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THE LOWER CRETACEOUS SPARKY FORMATION, LLOYDMINSTER AREA: STRATIGRAPHY AND PALEOENVIRONMENT

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ABSTRACT

The Sparky Formation of the Lower Cretaceous Mannville Group is the major oil producing formation in the Lloydminster heavy oil area (Twp 44-52, Rge. 25-28W3, 1-7W4). The depositional environment has not been well understood although several depositional models have been suggested in the past. This paper briefly reviews the literature and stratigraphy of the Sparky Formation and proposes a depositional model based upon extensive geophysical log and core studies in the area. The cores selected are from the Aberfeldy, Blackfoot and Wainwright fields.

The Sparky Formation in the Lloydminster area is interpreted to be a northeastward prograding, wave-dominated deltaic system. Shale-filled channels developed in this deltaic system commonly act as an important trapping mechanism; sand-filled channels locally form potentially thick reservoirs. The thick sand reservoirs are probably related to tidal inlet deposition.

INTRODUCTION

Forty to sixty billion barrels of oil in place (McCrossan et al., 1979, and Christopher Knudsen, 1979) have been estimated to occur within the Mannville Group of the Lloydminster heavy oil area (Alberta and Saskatchewan). The Sparky Formation contains up to 60 percent of the oil in place (Orr et al., 1977). The study area, which includes most of the Lloydminster heavy oil fields, (Fig. 1) encloses Twps. 44 - 52, Rges. 25 - 28W3M and Rges. 1 - 7W4M. Major Sparky oil accumulations are the Wainwright, Blackfoot, Epping and Aberfeldy fields.

This paper outlines the major regional depositional characteristics of the Sparky Formation. All wells in the study area were reviewed to categorize them into facies based upon the log signature of the Sparky Formation. Detailed core and log studies of Wainwright, Blackfoot and Aberfeldy fields have contribute significant data to this study. Previous stratigraphy and depositional models for the Sparky Formation are reviewed briefly and a revised depositional model is proposed.

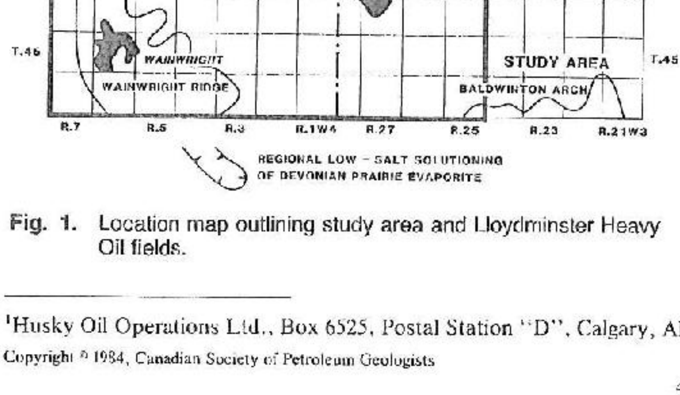

Fig. 1. Location map outlining study area and Lloydminster Heavy Oil fields.

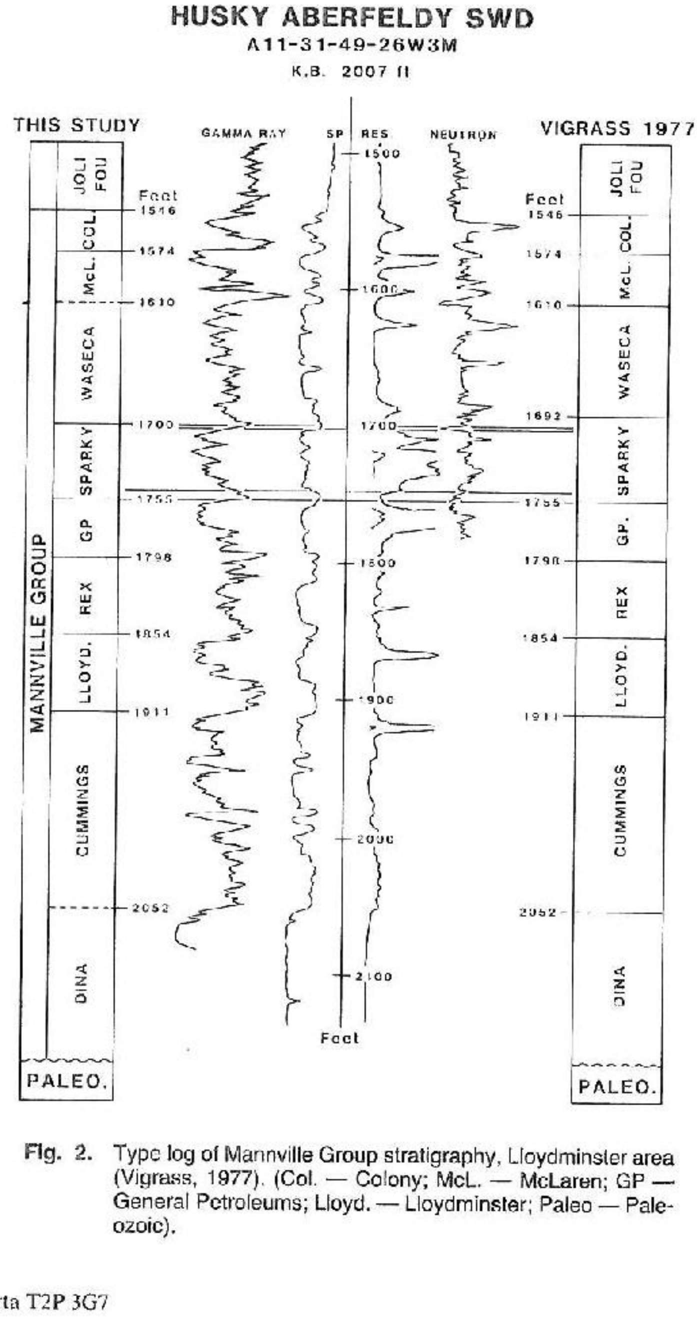

Fig. 2. Type log of Mannville Group stratigraphy, Lloydminster area (Vigrass, 1977). (Col. — Colony; McL. — McLaren; GP — General Petroleums; Lloyd. — Lloydminster; Paleo — Paleozoic).

