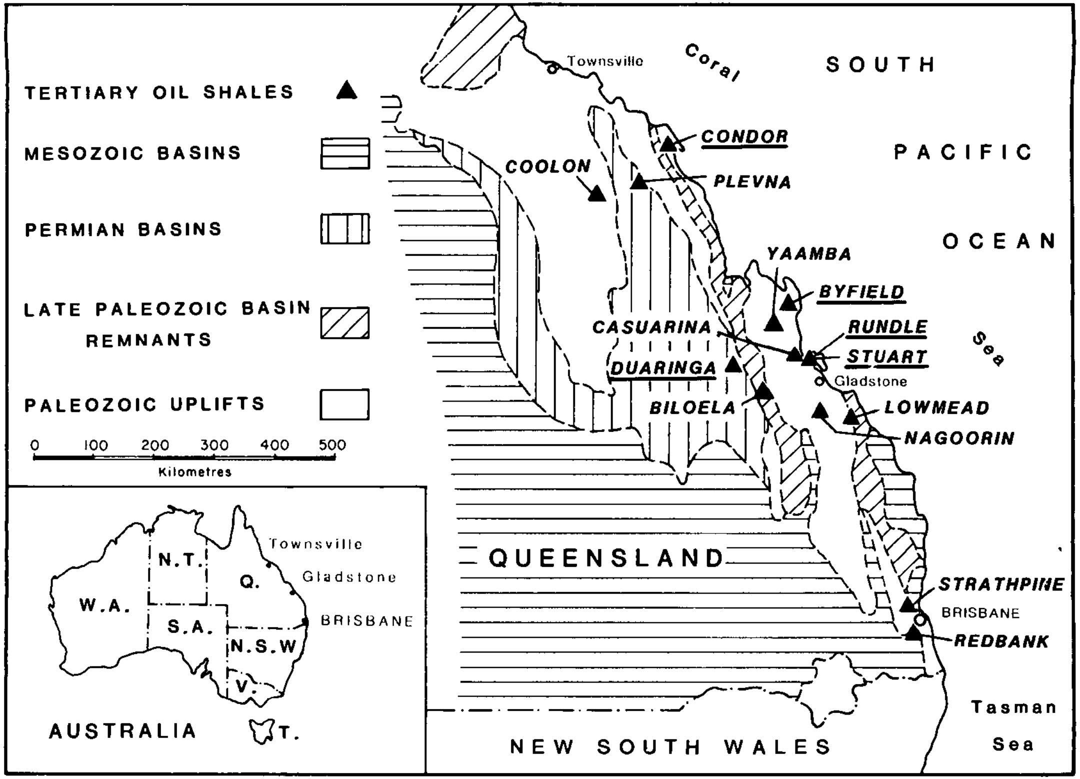

Figure 1. Location of Tertiary oil shale deposits, eastern Queensland.

