# DISTRIBUTION OF THE SPARKY FORMATION HEAVY OIL FIELDS WITHIN THE LLOYDMINSTER SUB—BASIN

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## ABSTRACT

Heavy oil in the Lloydminster area of Saskatchewan and Alberta is produced from the Lower Cretaceous Mannville Group, of which the Sparky formation is one of the most significant oil-bearing formations. Pre-Cretaceous high areas, termed the Baldwinton Ridge to the south, Wainwright Ridge to the southwest and Lindbergh Ridge to the north, form the limits of the Lloydminster Sub-basin. A structural depression to the east and northeast was caused by salt disolution of the Devonian Prairie Formation. Deposition of the Sparky formation has been influenced by the configuration of the Lloydminster Sub-Basin.

The Sparky formation can be subdivided into two major facies: Regional and Channel. Its characteristics suggest deposition within a wave-dominated deltaic system. Sandstones of the Regional Facies contain most of the heavy oil accumulations and can be up to 14m thick. The Channel Facies, which is predominantly shale-filled, locally develops excellent reservoir sandstones up to 40m thick.

The major Sparky formation heavy oil accumulations are situated in the central portion of the Lloydminster Sub-basin. Major oil fields include Aberfeldy, Epping, Golden Lake, Celtic, Westhazel, Marsden, Blackfoot and Wainwright. Four types of traps are recognized:

(A) Regional Facies sandstones abutting against shale-filled Channel Facies,
(B) Regional and Channel Facies sandstones trapped structurally; mainly due to salt dissolution of the Devonian Prairie Formation,
(C) Sandstones locally developed within the Channel Facies,
(D) Lateral pinch-out of the Regional Facies sandstones.

## INTRODUCTION

The Lloydminster heavy oil area of Saskatchewan and Alberta (Fig. 1) contains an estimated total of 8 to 11 billion $m^3$ (50 to 69 billion barrels) of oil in place[1]. New development drilling could add an additional 16 million $m^3$ (102 million barrels) of reserves while existing and new enhanced oil recovery (EOR) projects expect to increase the reserve base by approx- imately 43 million $m^3$ (272 million barrels)[1]. Approximately sixty percent of the oil in place occurs within the Sparky for...

The purpose of this paper is to:
(a) outline the major structural elements of the Lloydminster Sub-basin,
(b) relate regional depositional characteristics of the Sparky formation to the Lloydminster Sub-basin,
(c) illustrate the major hydrocarbon trapping mechanisms for the Sparky formation.

## STRATIGRAPHY OF THE MANNVILLE GROUP

The Lower Cretaceous Mannville Group is a series of very fine to fine grained sandstone, siltstone, shale, and coal beds which unconformably overlie eroded Paleozoic carbonates and are overlain by marine shales of the Joli Fou Formation of the Colorado Group (Vigrass, 1977). The most commonly used stratigraphic nomenclature for the Mannville Group was described by Vigrass (1977) and Orr *et al.* (1977). They both used the same nine informal stratigraphic subdivisions (Fig. 3) except that Vigrass called them members whereas Orr *et al.* refer to them as formations. Both of them placed the stratigraphic contacts at the top of the sandstones. MacCallum (1979) initiated the use of shale and coal marker beds to define these boundaries. The present authors believe the Mannville Group can be subdivided into correlatable subdivisions in the Lloydminster area based on regional marker beds, so these subdivisions should be referred to as formations.

## BASIN CONFIGURATION

The Sparky formation (Figs. 4 and 5) and other Mannville formations have a regional southwesterly dip of approximately 1.9m/km which is probably associated with the Laramide Orogeny (Christopher, 1980). The Sweetgrass Arch extends into the Lloydminster area with the Alberta Basin to the west and the Williston Basin to the southeast (Stelck, 1975) (Fig. 1).

The major structural elements forming the boundaries of the Cretaceous Lloydminster Sub-basin (Orr *et al.*, 1977) are illustrated on the Base of Fish Scale Zone to pre-Cretaceous unconformity surface isopach map (Fig. 6). The second order residual map of the pre-Cretaceous unconformity surface (Fig. 7) depicts structural highs where the isopach map shows thin areas. These features are termed... ...on of the Lower Cretaceous Mannville Group (Orr *et al.*, 1977).

(a) Wainwright Ridge - southwestern limit,
(b) Baldwinton Ridge - southern limit,
(c) Lindbergh Ridge - northern limit

...he study area encloses Twps. 42-54, Rges. 17-28 W3M and Twps. 42-54, Rges. 1-7 W4M and contains all the major Lloydminster heavy oil fields. The major Sparky oil pools and fields are depicted in ... 2. Approximately 12,000 wells have been drilled in the Lloydminster area and most of these wells penetrate the ...

The Devonian Woodbend Formation in Alberta is approximately stratigraphically equivalent to the ... Formation.

[1] Nova and Husky Submission to the National Energy Board.

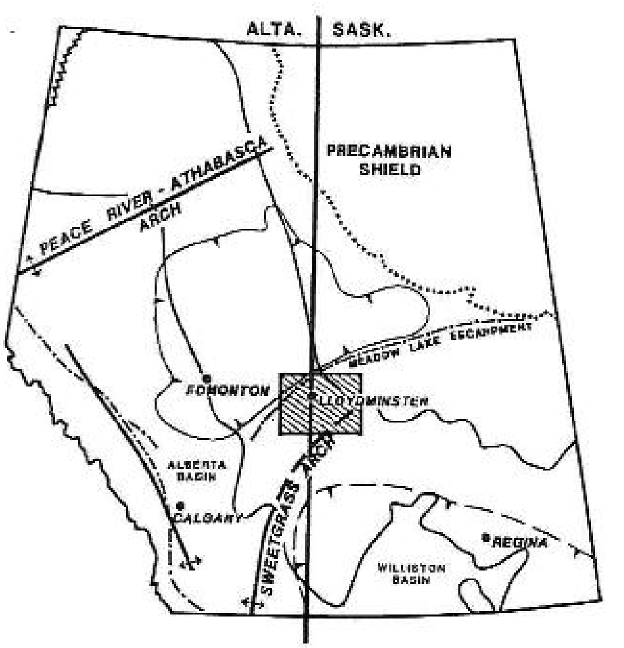



Fig. 1 - Location map indicating the study area and major structural elements. The Meadow Lake Escarpment was an important structural element during the Devonian and coincides with the northwest boundary of the study area. Whether the escarpment played any role during the Cretaceous has not been definitely shown at this time. (Modified after McCrossan and Glaister, 1964; Stelck, 1975).

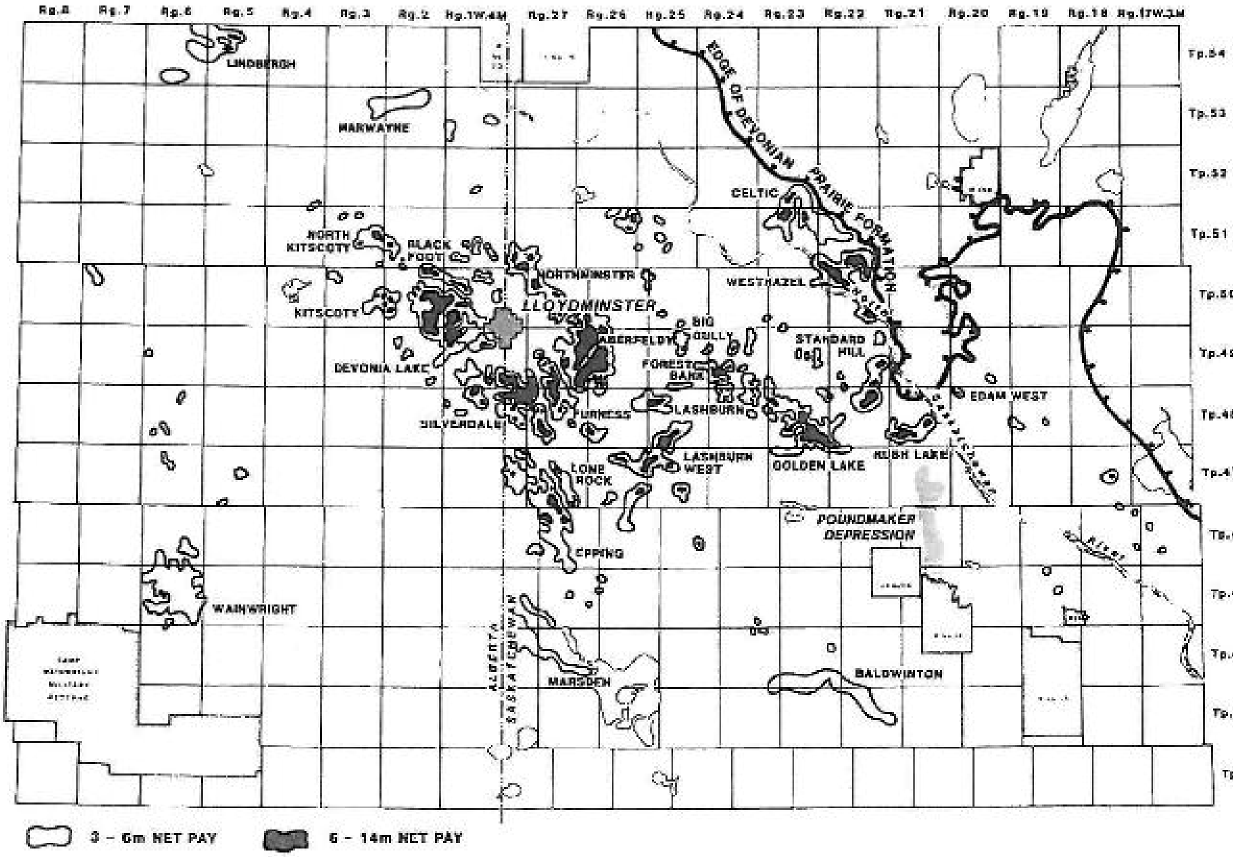



Fig. 2 - Net pay map for the Sparky formation's Regional Facies showing the major oil fields. Despite the thin reservoir sandstone/siltstone in the Wainwright Field, it is an important Sparky oil field because of its lower viscosity oil.