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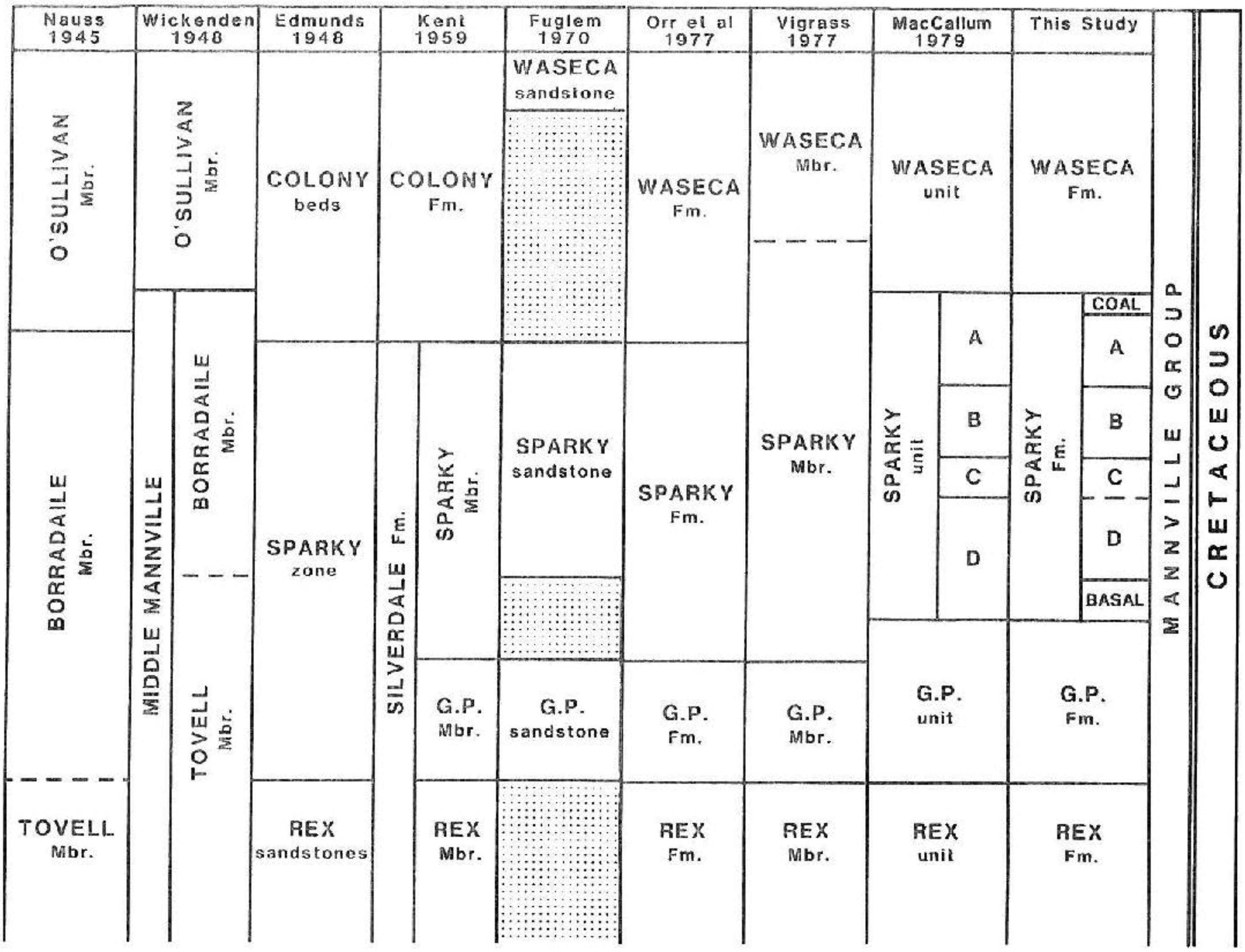

Fig. 3. Summary of previous Sparky Stratigraphic Nomenclature. (G.P. — General Petroleums).

Stratigraphy

The Mannville Group in the Lloydminster area is characterized by a series of sand-shale cycles with coal beds capping some cycles, and is lithologically different from the Mannville sequence in central Alberta. Marker beds within the Lloydminster area cannot be extended outside the region with any certainty. To the west and southwest, the sand units are not as easily correlatable. The Mannville Group in central Alberta is dominated by coal and shale beds. To date, correlation of the Lloydminster type Mannville stratigraphy outside of the Lloydminster heavy oil area has been problematic.

The most commonly used stratigraphic nomenclature in the Lloydminster heavy oil area was published by Vigrass (1977; Fig. 2) and Orr et al. (1977). Their stratigraphic subdivisions and names are the same except that Vigrass calls the units members, whereas Orr et al. refers to them as formations. The present authors believe that the Mannville Group can be subdivided into nine regionally mappable units, and thus will refer to the units as formations.

The current Mannville stratigraphic nomenclature was based upon early driller terminology and was summarized by Edmunds (1948). Generally, the early workers (Fig. 3; Nauss, 1945; Wickenden, 1948; Edmunds, 1948; Ambler, 1950; Kent, 1959; Fuglem, 1970; Orr et al., 1977) correlated the top of the formation boundaries as being at the top of the sands. Nauss (1945) and Wickenden's (1948) stratigraphic nomenclature, which was based upon earlier drilling in the Vermilion area, was never generally accepted around Lloydminster. MacCallum (1979) was the first to introduce correlations using coal and shale marker beds. These marker beds can be traced over long distances in the study area and are assumed to represent time stratigraphic markers.

The type log for the Mannville section (Vigrass, 1977) was taken from Husky Aberfeldy SWD A11-31-49-26W3M in the Aberfeldy field (Figs. 2 and 4). A regionally exten-