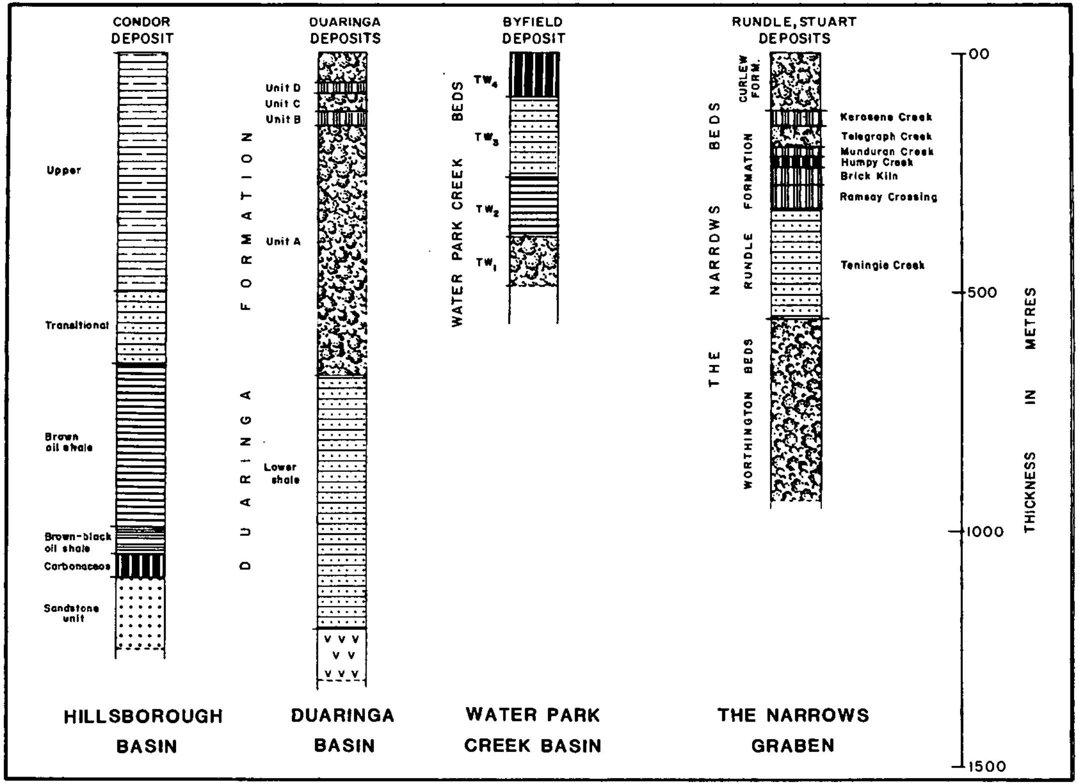

Figure 2. Diagrammatic columnar sections showing oil shales in four basins.