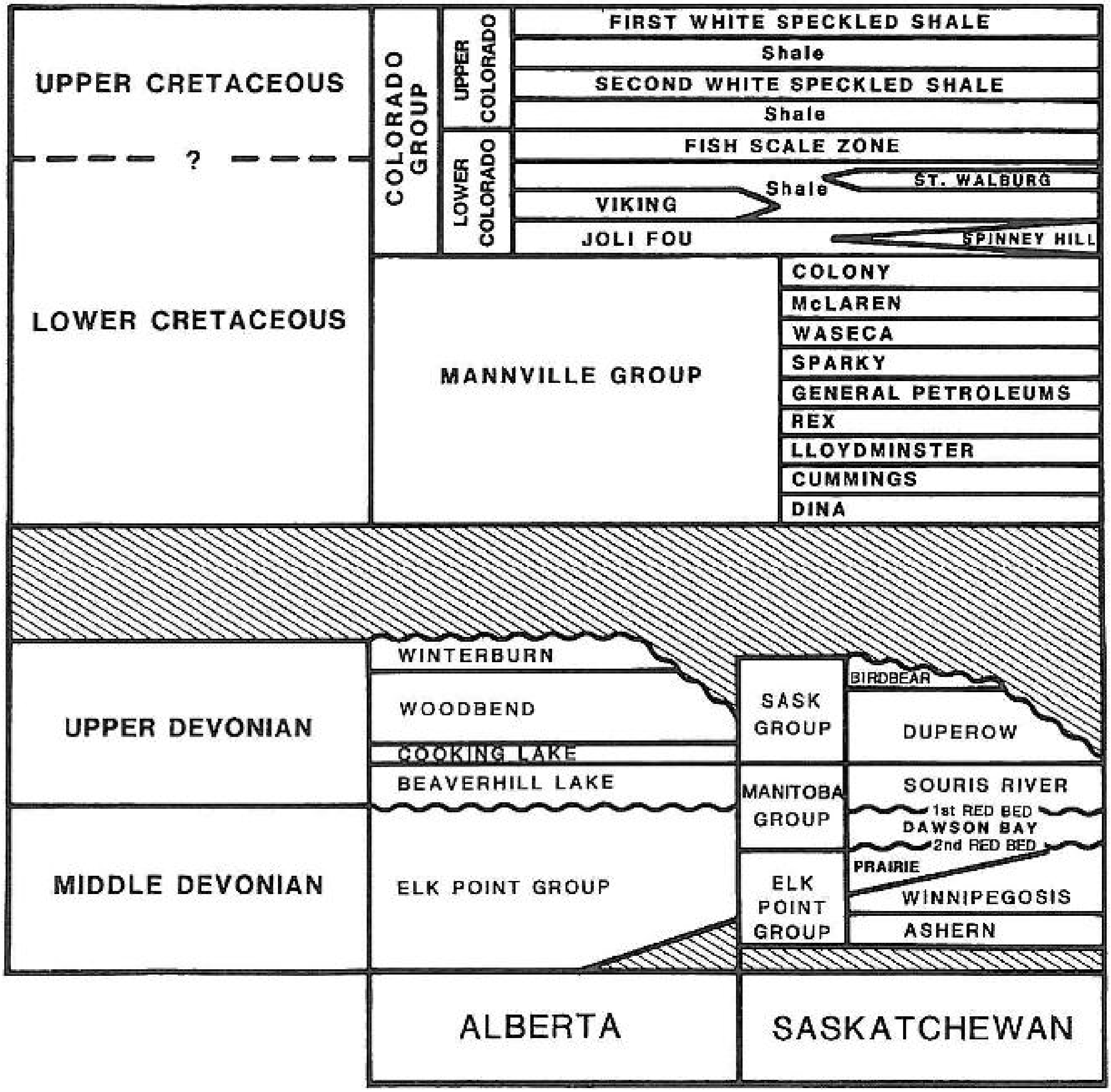



Fig. 3 - Stratigraphic Nomenclature, Lloydminster Area.

in Saskatchewan and subcrops on the Wainwright, Baldwinton and Lindbergh Ridges (Figs. 4, 5, and 7) (Formation names in parentheses are the Saskatchewan equivalents to the Alberta nomenclature used in this paper). The Devonian Winterburn (Birdbear) Formation also subcrops on the Wainwright Ridge but is absent on the other ridges. The Lindbergh Ridge is less pronounced than the other two ridges with the Woodbend Formation being relatively thin in this area. The Devonian Cooking Lake (lower part of the Duperow) and Beaverhill Lake (Souris River) Formations subcrop in the eastern part of the Lloydminster area. The Wainwright, Baldwinton and Lindberg Ridges separate the Lloydminster Sub-basin from the following areas, respectively: Central Alberta, the Kindersley heavy oil area and the Cold Lake oil sand area.

The Meadow Lake Escarpment (Fig. 1) which was an important structural element during Middle Devonian Lower Elk Point salt deposition, coincides with the northwestern limit of the Lloydminster Sub-basin. Orr *et al.* (1977) found no apparent relationship with Mannville deposition. MacCallum (1979), however, shows that the extent of the Lloyminster formation sandstones coincides with the Meadow Lake Escarpment. The escarpment may, therefore, have had some influence on Mannville deposition.

In the eastern part of the study area, salt dissolution of the Devonian Prairie Formation has resulted in structural reversal of the overlying strata (Figs. 4 and 5). The second order residual map on the pre-Cretaceous unconformity surface

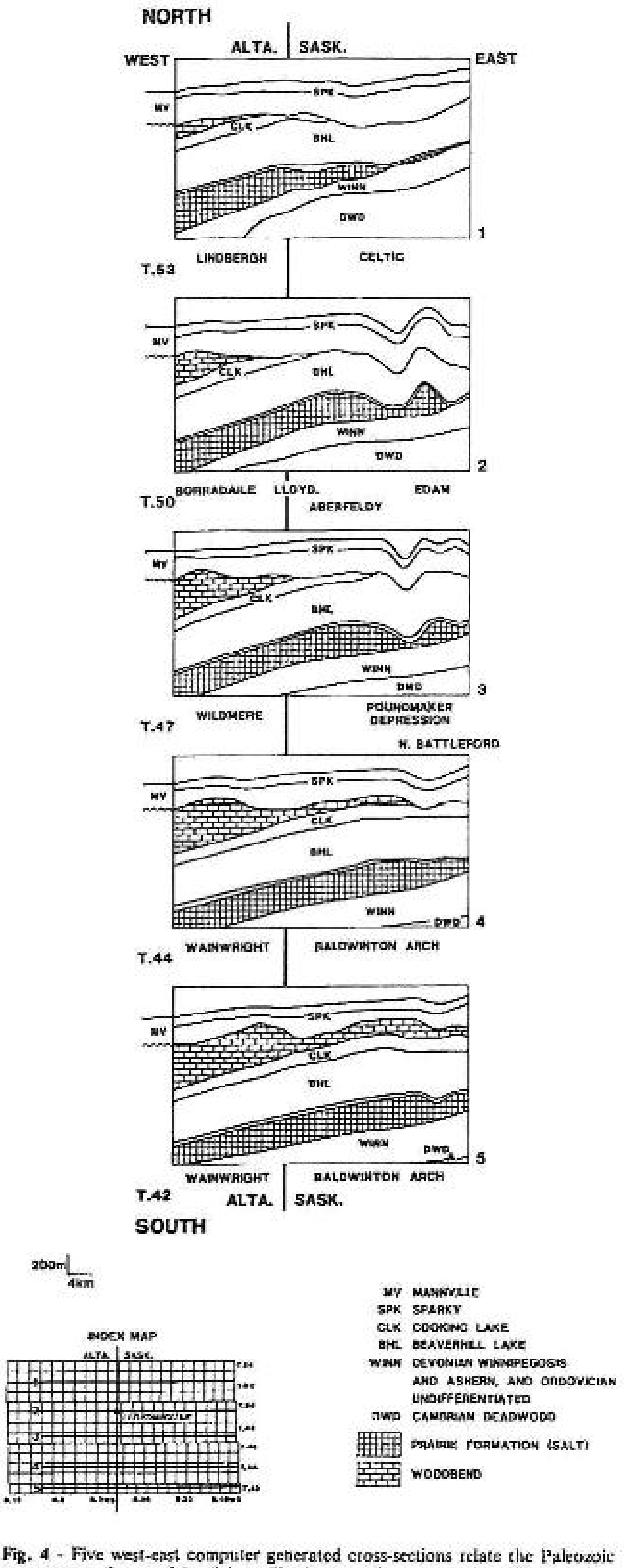



**Fig. 4** - Five west-east computer generated cross-sections relate the Paleozoic structure to the overlying Mannville Group. The cross-sections illustrate the Paleozoic ridges formed by the subcropping Devonian Woodbend Formation in the western part of the study area and the salt dissolution of the Prairie Formation in the eastern part. All deep Paleozoic tests in the area were used and originated partly from Digitech and partly from Husky Oil data. The Mannville tops are the author's own data and have also been used in Figures 7 and 8.

(Fig. 7) depicts a low corresponding to the area of salt dissolution. Thickening of the Base of Fish Scale Zone to pre-Cretaceous unconformity surface isopach map (Fig. 6) suggests that the area was structurally low during Cretaceous deposition.

Salt dissolution of the Prairie Formation in Saskatchewan has been documented to have occurred from the Devonian to the Recent (DeMille *et al.*, 1964; Holter, 1969; Horner and Hasegawa, 1978). Christopher (1980) indicated that some salt dissolution occurred during Mannville deposition but that most of the dissolution was post-Mannville. He, however, states that "solution sinks remained active throughout Mannville deposition and account for abrupt thickening and changing of facies in the latter". In the Edam area of Saskatchewan, Wilmot and Oliver (1983) have suggested that salt dissolution occurred in discrete phases that were interrrupted by periods of no salt dissolution. The oldest event was approximately synchronous with lower Mannville deposition (ibid). The major phase of dissolution occurred post-Second White Specks, and accounts for most of the structural highs and lows in the eastern part of the study area (ibid).