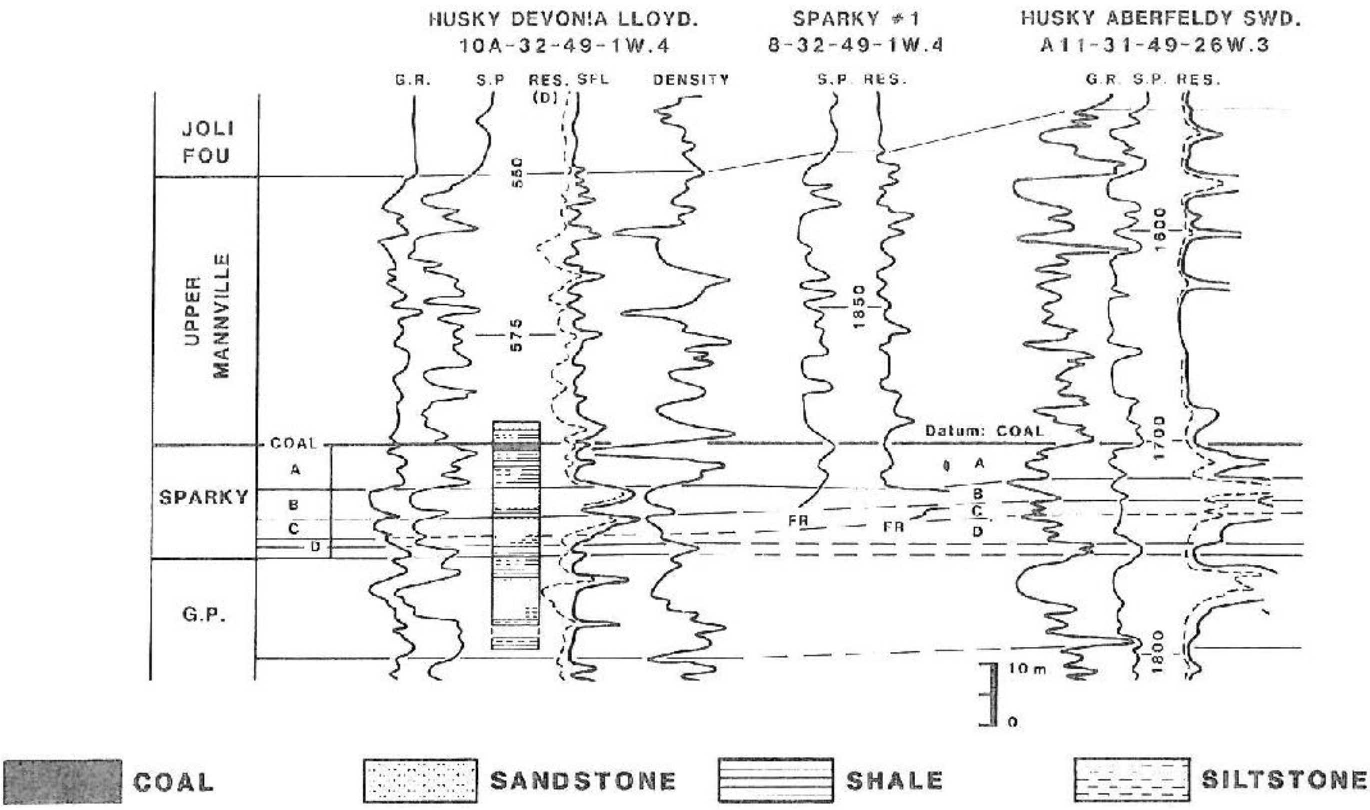

Fig. 4. Comparison between Vigrass (1977) type well with the Sparky discovery well (Sparky #1) in the Blackfoot area (Devonia Lake field) and a nearby Sparky cored well in the Devonia Lake field.

sive shale is taken as the base of the Sparky Formation, whereas the top is defined by a laterally extensive coal that caps the sand-shale sequence (MacCallum, 1979). A cased hole Neutron-Gamma Ray log run on this well shows the Sparky coal to be slightly below where Vigrass (op. cit.) had picked the top of the Sparky (Fig. 2). This log was not available to him during his study.

The Sparky Formation can be divided into informal sub-units, in descending order: Coal, A, B, C, D and Basal (MacCallum, 1979). These sub-units definitely can be correlated within some pools and also seem to be correlatable over long distances. However, whether the correlation of these sub-units actually represents time stratigraphic markers, is still a matter of debate.

Facies Description

Introduction

The Sparky Formation can be grouped into two major facies based mainly upon well log signature (Spontaneous Potential and/or Gamma Ray) and substantiated by cores: i) Regional facies and ii) Channel facies (Fig. 5)

Well logs have been used to differentiate channel facies from the regional facies. However, log interpretation in the study area is difficult owing to the preponderance of earlier, less definitive electric logs. Modern logs (Porosity and Gamma Ray logs) usually are common along the fringes of the fields and in enhanced oil recovery (EOR) pilots. In addition, cores are sparse and are concentrated mainly in EOR pilots. Cores tend to deteriorate rapidly in storage due to the unconsolidated nature of the sands, making them of limited use within a few years.

Where the regional facies of the Sparky Formation occurs, the formation is composed of the Sparky Coal, A, B, C, D and Basal sub-units (Figs. 6 and 7). Generally the A, B, C and D sub-units represent coarsening upward cycles of interbedded silty shale and sand grading into coarser grained sand. The sands within the sub-units display a sheet-like character. However, in some areas one or more sub-units and/or the underlying formations may grade into shales. This can be interpreted as either a local lateral change of lithology within the regional facies or a major change to the channel facies. A local facies change is interpreted if the shale-outs occur strictly within the Sparky Formation.

Areas where the marker beds subdividing the Sparky Formation and the upper part of the GP Formation are absent are interpreted as the Sparky channel facies. The Sparky and GP Formations are two different genetic units and the absence of the upper marker bed of the GP Formation indicates that it must have been removed by erosion.

A southwest-northeast stratigraphic cross-section in the Devonia Lake field (Figs. 6 and 8) illustrates some charac-

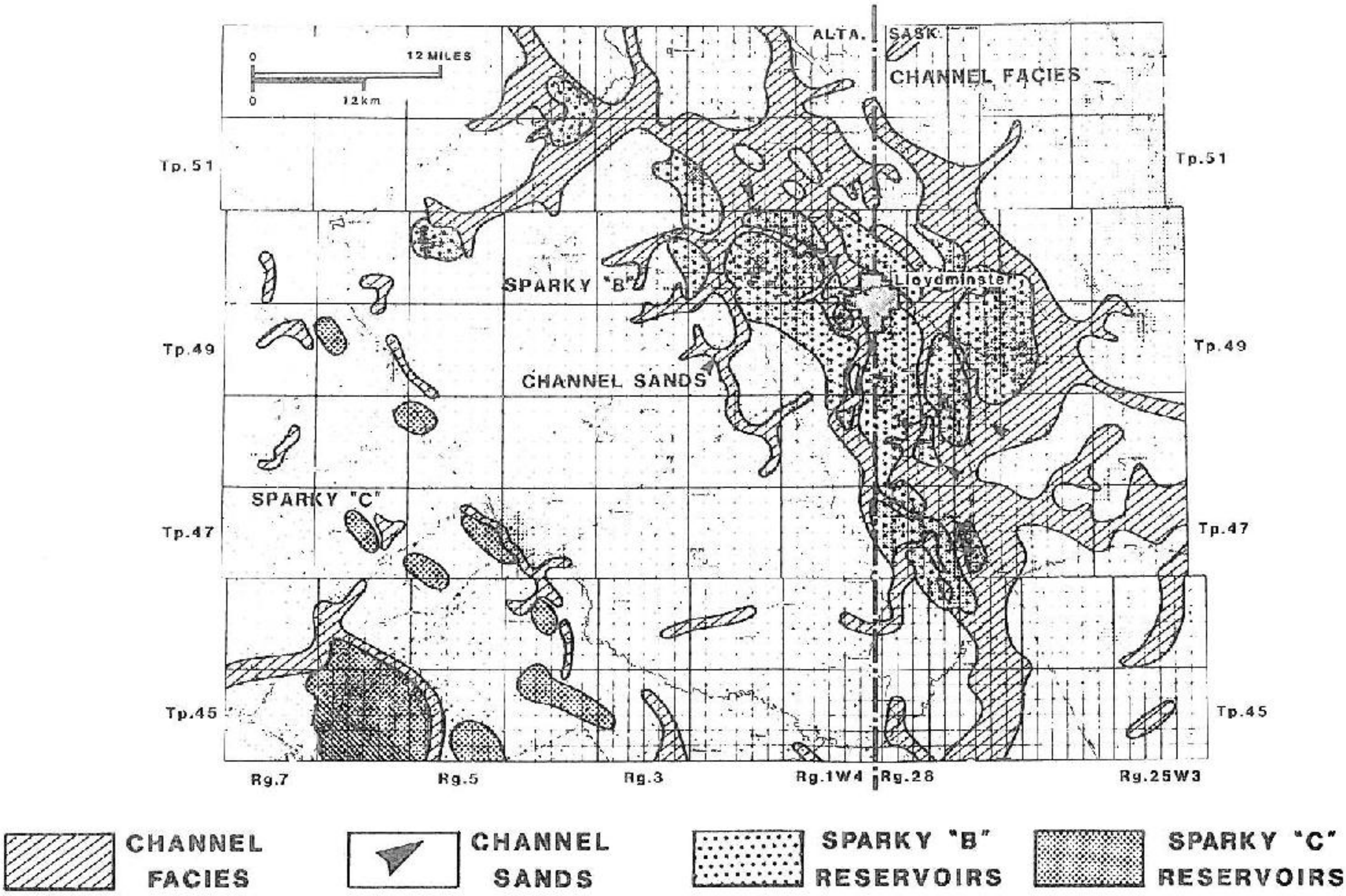

Fig. 5. Outline of Sparky channels and Sparky B and C reservoirs.