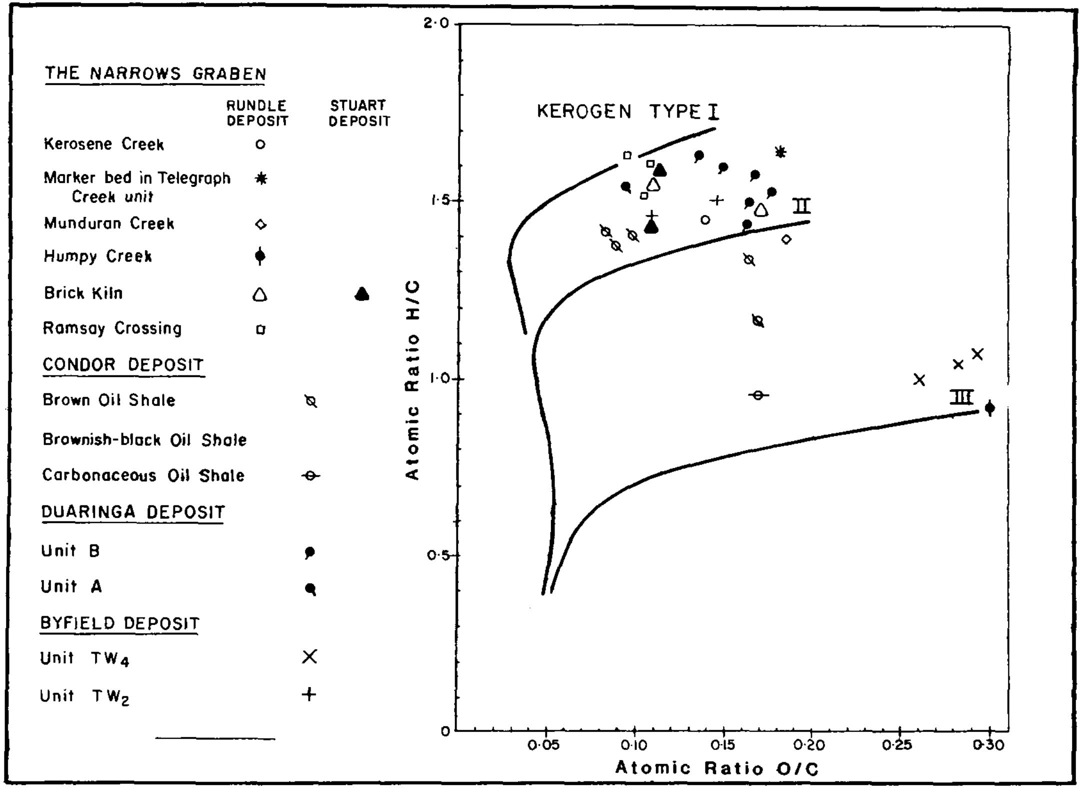

Figure 3. **Van Krevelen diagram of some Queensland Tertiary kerogens.**

TABLE I

MAJOR ELEMENTS AS OXIDES

Deposit	Seam	Rock Type[a]	No. of Analyses	SiO_2	TiO_2	Al_2O_3	Total Fe as FeO_3	Mno	MgO	CaO	NaO_2	K_2O	P_2O_5	Range of Yields by mFA[b] (LTOM)	Av. Moisture[c] W+%
Stuart	Kerosene Ck.	O.S	4	63.4	0.6	16.3	9.1	0.2	2.4	5.8	0.8	2.2	0.4	45-230	22
	Munduran Ck.	O.S	3	61.8	0.7	16.6	8.7	0.2	2.3	6.3	1.2	2.2	0.3	109-202	18
	Humpy Ck.	C/C.S	3	66.8	0.6	12.1	6.6	0.1	1.5	2.5	2.0	0.9	0.1	81-112	24
	Brick Kiln	O.S	14	61.9	0.8	16.5	9.8	0.2	2.6	6.1	1.2	1.6	0.3	44-193	18
	Ramsay Crossing	O.S	9	62.2	0.8	16.0	9.3	0.2	2.9	5.3	1.0	1.9	0.2	25-179	17
	Teningie Ck.	L.O.S	3	66.7	1.0	18.6	7.0	0.1	2.0	3.5	0.9	1.7	0.3	33-43	N.A.
Duaringa	Unit B	L,M,H,O.S	3	66.2	0.8	19.0	8.6	0.3	1.3	0.6	0.6	2.3	0.3	27,57,119	24-33
Condor	Brown oil shale	O.S	18	68.3	0.9	17.1	8.9	0.1	1.4	0.8	0.5	1.0	0.3	25-104	8
	Brown-black oil shale	L.O.S	3	59.1	1.3	25.2	11.7	0.2	1.6	1.1	0.5	1.4	0.3	22-46	9
	Carbonaceous unit	C/C.S	4	58.2	1.4	30.3	5.0	<0.03	1.0	0.7	0.5	1.42	0.2	48-106	155

a. O.S. - Oil shale
C/C.S - Coal, carbonaceous shale
L,M,H,O.S - Low, medium, highgrade oil shale

Analyses are reported on a dry total ash basis. b) Range of oil yields and c) average moisture are included for an appreciation of the organic and volatile components of the various oil shales. Moisture value includes free and combined water. Oil yield is expressed as liters per ton of oil shale on a dry (zero moisture) basis (LTOM).

TABLE II

MINERAL COMPOSITION OF OIL SHALE SEAMS IN THE STUART, DUARINGA, BYFIELD AND CONDOR DEPOSITS

Deposit	Seam	Rock Type	m. FA (LTOM)	Amorphous Material	Quartz	Opaline Silica	Montmorillonite Inter stratified Illite	MICA/Illite	Kaolinite	Feldspar	Buddingtonite	Siderite	Calcian Siderite	Calcite	Calcite (substituted Mg.)	Pyrite	Gypsum	Jarosite	Alunite	Halite	Anatase
Stuart	Kerosene Ck.	O.S.	45-230		xx/xxxx	xx/xxxx	xxxxx	xx	xx	x/xx		x		xx		x/xx	x	x/xx		x	
	Munduran Ck.	O.S.	109-204		xx/xxx	xxx/xxxx	xxxxx	xx	xx	x/xx		xx		xx	xx	x/xx	x				
		CL/O.S.	33-47		xx	xx/xxx	xxxxx	x/xx	xx	x		xx			xx/xxx	x	x				
	Humpy Ck.	C.O.S.	81-112	xxx	xx/xxxxx		xxx/xxxxx		xx	x						x	x/xx			x/xx	
	Brick Kiln	O.S.	50-193		xx	xx	xxxxx	x/xx	xx	x/xx		xx		xx/xxx		x			x		
	Ramsay Crossing	O.S.	25-179		xx/xxx		xxxxx	x/xx	xx/xxx	x/xx		x/xx		xx/xxx	x	x			x		x
Duaringa	Unit D	O.S.	29-62		xx/xxx		xxx		xxx	x		x				x	x				x
	Unit B	CL/O.S.	5-20		xxx/xxxxx	xxxxx	xx/xxxx	xx	xxx/xxxx	x		xx									x
		O.S.	22-148		xx/xxx	xxx/xxxxx	xxxx/xxxxx	xx	xx/xxx	x		x/xx				x	x				x
	Unit A	O.S.	~90		xxxxx		xxxx	xxx								x					
Byfield	Unit TW4	C.O.S.	~80		xxxxx		xxxx	xxx													
	Unit TW2	O.S.	~80		xxxxx		xxx	xx				xxxx				x					
Condor	B.O.S.	O.S.	25-104		xxxxx		xxx		xx		xx x	xx	xx			x					
	B/B.O.S.	O.S.	29-46		xx/xxx		xxx		xxxxx			xx									
		C.O.S.			xx		xx/xxx		xxxxx			xx		x?		x?					