The Paleozoic carbonate ridges at the Pre-Cretaceous unconformity (Fig. 6) are dissected by paleo-valleys that connect the Lloyminster area with Central Alberta (Christopher, 1980). One paleo-valley is situated in the Manitou Lake area while another one occurs in the Vermilion area. These paleo-valleys are filled by lower Mannville (Dina) sandstones (Orr *et al.*, 1977; Vigrass, 1977; Christopher, 1980; Putnam, 1982). Sedimentation in the middle and upper Mannville has not been previously shown to be related to the pre-Cretaceous unconformity surface. This paper suggests that the paleotopography during Sparky deposition was similar to the pre-Cretaceous topography because the pre-Cretaceous ridges, and major low to the east, are also indicated on the second order residual map of the Sparky formation (Fig. 8). The magnitude of these highs and lows is, however, less than the pre-Cretaceous unconformity surface, suggesting lower topographic relief. Other evidence is presented later in this paper to support this relationship.

## FACIES

### INTRODUCTION

The Sparky formation can be subdivided into two major facies based on geophysical well log signatures and substantiated by cores. These facies are termed; a) Regional Facies and b) Channel Facies (van Hulten and Smith, in press). Generally, the formation is characterized by coarsening upward, sheet-like sandstones interbedded with siltstone/shale (Fig. 9). The lower boundary of the formation is the base of a regional shale, and a regional coal, the Sparky coal, generally caps the Sparky formation. This sequence is defined as the Regional Facies. In some areas, the Regional Facies and parts of the underlying formations have been eroded by Channel Facies which are sandstone and/or shale-filled channels (Figs. 11 and 12).

In the Lloydminster area, cores are not abundant and are generally confined to the edges of the older fields, enhanced oil recovery (EOR) projects, and newly discovered pools. Most of these cores are from the Regional Facies because of the more productive nature of this facies. Very few wells in the Channel Facies have been cored.

#### (a) Mineralogy

Mineralogical studies of the Sparky formation, in particular Maccagno and Watson (1980), Putnam (1982), and Smith (in

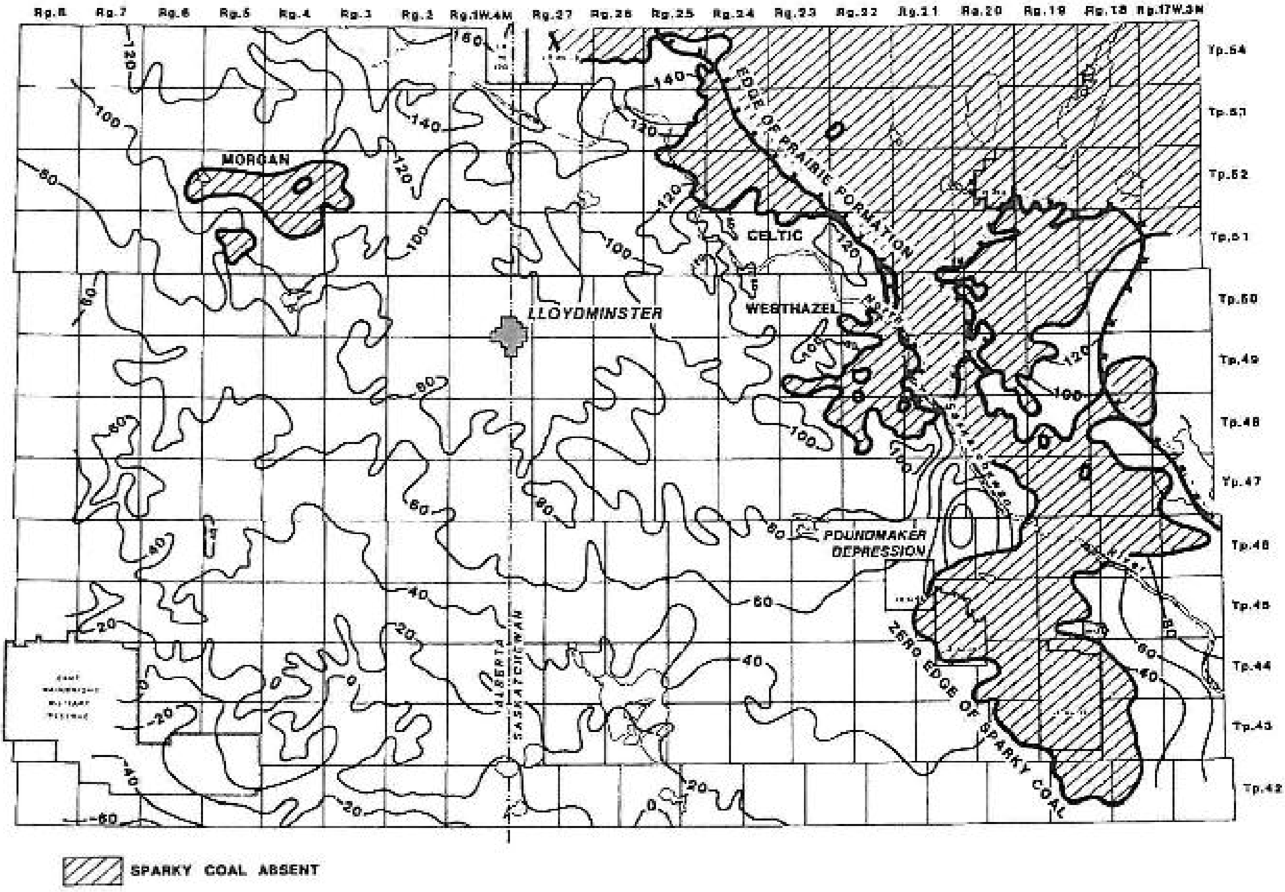



Fig. 5 - Sparky coal structure map illustrating the regional dip to the southwest, and the absence of the Sparky coal in the northeast and east. The edge of the Devonian Prairie Formation salt roughly coincides with the area where the Sparky coal is not present. (Map was constructed by using one well per section, if available.)

press) have shown that in the sandstone, siltstone, and also the shale beds, monocrystalline quartz is the principal framework grain (up to 90%) with polycrystalline quartz (up to 10%) occurring in lesser amounts. Feldspar (less than 10%), rock fragments (less than 5%) and other minerals (trace) such as glauconite, mica, and heavy minerals are minor constituents. The rock fragments are mainly shale, siltstone, and sandstone clasts. Plant remains and carbonaceous debris are common, particularly in the shale beds. Clays (up to 15%), and also carbonaceous material, form the depositional matrix between the framework grains. In the best reservoir sandstones, the clay content is typically between 2 and 6%.

The dominant clay mineral is kaolinite with illite being the next most abundant. Minor amounts of chlorite, smectite, and mixed-layer clays are present. Vermicular kaolinite booklets (60-90% of the clay fraction) occur as pore-filling cement. Illite (up to 40% of the clay fraction) and minor amounts of chlorite form the depositional matrix.

The shale beds have a slightly higher total clay content (11-12%, bulk XRD) compared to the sandstone and siltstone beds (2-6%). In the clay fraction (XRD), shales have a higher illite content (15-40%) than the sandstone/siltstone (10-18%), reflecting its increased detrital matrix.

Carbonates (siderite, dolomite, and calcite), kaolinite, and quartz overgrowths occur as pore-fill and pore-lining cements which reduce primary intergranular porosity. In rare cases, carbonate cementation has completely occluded all pore spaces.

**(b) Log Response**

The Gamma Ray curve should be used in preference to the Spontanteous Potential curve as a lithological indicator in the Sparky formation. The Gamma Ray counts are predominatly derived from illite and K-feldspar which are more abundant in the finer grained sediments, siltstone and shale, (Maccagno and Watson, 1980).

The Spontaneous Potential curve is influenced by formation fluids and permeability. Heavy oil and carbonate tight streaks can produce a positive Spontaneous Potential deflection, suggesting the lithology is a sandy siltstone or shale when, in fact, it is a clean sandstone. (Fig. 12 - see A11-26-47-22W3M, depth 454m, inidcated by number 1). Conversely, a waterleg may indicate a clean sandstone on the Spontaneous Potential log when the lithology is a shaly sandstone or siltstone (Fig. 9 - see 10A-32-49-1W4M, depth 605m, indicated by number 2). In the 10A-32-49-1W4 core, the Sparky D sub-unit is a siltstone whereas the Spontaneous Potential suggest it to be a clean sandstone.

The recognition between the Regional and Channel Facies is sometimes hampered by the Gamma Ray and Spontaneous