teristics of the regional facies sands and their relationship to the channel facies. The C and D sub-units are difficult to differentiate so they have been grouped together. The A, B, and C sub-units are correlatable throughout the area.

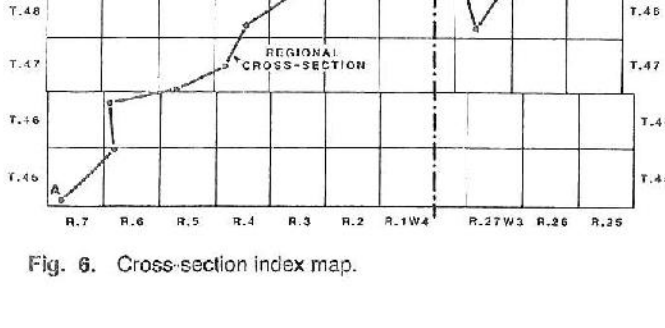

Fig. 6. Cross-section index map.

Special features to note are the absence of the reservoir sands in the A sub-unit and the thinning or shale-out of the B sand towards the southwest. Towards the northeast, a shale-filled Sparky channel facies was eroded into the Rex Formation. The Sparky Coal is continuous across the area and overlies the channel facies.

Later erosion by upper Mannville channelling has removed part of the Sparky sequence in some areas but the channel facies discussed in this paper are genetically related to the Sparky regional facies. A genetic relationship is suggested for the following reasons:

(1) The Sparky Coal commonly overlies the channel facies.

(2) The Sparky sands appear to become shalier and siltier in proximity to the channel facies. Maccagno and Watson (1980) show a sand isolith map for the Sparky Formation at Aberfeldy which indicates thinning of the sands adjacent to a shale-filled channel facies. Cores from C11-21-49-26W3M (Aberfeldy) which is adjacent to the channel facies, indicate bioturbated silty sands throughout the Sparky Formation.

(3) In some areas, such as Devonia Lake, (10A-16-49-1W4M), the channel facies originates below the Sparky B sub-unit and extends down into the GP Formation.

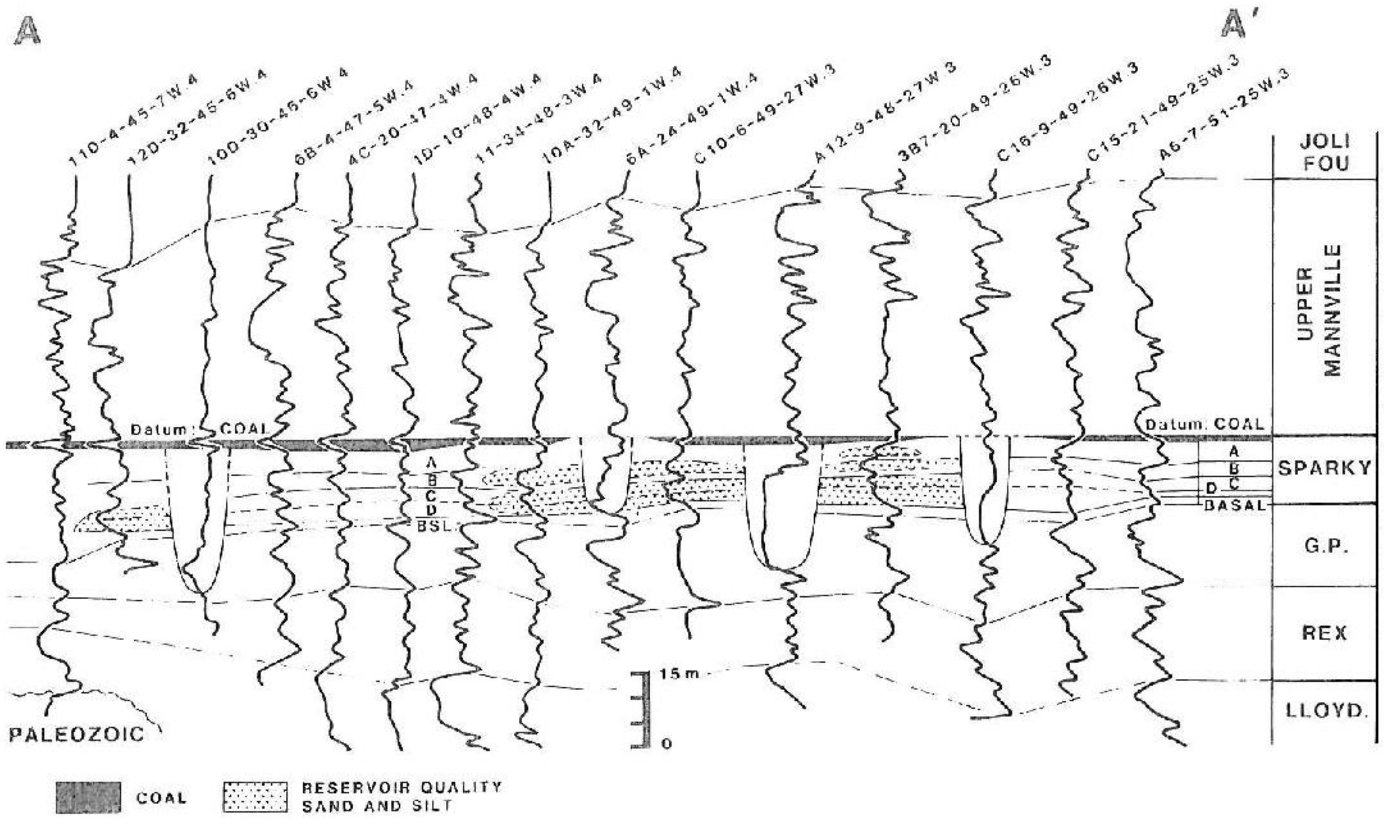

Fig. 7. Regional stratigraphic gamma ray cross-section A-A'.