Reference: - O.S. - Oil Shale C.O.S. - Carbonaceous Oil Shale CL - Claystone
+++++ Dominant, ++++ Co-dominant, +++ Sub-dominant (>20%), ++ Accessory (5-20%), + Trace (<5%).

TABLE III

ELEMENTAL ANALYSES, KEROGENS AND SHALE OILS; ATOMIC RATIOS H/C, O/C.

Deposit	Unit	Location	Fischer Assay Yield (LTOM)		Elemental Analysis (K=kerogen; O=oil) C	H	N	O	S	Atomic Ratio H/C	O/C
Rundle	Kerosene Ck.	Auger sample	High grade	K	74.4	9.0	2.0	13.7	0.9	1.45	0.138
	O.S. Marker in Telegraph Ck.	RDD31 25m	Low grade (<40)	K	71.8	9.9	1.3	14.9	2.1	1.64	0.156
	Munduran Ck.	RDD31 110.5m	High grade	K	70.9	8.3	1.9	17.4	1.5	1.40	0.184
	Humpy Ck.	RDD43 80.5m	Medium grade	K	64.9	4.9	3.1	25.9	1.1	0.91	0.300
	Brick Kiln	RDD31 161.0m	High grade	K	73.4	9.1	1.1	15.1	1.3	1.48	0.154
	Brick Kiln	RDD25 111.0m	High grade	K	75.5	9.7	2.0	11.0	1.8	1.54	0.109
	Ramsay Crossing	RDD41 67.5m	High grade	K	76.6	10.3	0.7	10.9	1.5	1.61	0.107
		RDD41 85.0m	High grade	K	77.6	10.6	1.0	9.6	1.2	1.63	0.093
		RDD41 99.2m	High grade	K	77.0	9.8	1.5	10.5	1.2	1.52	0.102
Stuart	Brick Kiln	SDD51 50- 52m	193	K	74.7	9.9	1.7	11.6	0.2	1.59	0.116
				O	85.4	12.8	0.9	0.7	0.2	1.80	0.006
		SDD51 62- 64m	76	K	72.3	8.6	1.2	17.8	0.3	1.43	0.118
				O	84.7	13.0	1.0	0.9	0.4	1.84	0.008
Byfield	TW_4	BYD1 68- 70m	98	K	66.8	5.8	2.2	25.2	0.5	1.05	0.283
		BYD1 84- 86m	83	K	67.9	5.7	2.1	23.5	0.8	1.00	0.260
		BYD1 84- 86m	83	K	65.6	5.8	2.3	25.6	0.5	1.07	0.292
				O	82.0	10.8	1.0	5.6	0.6	1.58	0.051
		224-226m	Average grade	K	75.3	9.1	2.2	11.9	1.5	1.44	0.119
		BYD1 290-292m	73	K	72.5	9.2	2.2	14.0	?	1.52	0.144
				O	84.7	11.8	1.2	1.7	0.6	1.67	0.015
Duaringa	B	DD10 66- 68m	64	K	71.6	9.5	1.4	14.2	1.4	1.60	0.149
				K	60.6	7.7	1.0	14.2	4.8	1.53	0.176
				O	85.9	11.6	1.3	1.4	0.5	1.62	0.012
		DD10 74- 76m	130	K	71.3	9.4	1.0	15.5	1.4	1.58	0.166
				K	69.1	9.4	1.2	12.3	3.8	1.63	0.133
				O	85.1	12.1	1.1	1.3	0.4	1.71	0.011
		DD52 92- 94m	26	K	68.8	8.6	1.3	14.9	1.2	1.50	0.163
				K	50.4	6.1	1.3	11.1	5.9	1.44	0.165
				O	86.1	11.3	0.9	1.5	0.6	1.57	0.013
		DD6 247.4m	Medium grade	K	78.3	10.0	1.7	9.5	0.5	1.54	0.091
Condor	Brown Oil Shale	Auger sample	65-77	K	77.5	9.1	2.3	8.3	2.5	1.41	0.081
		CDD1 380.1m	Average grade	K	72.9	9.0	2.8	9.1	0.4	1.38	0.087
		CDD6 352-354m	66	K	70.0	8.2	1.9	9.4	4.2	1.41	0.101
		CDD11 106-108m	82	K	70.2	7.9	1.9	15.1	5.1	1.34	0.161
		CDD11 68- 70m	62	K	68.9	6.7	2.7	15.4	6.6	1.17	0.168
	Carbonaceous	CDD26 308-310m	75	K	72.4	5.7	2.9	16.1	1.4	0.95	0.169
Stuart	Brick Kiln	SDD51 36- 38m	172	O	85.8	12.3	0.8	0.7	0.4	1.72	0.006
		92- 94m	75	O	85.3	12.6	1.1	0.5	0.5	1.77	0.004
		134-136m	38	O	85.6	12.3	1.2	0.3	0.5	1.73	0.003
Duaringa	B	27 Oils	Range 20-130	O	83.8	11.8	1.1	3.2	0.5	1.69	0.028
Condor	Brown Oil Shale	18 samples		O	85.3	12.1	1.5	1.0	0.5	1.70	0.009
	Brown black Shale	3		O	83.7	11.2	1.4	2.6	0.6	1.61	0.023
	Carbonaceous	3		O	84.0	10.5	1.4	5.2	0.6	1.50	0.047