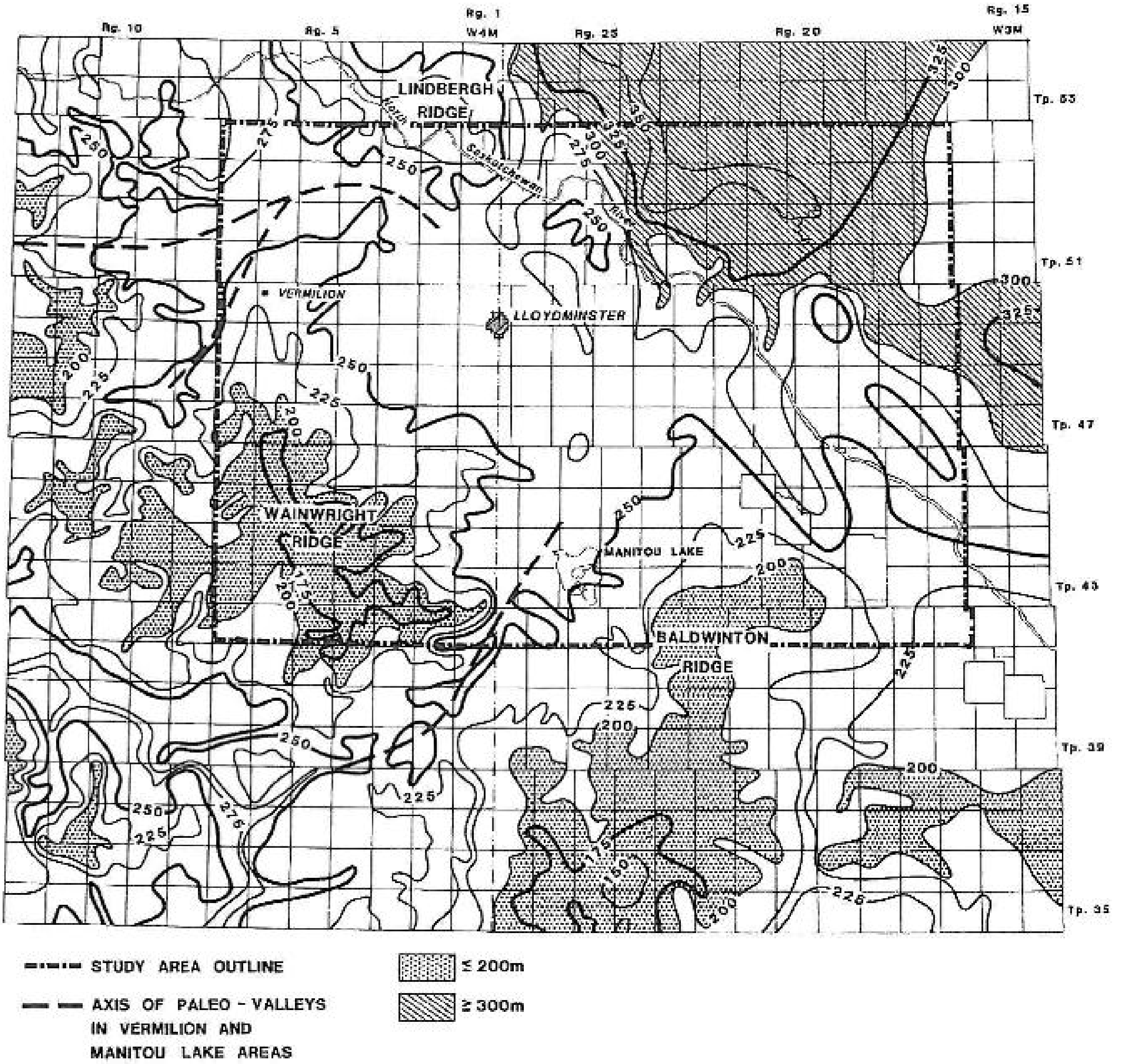



Fig. 6 - Isopach map of the Base of Fish Scale Zone to Pre-Cretaceous unconformity surface, using data derived by previous Husky Oil workers. One Paleozoic well per section was used if available. The map outlines the boundaries of the Lloydminster Sub-basin.

Potential curves having different log signatures. The Gamma Ray curve should be used in these cases to determine if the log signature is a coarsening upward sequence, typical of the Regional Facies, or a blocky or bell shaped curve, typical of the Channel Facies. For example, a water zone at the base of a Channel Facies sand may produce a negative Spontaneous Potential response whereas heavy oil suppression in the upper part gives a positive Spontaneous Potential response. The Spontaneous Potential curve may show in some cases a blocky or bell-shaped curve suggesting a channel-fill whereas the Gamma Ray curve will display a typical coarsening upward sequence indicating Regional Facies' log character.

## REGIONAL FACIES

### (a) Descripton

The Regional Facies is defined as the stratigraphic sequence between the Sparky coal, or its stratigraphic equivalent (ie. the overlying Waseca beds are correlatable), and the basal Sparky shale (Fig. 9). The sequence varies from 10-20m in thickness. The basal Sparky is a carbonaceous, bioturbated, silty shale, generally 1-3m thick. This sub-unit is correlatable over the entire study area except where it has been removed by erosion. Dinoflagellates and foraminifera have been identified in the

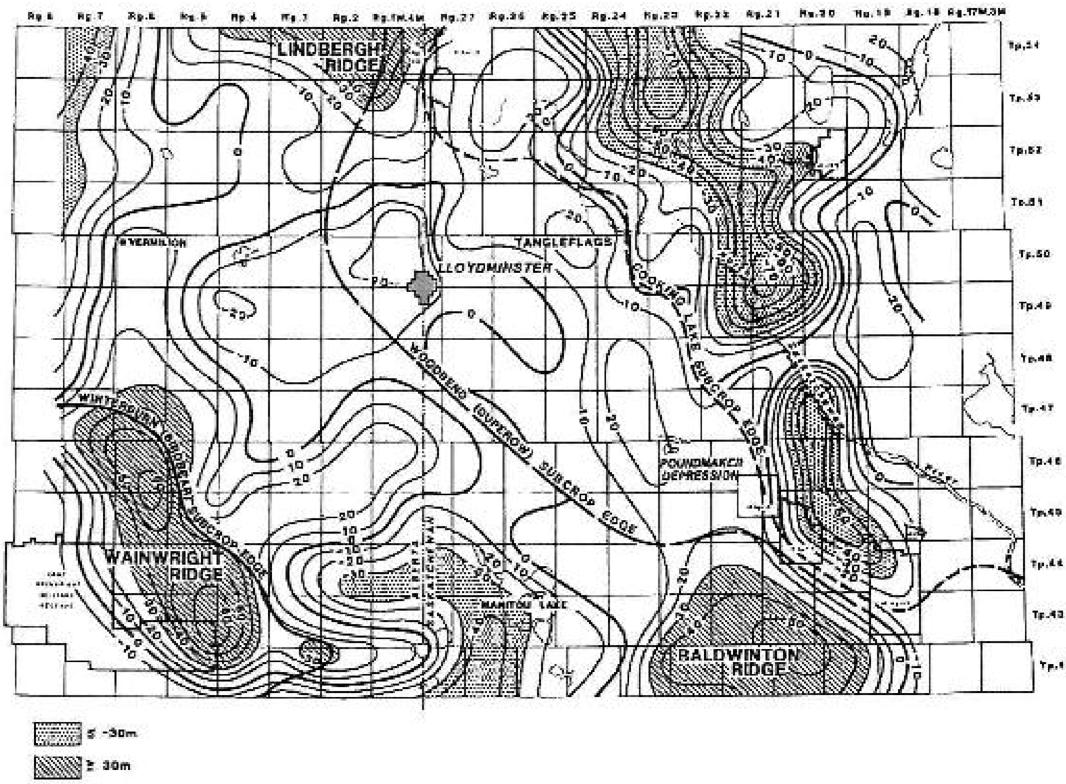
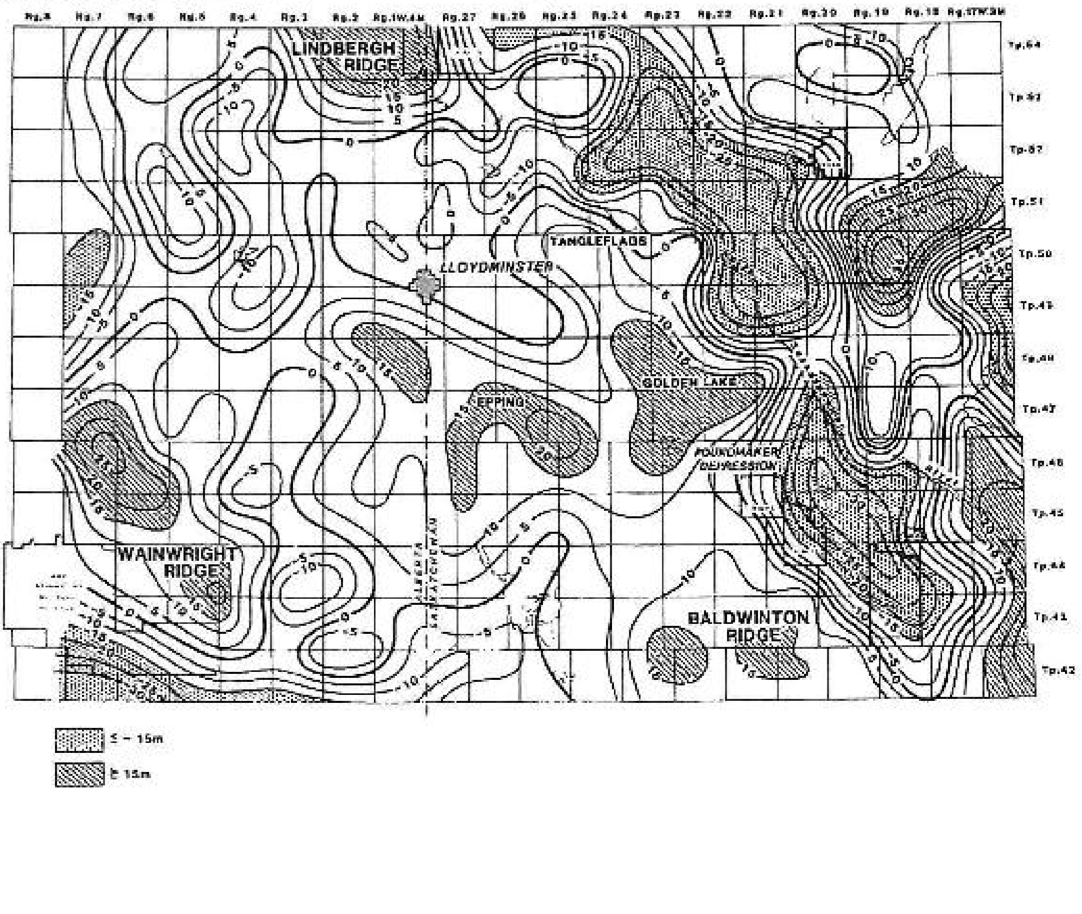



Fig. 7 - Second order residual map of the Pre-Cretaceous unconformity surface illustrating the major structural elements of the Lloydminster Sub-Basin. (Map was generated by using one data point per township. First, second, and higher order residual maps depict the same features. The second order residual map provided optimal definition of the ridges bordering the sub-basin.)

Fig. 8 - Second order residual map on the top of the Sparky formation illustrating the features which were also observed on the second order residual map of the Pre-Cretaceous unconformity surface. The magnitude of these high and low areas is, however, less. (Map was generated using one data point per township.)