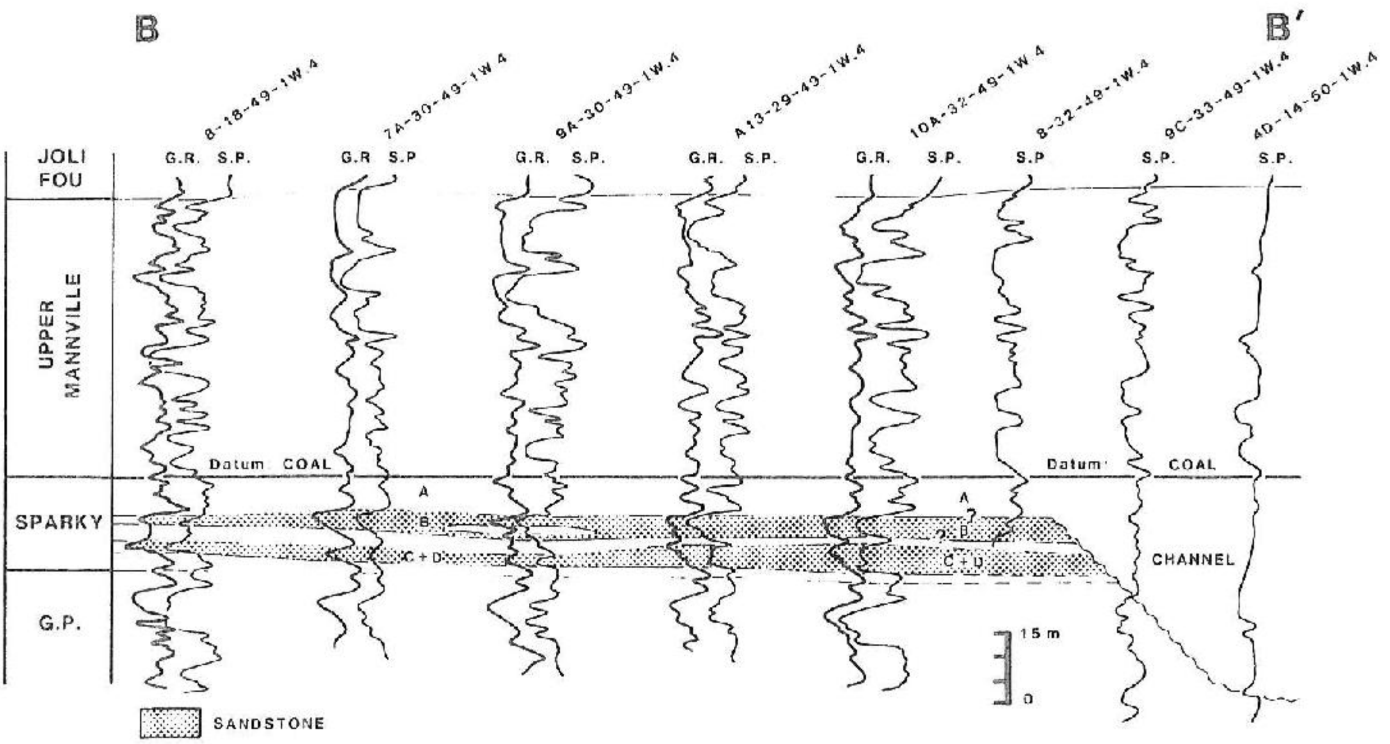

Fig. 8. SP and gamma ray stratigraphic cross-section B-B' in the Devonia Lake field, illustrating the relationship between the regional facies and the channel facies.

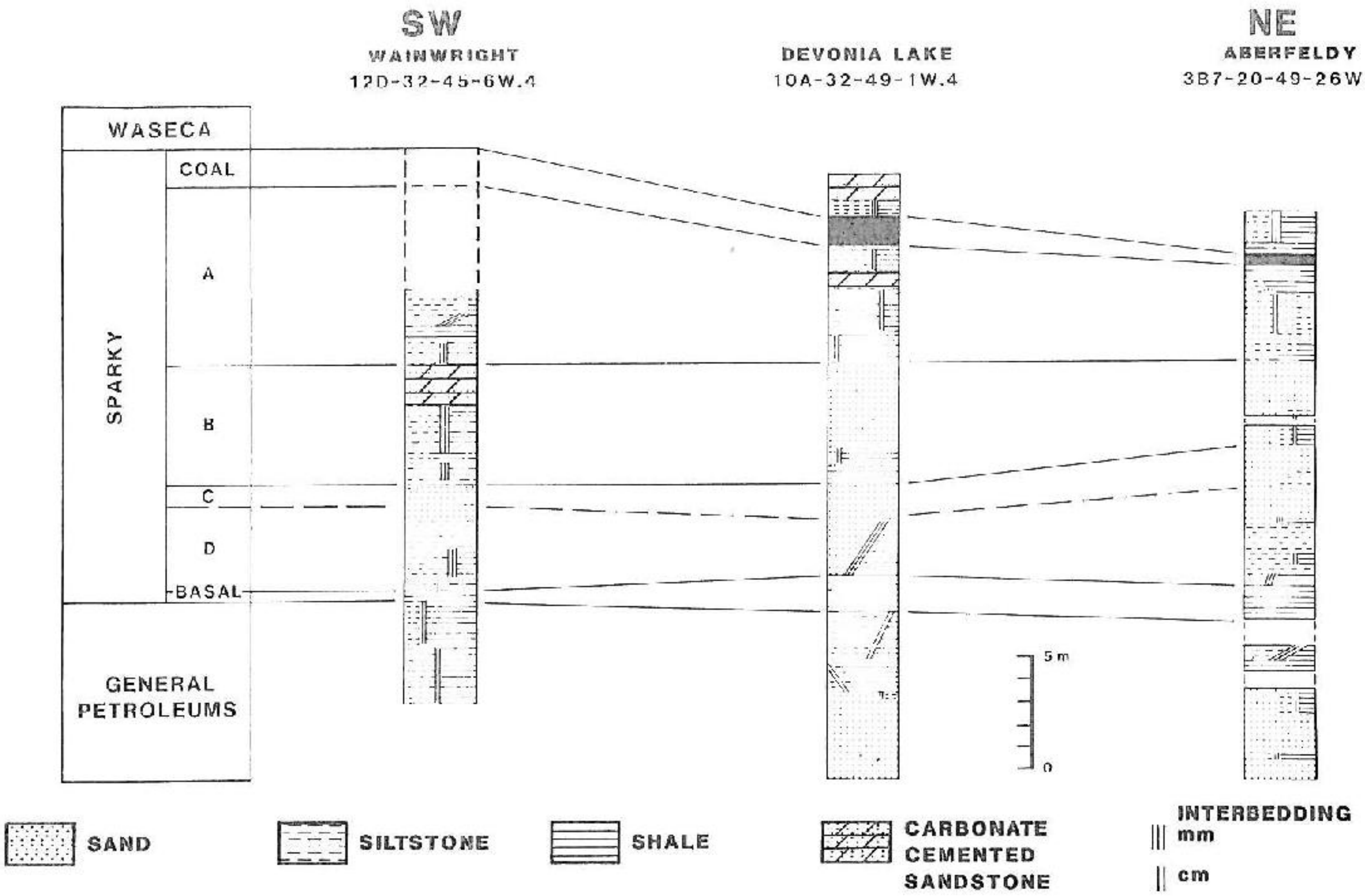

Fig. 9. Representative cores from the Wainwright, Devonia Lake and Aberfeldy fields, illustrating regional facies variations northeastward across the Lloydminster area.