This is consistent with the oils being derived primarily from the algal component of the oil shales. The oils derived from the carbonaceous units differ from those derived from lamosites. The carbonaceous units yield oil with a higher heteroatom component, indicating presence of vitrinite or kerogen sourced from higher forms of plant life. The higher aromatic or unsaturates content in oils from carbonaceous units is also supported by a lower oil yield per unit kerogen content as observed by Eckstrom et al. (8).

DEPOSITIONAL ENVIRONMENT

All Tertiary sedimentary basins considered contain a substantial proportion by volume of clastic rocks devoid of organic content. Such units typically contain bioturbated, sandy and silty claystones with reddish and brownish coloring. At Duaringa these units are interbedded with oil shales. In the other deposits, low grade or barren interbeds do not display oxidation colors. It seems that once the conditions supporting growth of plant organisms was established, the regime continued, although variation took place in the amount and type of vegetal matter contributed and preserved in the accumulating deposits. Such variations occur with greater frequency in The Narrows Graben (as shown by numerous carbonaceous horizons interbedded in the lamosite sequence) and cyclicity in this sequence has already been referred to. At Condor, once the lignin-like material was supplemented by the lamellar alginite dominant in the brown oil shale, conditions remained relatively unchanged until several hundred meters of sediment accumulated.

While the evidence (fossils, sediment type, stratification) supports a lacustrine environment for all the deposits, the monotonous sequence at Condor is unique. At Condor, a stratified lake system similar to that proposed by Smith and Lee (9) for density stratification in the Piceance Creek Basin may have developed.

There may be a combination of circumstances in the Queensland Tertiary lakes (sedimentation rate, supply and range of organic matter, water depth, etc.) from which a regional model can be deduced. The relationship of time, climate, provenance and preservation of this energy resource is a topic for much further study and research.

ACKNOWLEDGMENTS

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