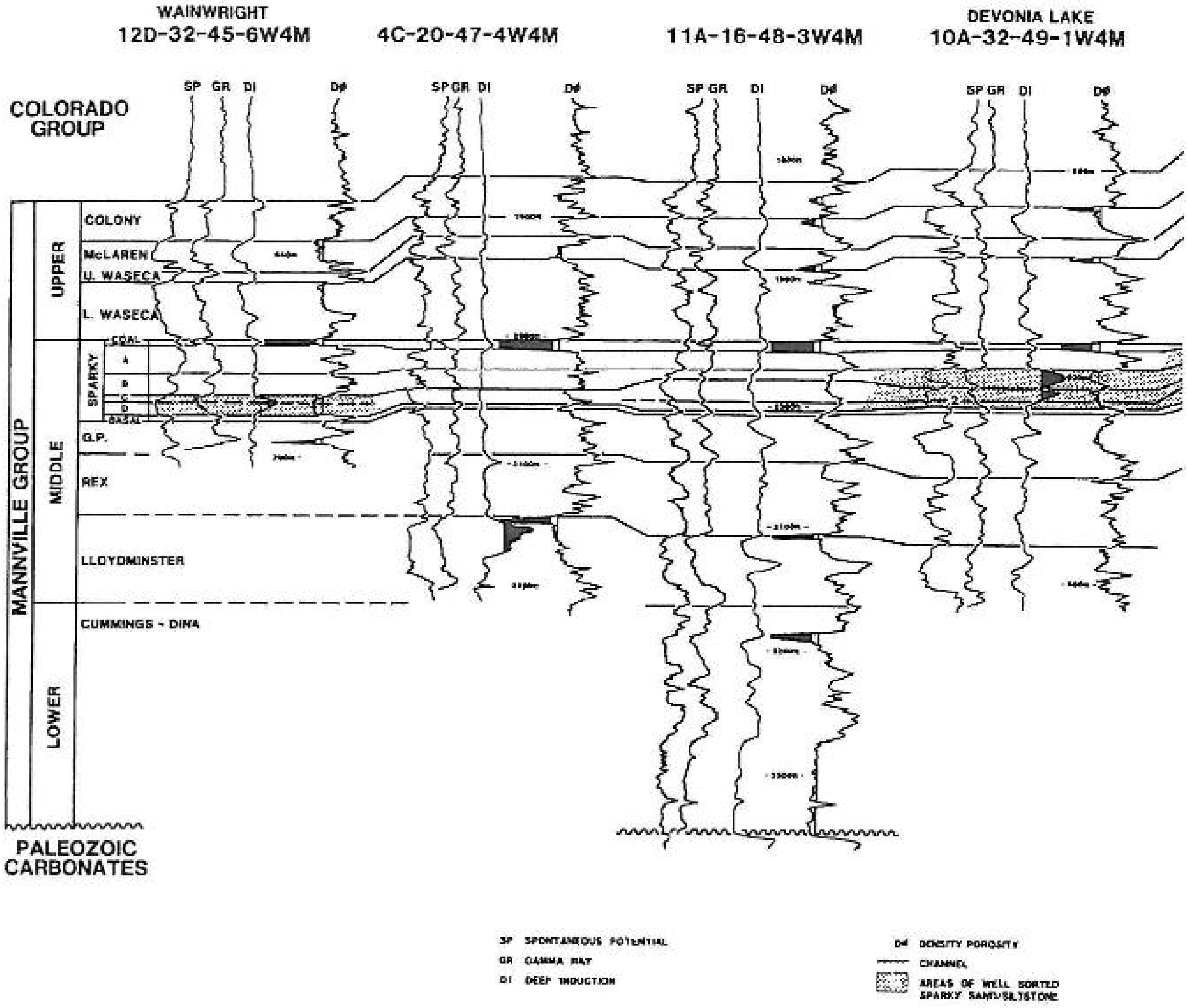
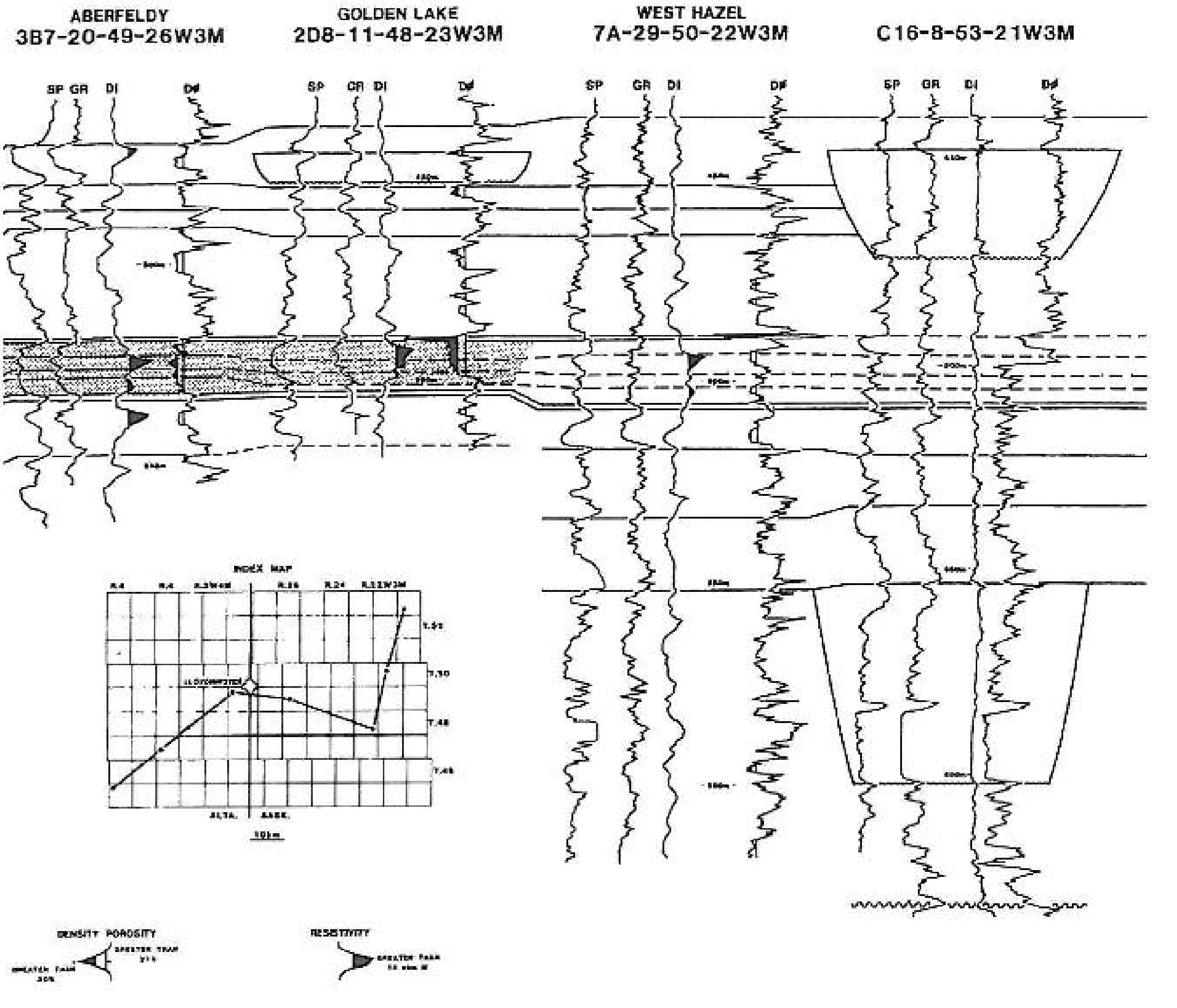



Fig. 9 - Regional southwest-northeast stratigraphic cross-section of the Mannville Group in the Lloydminster area, illustrating the correlation of the Sparky formation, its sub-units, and the development up-section of the sandstone/siltstone sub-units to the northeast. (Datum: top of Sparky coal; dashed lines indicate areas of uncertain correlation.)

basal Sparky at Aberfeldy by Fuglem (1970) and AGAT Consultants Ltd. (pers. comm.).

Subdivision of the Sparky formation into sub-units between the Sparky coal and basal Sparky has been useful in mapping in particular pools and fields (MacCallum, 1979; Maccagno and Watson, 1980; Smith, in press). On the Alberta and part of the Saskatchewan side of the study area, these sub-units are correlatable (Fig. 9). Although correlations can be made, they are more uncertain in eastern parts of the study area. These subdivisions are informally termed, in descending order A, B, C, D. The base of the A, B, C and D sub-units is indicated on the Gamma Ray and/or Spontaneous Potential logs as a shale bed. In cores, the basal bed can vary from a silty sandstone to interbedded shale/sandstone to shale. Regionally, the Sparky coal, A sub-unit and basal Sparky appear to be the most contínous sub-units with the major facies changes occurring in the B, C and D intervals.

Each of these sub-units generally represents a coarsening upward sequence, varying from 2 to 6m thick. Either silty sandstone, interbedded shale/sandstone or shale occurs at the base and grades upwards into coarser grained and better sorted sandstone or siltstone. The lower part of the coarsening upward sequence can be either bioturbated or wavy-bedded. Wave ripples and plant debris along laminae are frequently observed. Vertical corkscrew type burrow, *Gyrolythos* (G. Pemberton, pers. comm.) are common, particularly in the lower sub-units, C and D. The sandstone interbeds are very fine grained and moderately well sorted. The sandstones at the top of the coarsening upward sequence are dominantly very fine to fine grained and well sorted. In some pools, the reservoir is not always a sandstone but is actually a well sorted, quartzose siltstone; for example the lower two-thirds of the reservoir in the Wainwright Field and the lower sub-units in the Aberfeldy Field. Sedimentary structures in the sandstone beds are often difficult to observe due to the heavy oil staining. Low angle and parallel laminations are the dominant sedimentary structures observed. Bioturbation and wave ripples are




more common in sub-unit C and more particularly sub-unit D. High angle laminations (tabular cross-beds?) have been observed, usually in sub-unit B or in sub-units exhibiting a blocky log character.