The laterally continuous regional facies has been truncated by the genetically related Sparky channel facies (Fig. 7). Putnam (1982) described the middle Mannville as comprising sheet sandstones and ribbon deposits. The ribbon deposits of Putnam are analogous to our channel facies; his sheet sandstones are similar to the sands of the regional facies.

Regional Facies

Lithological Description

Oil from the Sparky Formation is produced mainly from the sands of the regional facies. Representative cores from three major oil producing fields (Wainwright, Blackfoot and Aberfeldy) in the Lloydminster area are used to illustrate the characteristics of sand bodies in the regional facies (Fig. 9). A coarsening-upward cycle starts with interbedded silty shale and sand at the base and grades upward into coarser grained and better sorted sands. The contact with the underlying sub-unit is sharp and commonly undulatory. The uppermost sub-unit A is capped by a regionally extensive coal. Locally, a coal bed can occur at the base of the A sub-unit.

The Sparky reservoir sands are dominantly very fine to fine grained, well sorted and quartzose, and commonly exhibit low angle and parallel laminations. Interestingly, some of the Sparky reservoirs actually consist of well to very well sorted siltstone. This is particularly true at Wainwright for the lower two-thirds of the reservoir and in the lower sub-units at Devonia Lake and Aberfeldy. Bioturbation and wave ripples are observed but are more common in the sub-units C and in particular, D. High angle laminations, interpreted as tabular cross-bedding, have also been recognized in sub-unit B. Glauconite is present in minor amounts.

The interbedded silty shale and sand at the base of the sub-units can be either wavy-bedded or highly bioturbated. Wave ripples and plant debris along laminae have been recognized. Vertical corkscrew type burrows, *Gyrolythos* (G. Pemberton, pers. comm.), are common in the silty shales, especially in the lower sub-units, C and D. Both the sands and shales are quartz dominant; the sands being very fine grained and moderately sorted.

Regional Facies Distribution

In some areas correlation of these sub-units is problematic. Correlation problems arise when either:

1) a sand directly overlies the underlying sand sub-unit, therefore non-deposition or erosion of the basal interbedded silty shale and sand occurred (Smith, this volume); or

2) a sand pinches out laterally such that the interbedded silty shale and sand may thicken and coalesce with the interbedded zone of the overlying sub-unit (Smith, this volume).

The schematic core cross-section (Fig. 9) from Wainwright to Devonia Lake to Aberfeldy, which is roughly perpendicular to the reservoir sand orientation, illustrates the general development of the reservoir sands up-section in a northeastward direction. In the Wainwright field, the Sparky C and D sub-units are the primary producing zones. In the Devonia Lake Field, the Sparky B, C and D sub-units are the primary reservoirs, whereas at Aberfeldy the reservoir sands occur in all four sub-units (A, B, C and D). The Sparky B sub-unit is considered to be the best quality reservoir sand and most of the oil is produced from this zone in the Devonia Lake and Aberfeldy fields.

At Devonia Lake carbonaceous, silty shale and carbonate cemented sand occur at the same stratigraphic position as the reservoir sands of sub-unit A at Aberfeldy. Similarly, at Wainwright carbonaceous silty shale and carbonate cemented sand of sub-unit B lie at the same stratigraphic position of the Sparky B reservoir sands at Devonia Lake and Aberfeldy. This suggests a northeast progradation of the Sparky Formation which is also indicated by the following data:

(a) Whereas the Sparky Formation has a relatively constant thickness throughout the study area, the interval from the Sparky Coal to the top of the reservoir sand generally decreases in thickness northeastward from Wainwright to Aberfeldy (Figs. 6, 7 and 9), where the Sparky reservoir sands are the thickest. Towards the Tangleflags field the sands become thinner and more shaly. The replacement of carbonaceous silty shale and carbonate cemented sands by quartzose reservoir sands (and silts) in the upper part of the Sparky Formation towards the northeast (Fig. 9.) suggests lagoonal deposition contemporaneous with the barrier island sands of the Aberfeldy-Devonia Lake area.

(b) The Sparky Coal, interpreted as marsh deposits, generally thickens around the Wainwright area in the southwest, thins towards the east and finally disappears northeastward outside of the study area, in the Celtic-Westhazel area (Young, 1984).

Channel Facies

The channel facies can vary from being shale-filled to sand-filled. Similar Mannville channels have been recognized and are discussed in detail by Gross (1980).

The well log signature (Gamma Ray and Spontaneous Potential) in the channel facies of the Sparky Formation varies from:

(1) uniform deflection to the right (shale-filled); to (2) bell shape curve (fining upwards sequence); to (3) blocky (sand-filled).

The Gamma Ray log is the more reliable indicator of lithology because the Spontaneous Potential curve is influenced by formation fluids and permeability.

Shale-filled channel facies are the most prominent type and act as the trapping mechanism for many of the heavy oil fields (Vigrass, 1977). Sand-filled channel facies and channel facies exhibiting a fining upwards sequence are present in a few places. Wells with sand-filled channel facies that have been recognized to date are indicated in Figure 5 by arrows.

In length the channel facies extend for tens of kilometers but do not exceed 100 km, whereas the width varies from 0.3 km to 2 km. The channel facies generally form wedge shaped bodies that thicken towards the northeast. They range generally from 10 to 30 m thick but can be locally up to 50 m.

A schematic cross-section within one of these channel facies (Fig. 10) illustrates some of the variations in a sand-filled portion. Cores from the 3A-2 well (Home Oil's EOR project at Kitscoty) indicate it is a good example of a thick channel facies sand. The wells to the right of the 3A-2 well illustrate the thinning of the channel facies towards the southwest.

The distribution of the channel facies, the major channel sands, and the principal reservoir sands and silts for sub-units B and C are illustrated in Figure 5. Thick channel facies sands have only been identified in a few areas and correspond to the area where the B sand of the regional facies is an excellent reservoir and also to where the channel facies is the thickest.

The map (Fig. 5) shows that the channel facies occurs in two areas:

(1) The largest concentration of the channel facies is in the central portion of the study area (southeast and northwest of the town of Lloydminster); (2) the second area occurs in the vicinity of the Wainwright field.

In the central portion of the study area the oilfields are elongated in a northwest to southeast direction and are repeatedly truncated by the channel facies. The Sparky B sand (Fig. 5) trends northwest-southeast. The channel facies trending north-northeast in the Aberfeldy, Epping and Blackfoot areas were formed contemporaneously with nearshore marine sand bodies and are generally perpendicular to the sand bodies, although they may be locally oriented in other directions.

The basin configuration (Ranger, 1983) also suggests that the channel facies trends northeast. Regional highs (Fig. 1) were developed in the southwest (Wainwright Ridge), southeast (Baldwinton Arch) and north (Lindbergh Ridge). A regional low was created by solution of the Devonian Prairie Evaporite towards the northeast in the Celtic - Westhazel area (Twp. 49, Rge. 21W3 to Twp. 52, Rge. 23W3M). Multiple channel migration and abandon-

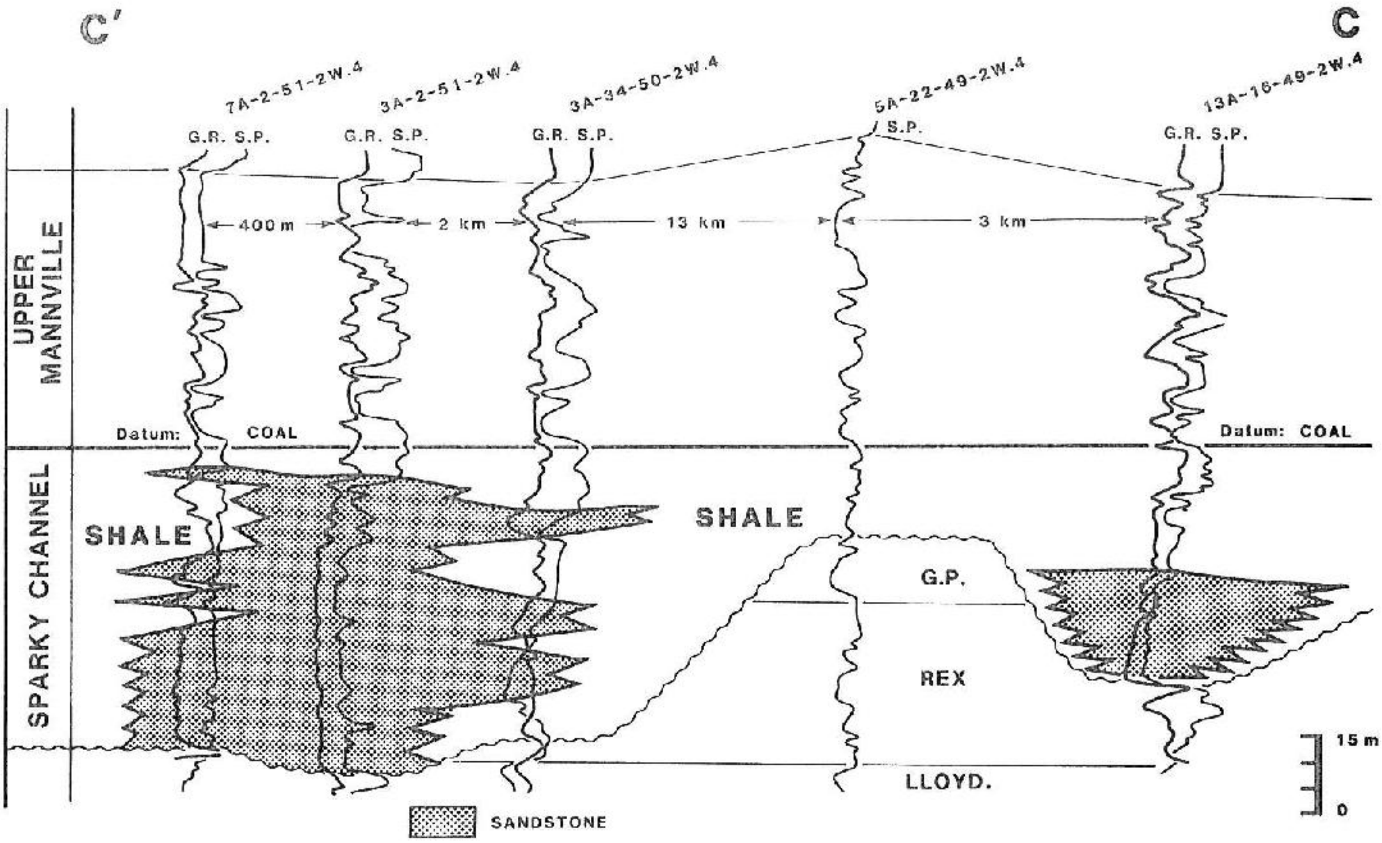

Fig. 10. SP and gamma ray stratigraphic cross-section C'-C, illustrating lithological variations within a sand-filled portion of the Sparky channel facies.

ment has partly obscured the initial trend of the channel facies.

Interestingly, the channel facies is absent in some areas, such as around the Tangleflags field. In this area the Sparky regional sands are present but are siltier than those farther west and are not very good reservoir sands. The lack of the channel facies northeast of the Aberfeldy field and the silty nature of the sands may indicate that the area was farther offshore than the Aberfeldy-Devonia Lake region.

Depositional Models

Five depositional models have been proposed for the Sparky Formation by previous workers. Nauss (1945) and Wickenden (1948) proposed a deltaic model which was generally accepted until Fuglem (1970) introduced the tidal flat model. MacCallum (1979) has also advocated a tidal flat model. Burnett and Adams (1977) added the offshore tidal bar model but Orr et al. (1977) interpreted the Sparky Formation as a beach/barrier sequence. Vigrass (1977) used a variation on the deltaic model and called the Sparky sands prodeltaic sand deposits. Criteria on which these interpretations were based are summarized in Fig. 11. Most recently, Putnam (1982) has described the Sparky and other middle Mannville sediments as having been formed in a wave-dominated shoreline environment.

The presence of foraminifera (Fuglem, 1970), dinoflagellates (Fuglem, 1970 and Putnam, 1982), glauconite and the well sorted, quartzose nature of the sands indicates marine deposition (Fig. 12). The coarsening-upward sequence, sedimentary structures such as low-angle and parallel laminations, wave ripples and bioturbation near the base, and the coal capping the Sparky Formation are similar to features seen in modern day barrier island sequences (Hayes and Kana, 1976).

Previous workers concur that the Sparky Formation was deposited in a nearshore marine environment and exhibits characteristics similar to a typical beach environment. Disagreement arises as to the type of nearshore marine environment. They disagree on the direction of the sea, and the presence and significance of channelling (Fig. 11). In the tidal flat model, where the sea is assumed to have been towards the northwest, the sand bodies would be oriented perpendicular to the coastline (MacCallum, 1979), similar to the German North sea coast. In the deltaic and offshore tidal bar models, the sea was considered to be towards the northeast and the sand bodies, subparallel to the coast (Nauss, 1945; Wickenden, 1948; Burnett and Adams, 1977).