**(b) Lateral Lithological Variations**

Laterally, the upper sandstone/siltstone portion of the sub-units can grade into shale or interbedded sandstone/shale. This aspect is illustrated in the regional southwest-northeast cross-section between the Wainwright, Devonia Lake, Aberfeldy and Golden Lake Fields (Fig. 9) (van Hulten and Smith, in press).

The A sub-unit at Wainwright and Devonia Lake, is composed predominatly of carbonaceous, silty shale with minor carbonate cemented sandstone. At Aberfeldy and Golden Lake, however, this sub-unit is a moderately to well sorted, very fine to fine grained, quartzose sandstone. In addition, the sub-unit at Devonia Lake, Aberfeldy, and Golden Lake is also a well sorted, very fine to fine grained, quartzose sandstone, whereas at Wainwright, it is a carbonaceous, silty shale with a thin, carbonate cemented sandstone occurring at the top of the sequence. The development of the sandstone sub-units up-section towards the northeast is interpreted as to representing progradation in the same direction (Fig. 9).

The major sandstone body trends correspond to the areas of net pay development in the Regional Facies. In the Wainwright Fields, the sandstone/siltstone body is thin and occurs in the C and D sub-units. The Blackfoot/Epping/Aberfeldy/Golden Lake area is characterized by thick development of sandstone/siltstone in the B to D sub-units. The net pay is thickened in the Aberfeldy/Golden Lake area by the addition of porous sandstones in the A sub-unit. In general, the B sandstone sub-unit is best developed in the Blackfoot/Aberfeldy/Epping Golden Lake area (Fig. 9).

Sparky sub-units are generally correlatable within pools and also regionally between some of the pools. A detailed study of

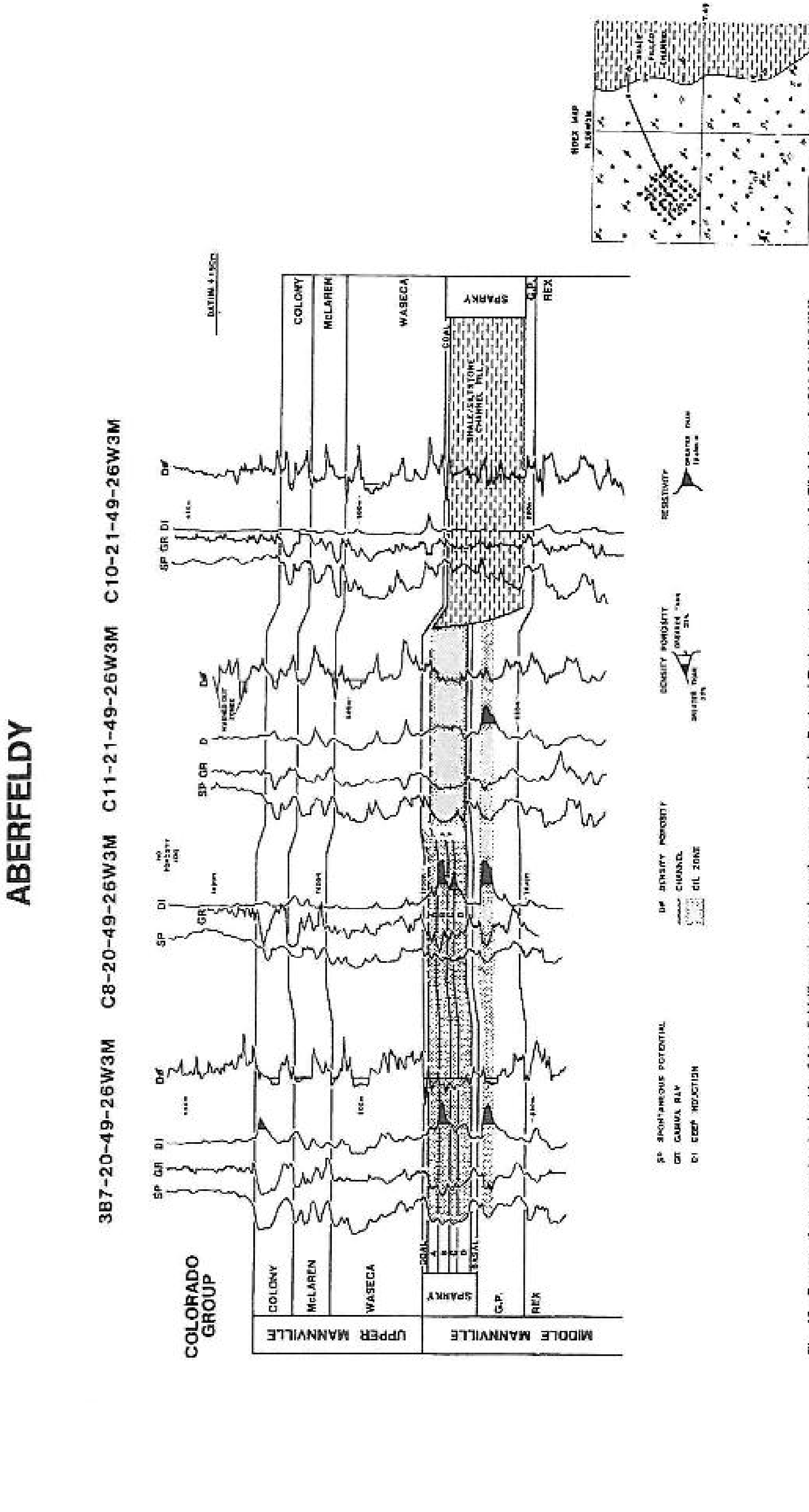



Fig. 10 - Structural cross-section in the Aberfeldy field illustrating hydrocarbons trapped in the Regional Facies sandstones by a shale-filled channel. C11-21-49-26W3 depicts the Sparky sub-units becoming shalier and siltier in proximity to the channel. (Dashed lines indicate areas of uncertain correlation.)

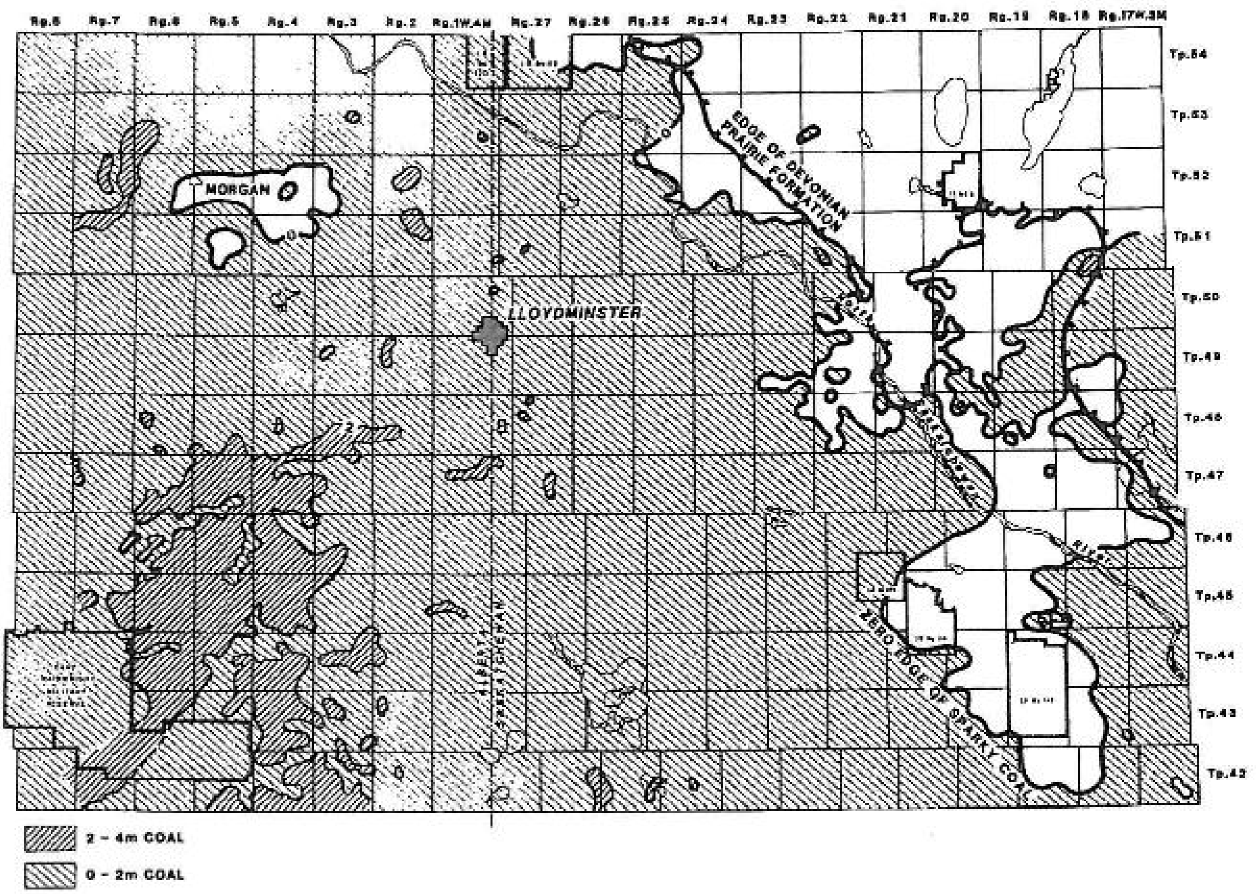



Fig. 11 - Sparky coal isopach map indicating the thick coal development in the Wainwright area and the absence of the Sparky coal to the northeast and east, roughly coinciding with the edge of the Devonian Prairie Formation salt.

the Aberfeldy steamflood pilot, (Smith, in press), however, illustrates that correlation of these sub-units becomes difficult when either:

(a) the lower shale beds in the coarsening upward sequence were not deposited such that the sandstones of the sub-unit directly overlie the underlying sub-unit's sandstone body; or

(b) a sandstone body pinches out laterally so the lower shale beds were deposited on top of the underlying sub-unit's lower shale beds.