Channelling was interpreted by all these workers except the offshore tidal bar advocates who do not recognize any contemporaneous Sparky channelling and believe that the

	TIDAL FLAT	BEACH/BARRIER	DELTAIC	OFFSHORE TIDAL BAR
PALEOGEOGRAPHY	SAND BODIES PERPENDICULAR TO COASTLINE		PROGRADING DELTAS	SAND BODIES SUB-PARALLEL TO COASTLINE
	SEA TO NW	SEA TO NW	SEA TO NE	SEA TO NE
SAND BODY GEOMETRY	TRANSITION FROM INTER-CHANNEL SANDS TO CHANNEL	SHEET SAND TRUNCATED BY RIBBON DEPOSITS	MAJOR DISCONFORMITY (VIGRASS, 77)	LINEAR FORM ENCASED BY OPEN MARINE SHALES
	CHANNELS	CHANNELS	CHANNELS	NO CHANNELS

Fig. 11. Criteria used for previous Sparky Formation depositional models.

SAND BODY GEOMETRY	SHEET-LIKE TRENDING NW-SE CUT BY N-NE TRENDING CHANNELS THICKEST CHANNEL RELATED TO TIDAL INLETS PROGRADING NATURE OF SAND BODIES SEA TO NE
VERTICAL SEQUENCE	COARSENING UPWARDS LAMINATED WAVE RIPPLE (MINOR) BIOTURBATED CAPPED BY LATERALLY EXTENSIVE COAL UNDERLAIN BY MARINE SHALES
PETROGRAPHY	Vf-F WELL SORTED, QUARTZOSE SANDS GLAUCONITE
FAUNA/FLORA	RESTRICTED MARINE: FORAMS, DINOFLAGELLATES SUBAERIAL EXPOSURE: COALS

Fig. 12. Sedimentological characteristics of the Sparky Formation.

Sparky sand bodies are encased by open marine shales. Vigrass (1977) identified channelling; he proposed that this process occurred after Sparky deposition during a major drop in sea level.

The authors propose that the Sparky Formation was deposited in a wave-dominated deltaic environment (Fig. 13). The regional facies and the channel facies were deposited contemporaneously in this environment. The coarsening-upward sequence, sedimentary structures and associated coal within the regional facies are similar to a barrier island sequence (Hayes and Kana, 1976).

The basin configuration, the prograding nature of the sands northeastward, and the facies distribution (Fig. 5) suggest that the sea was towards the northeast and not towards the northwest, as suggested by other workers. The clean reservoir sands generally trend in a northwest-southeast direction (Blackfoot-Epping), although detailed oilfield studies reveal a more complex orientation of the sand bodies (Smith, this volume).

The sand bodies are dissected by 10 to 30 m deep channel facies which become shalier towards the southwest. In the channel facies clean sands are locally present in areas of well developed Sparky B sands; these channel facies sands are interpreted as being genetically related to the regional facies, probably as tidal inlet channel sands. The channel facies are dominantly thick shale deposits which may represent abandoned distributary channels or portions of a lagoonal environment.

Sparky sands are interpreted as a series of barrier island sequences that were truncated by distributary channels. The channels deposited sediments into river mouth bars and tidal deltas. These sediments were reworked by wave action into a barrier island complex. Lagoonal muds, silts and occasional sands were deposited behind the barrier island complex while muds and silts were deposited seaward of the barrier, farther offshore. Marsh deposits capped the entire sequence. Subsequent channel migration and progradation of the system seaward caused the barrier islands to be dissected by distributary channels. The best reservoir sands are related to areas where waves were most active, such as along the upper shoreface regions of the barrier island sequences and in association with tidal inlets.

In modern wave-dominated deltaic systems distributary channels are closely associated with barrier island development (Coleman and Prior, 1980). Sand-filled tidal inlets are common in the barrier island complexes, whereas the distributary channels can be either sand and/or shale filled.

Conclusions

(1) The Sparky Formation limits are defined by regionally correlatable marker beds. A coal bed occurs at the top; the base is defined by a shale bed.

(2) The Sparky Formation can be subdivided into two major facies:

(a) Regional Facies — Three or possibly four sub-units are composed of interbedded silty shale and sand grading upward into coarser grained and better sorted sands. The uppermost sub-unit is capped by a coal.

(b) Channel Facies — This facies is dominantly shale-filled or exhibits a fining upward sequence with local areas completely sand-filled.

(3) The channel facies is present in (a) the Wainwright area, and (b) the Blackfoot - Aberfeldy area.

(4) Regionally, reservoir sands occur in the Sparky C sub-unit in the Wainwright area whereas in the Blackfoot-Epping area, the reservoirs are in the Sparky B and C sub-units. In the Aberfeldy area, the Sparky A, B and C sub-units contain the reservoir sands.

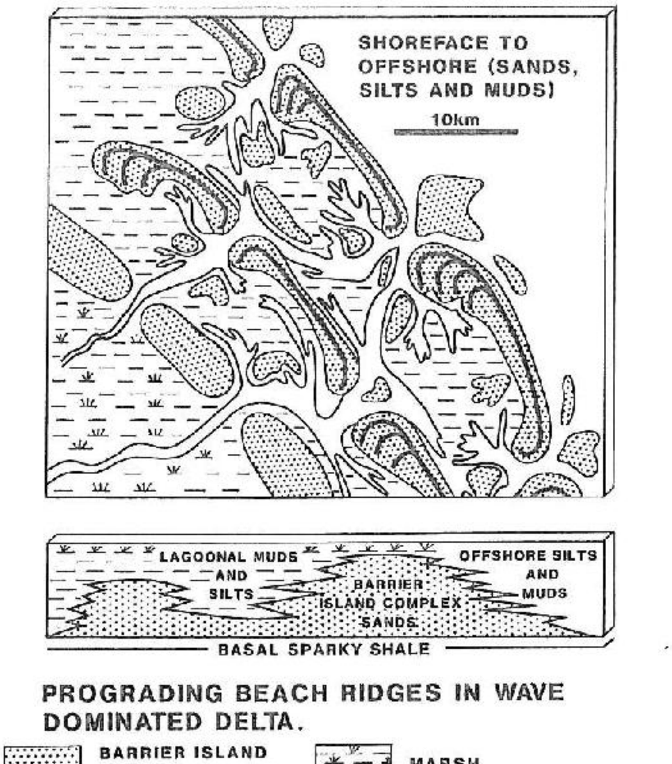

Fig. 13. Depositional model proposed for the Sparky Formation: Wave-dominated delta.

(5) Channel facies sands, although locally developed, form very good reservoirs along the Blackfoot-Aberfeldy-Epping trend. These sands are interpreted to be genetically related to the regional facies.

(6) The Sparky Formation is interpreted as having been deposited in a wave-dominated deltaic environment:

(a) the regional facies is suggestive of barrier island deposition (coarsening-upward sedimentary sequence, presence of foraminifera, dinoflagellates and glauconite, and the well sorted, quartzose nature of the sands);

(b) the channel facies is genetically related to Sparky deposition, and may represent distributary channels, tidal inlets or portions of a lagoonal environment;

(c) coals within the Sparky Formation, and the regionally extensive coal that caps the Sparky shale-sand sequence, indicate subaerial exposure in a marsh environment.

(7) The sea, during deposition of the Sparky Formation, is suggested to have been towards the northeast as indicated by the basin configuration, the development up-section of the reservoir sands towards the northeast and the distribution of the channel facies.

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