Differentation within part or all of the Sparky formation into these sub-units is impossible when the log signature has a general blocky character, representing continuous silty sandstone or clean sandstone. This commonly occurs in areas adjacent to the Channel Facies (Fig. 10). Channel - like features on well logs (blocky or bell shaped log signature) are recognized within the B to basal Sparky interval(e.g. Marsden South Pool). The basal Sparky is still present so it falls within the definition of the Regional Facies. The Gamma Ray log signature, absence of correlatable sub-units (C and D) and presence of tabular cross-beds suggests these deposits may be channel-fill sandstones.

### (c) Sparky Coal

The Sparky coal is a sub-bituminous coal bed (AGAT, pers. comm.) with interbeds of carbonaceous shale, and an associated underlying carbonaceous shale with rootlets. This sub-unit is up to 6m thick but is generally between 1 and 3m thick. Interbedded silty sandstone, siltstone and shale can locally underlie this sequence.

The Sparky coal is present throughout most the study area (Fig. 11). A northeast trending isopach thick occurs in the Wainwright area. The zero edge of the Sparky coal is located in the eastern part of the study area and also locally in the Morgan area of Alberta (ibid). Locally, the Sparky coal may not be present while adjacent wells have the coal developed (Fig. 10). The absence of the coal in isolated wells is interpreted to be due to non-deposition and not caused by post-Sparky channeling because the sub-units and the overlying Waseca formation sequence are correlatable from well to well.

## CHANNEL FACIES

### (a) Definition

The Channel Facies is recognized by the absence of the basal Sparky marker bed which is facilitated by the absence of the underlying General Petroleums and Rex formations. Upper Mannville channeling has occurred throughout the Lloydminster area (Fig. 12) but the Channel Facies referred to in this study are channel-fill deposits originating during Sparky deposition shown by the presence of the Sparky coal.

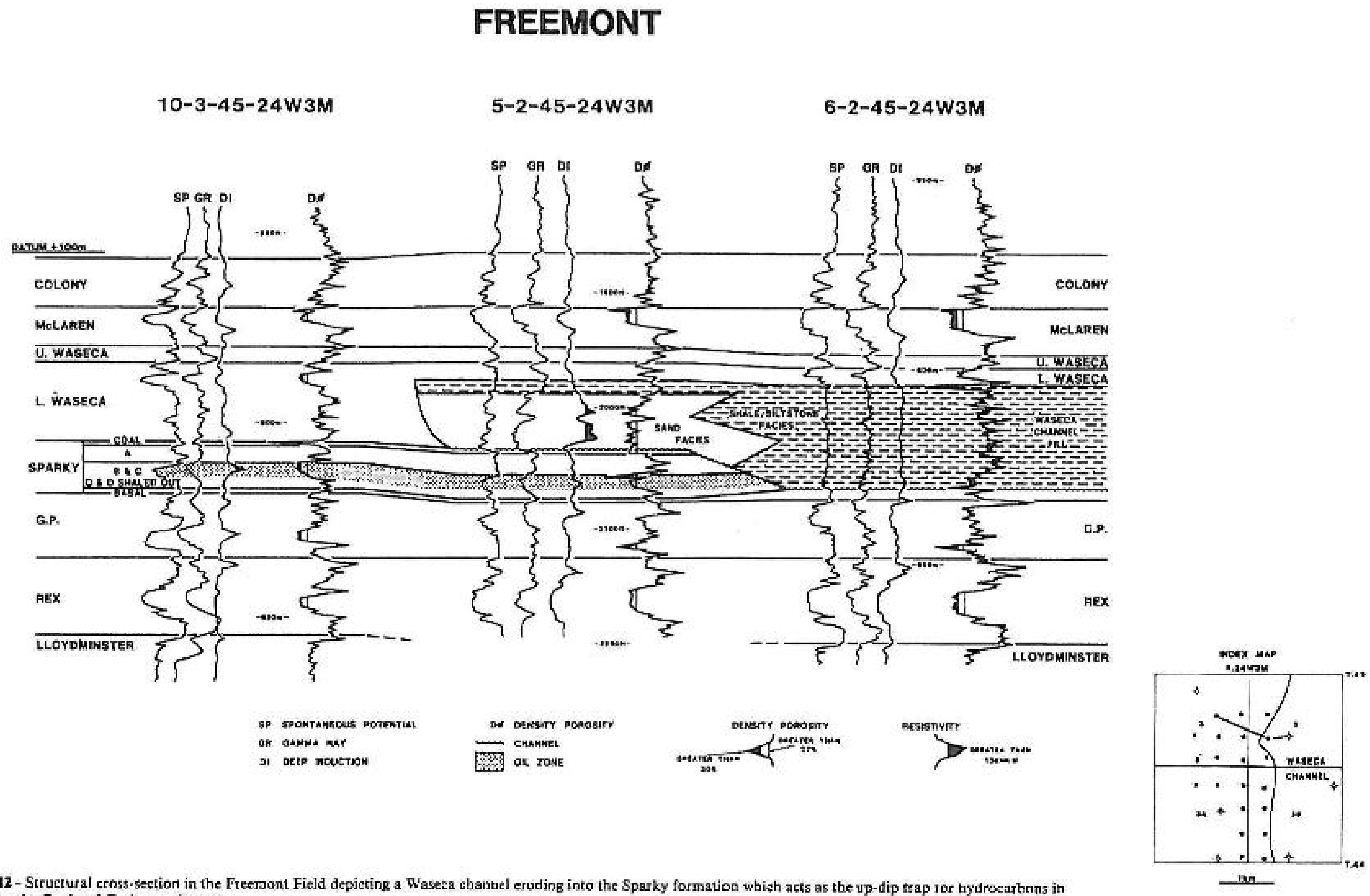



**Fig. 12** - Structural cross-section in the Freemont Field depicting a Waseca channel eroding into the Sparky formation which acts as the up-dip trap for hydrocarbons in the Sparky Regional Facies sandstones.

Three major well log signatures (Gamma Ray and Spontaneous Potential) are identifiable for the Channel Facies:

(a) uniform, deflection to the right (positive Spontaneous Potential; high Gamma Ray) - indicative of shale/siltstone-filled channel (Fig. 10),

(b) bell shaped curve - indicative of a fining upwards sequence from sandstone to shale/siltstone (Fig. 13),

(c) blocky curve - indicative of a sandstone-filled channel (Fig. 13).

### (b) Correlation Problems

Whether or not the Channel Facies is a Sparky, or pre-Sparky channel-fill deposit is sometimes difficult to determine. The basal Sparky marker is, however, distinctive and regionally correlatable so if the Channel Facies was associated with deposition of the pre-Sparky deposits, the basal Sparky would be present. Cores are rare within the Channel Facies, but when they are available, the basal Sparky marker is not observed.

Thin sandstone beds at the top of the sequence can be correlated as the A, B, C and/or D sub-units (Fig. 13) or may be part of the Channel Facies. These sandstone beds may be interpreted as sandstones of the Sparky sub-units which have migrated over an abandoned channel or as late sandstone deposits associated with the abandonment phase of the channel.

### (c) Description

The Channel Facies varies from shale-filled to sandstone-filled; however, the most dominant type is the shale-filled channel. Sandstone-filled channels are developed locally and the major occurrences are illustrated in Figure 14. The better developed channel-fill sandstones are well sorted and slightly coarser grained (fine to medium grained) than the Regional Facies sandstones.

The Channel Facies are generally 10-30m thick, and locally up to 50 m thick; they vary from 0.3 to 2 km wide and may extend to tens of kilometres, but do not exceed 100 km in length. The sandstone Channel Facies appear to form wedge-shaped sandstone bodies such as that present in Home Oil's Kitscoty EOR project. Many of these channel deposits have not, however, been delineated by drilling so the sand body geometry has to be inferred from seismic.

### (d) Distribution

Channel migraton and abandonment make it difficult to determine the initial trend of many of the Sparky channels. The general trend appears to be northwest-southeast.

Distribution of the Channel Facies is not uniform across the study area. The authors have outlined three areas of channeling (Fig. 14):

(a) Wainwright,
(b) Blackfoot/Aberfeldy/Epping,
(c) Golden Lake/Celtic Edam.

Channeling around the Wainwright area does not appear to connect with the other two areas but this may be explained by the lack of well control. The Blackfoot/Aberfeldy/Epping area appears to be connected with the Golden Lake/Celtic/Edam area; however, the Golden Lake/Celtic/Edam area has thicker channel-fill sandstone deposits.

## ENVIRONMENTAL DISCUSSION

### (a) Effect of Pre-Cretaceous Paleo topography on Sparky Deposition

The Pre-Cretaceous topography as derived from the Base of Fish Scale Zone to Pre-Cretaceous unconformity surface isopach map (Fig. 6) is also reflected on the second order residual maps of the Pre-Cretaceous unconformity surface (Fig. 7) and the Sparky formation (Fig. 8). All the maps depict the Pre-Cretaceous ridges and the paleo-low to the east.

The absence of the Sparky coal to the east roughly corresponds to the paleo-low indicated on the Base of Fish Scale Zone to Pre-Cretaceous unconformity surface isopach map (Fig. 6) suggesting the paleo-low was present during Sparky deposition. The widespread distribution of the Sparky coal indicates a low relief topography.

The thickest development of sandstone/siltstone of the Regional Facies (Fig. 2) and more abundant channeling occur between the Lindbergh and Baldwinton Ridges in the center of the Lloydminster Sub-Basin. In the Wainwright area, sandstone/siltstone occur in the Wainwright Ridge which was probably a topographic high relief feature during the early stages of Sparky deposition. However, the thickening of the Sparky coal in the Wainwright area, between the Manitou Lake and Vermilion paleo-valleys (Fig. 6), suggests that this area represents marsh deposition within a slowly subsiding lagoon or interdistributary bay during the final stages of Sparky deposition.

### (b) Timing of the Channel Facies

Channeling occurred prior to Sparky coal deposition as indicated by the Sparky coal overlying the channel-fill (Figs. 10 and 13). Some channeling may in fact be contemporaneous with deposition of the Regional Facies although difficult to prove. Contemporaneous deposition is suggested by:

(1) The Sparky sandstones occasionally become shalier and siltier in proximity to the Channel Facies (Fig. 10),

(2) Channel-fill sandstones are associated with areas in which Regional Facies sandstones such as the B sub-unit are better developed,

(3) Adjacent to the Channel Facies, the Sparky coal can split into two coal beds similar to levee deposits adjacent to channels described by Horne *et al.* (1978).

Channels have eroded down as deeply as the Lloydminster formation. Sparky sandstones, which may correlate as the A, B and/or C sub-units, overlie the Channel Facies (Fig. 13), but whether or not the sandstones are actually these sub-units or late sand influxes during channel abandonment cannot be determined. In these cases, the development of the Channel Facies may be as early as pre-C sub-unit to as late as post-A sub-unit deposition.

At the Aberfeldy steamflood pilot (Smith, in press), a narrow intra-Sparky channel-fill deposit, originated either during A sub-unit or pre-Sparky coal deposition. This interpretation was based on:

(a) The Sparky coal overlying the sequence,

(b) The A sub-unit is absent within this feature. The B, C and D sub-units generally underlie this area but locally the B and part of the C sub-units are also missing,

# RUSH LAKE

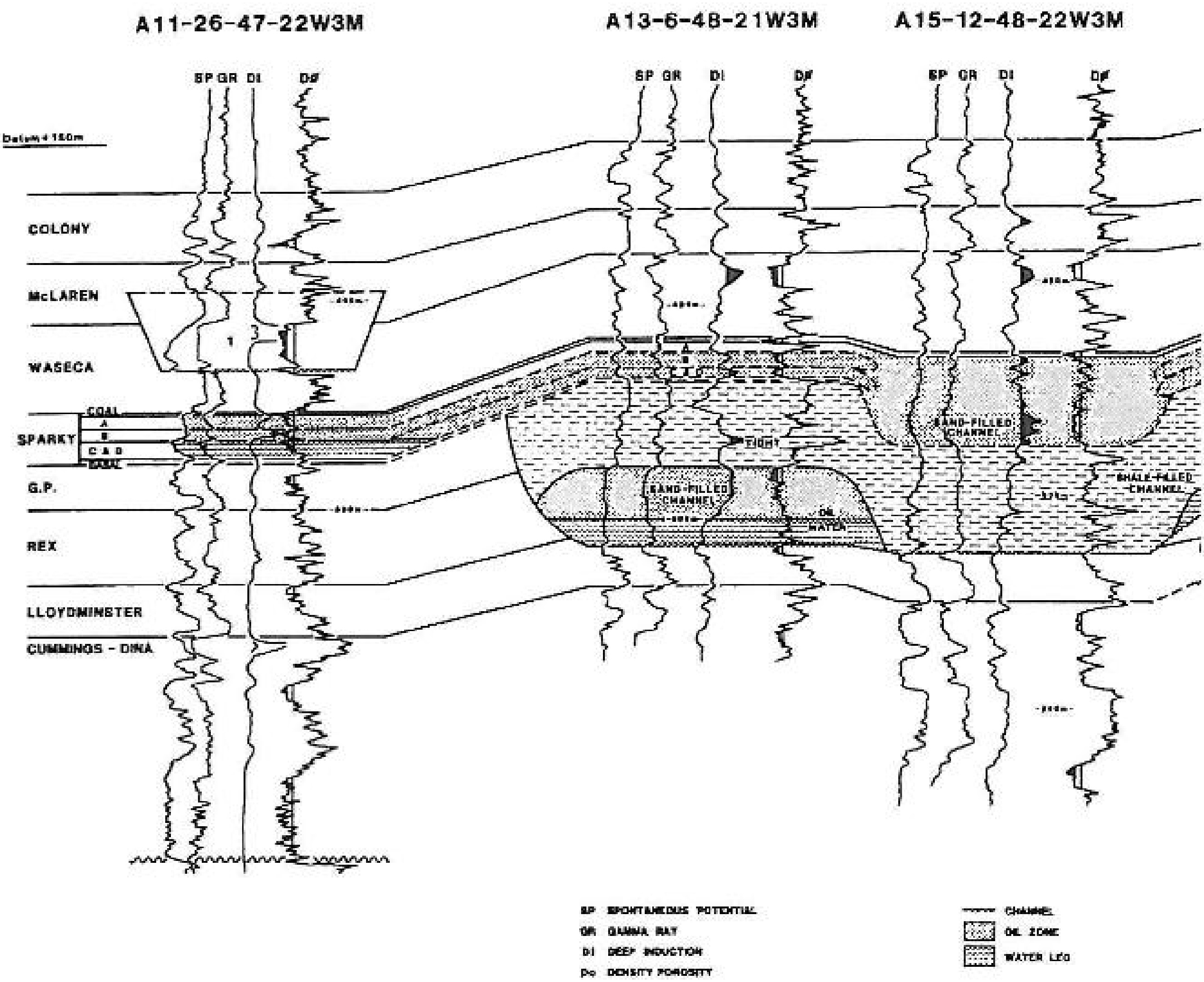



Fig. 13 - Structural cross-section in the Rush Lake Field showing hydrocarbons trapped within sandstone bodies of the Channel Facies. (Dashed lines indicate areas of uncertain correlation.)

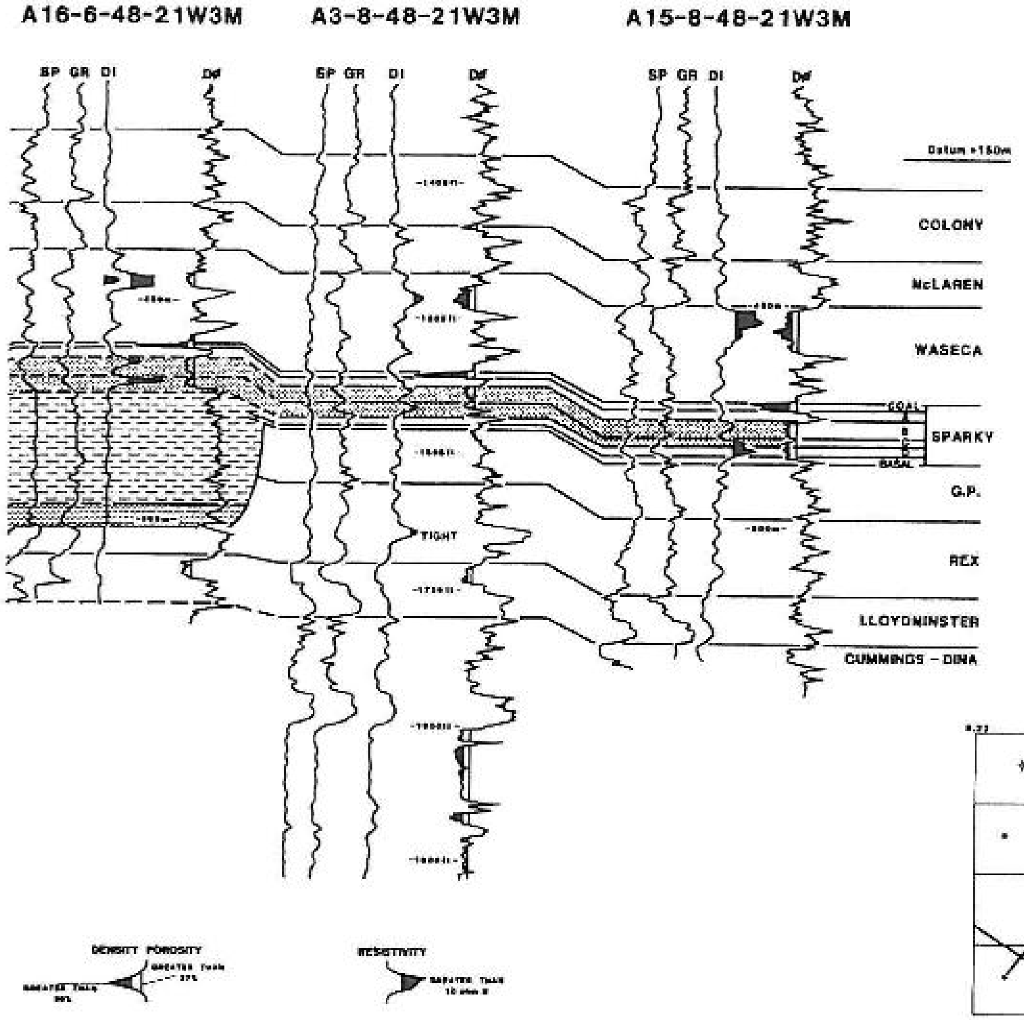
(c) the Sparky formation thins into this area with the change occurring over a very short distance, less than 100m.

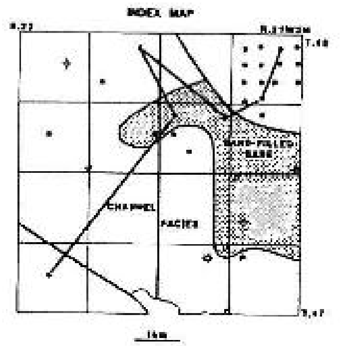
This narrow channel-fill can be traced to the shale-filled Channel Facies bounding the eastern side of the Aberfeldy Field so the channel-fill was interpreted to represent a crevasse splay channel which was abandoned and filled with silty sandstones, siltstones, and shale.

**(c) Environmental Interpretation of Regional and Channel Facies**

In the Regional Facies, the presence of foraminifera (Fuglem, 1970), dinoflagellates (Fuglem, 1970; Putnam, 1982), glauconite, and the well sorted, quartzose nature of the sandstones indicate marine deposition. The coarsening upward sequence as indicated by the lithology and grain size, and the sedimentary structures (low angle and parallel laminations, wave ripples and bioturbation) are similar to sequences in a wave-dominated shoreline (Orr *et al.*, 1977; Putnam, 1982).

A detailed core and mapping study of the Aberfeldy steamflood pilot (Smith, in press) suggested that the Sparky formation was composed of four depositional units: basal Sparky, lower Sparky (B, C and D sub-units), upper Sparky (A sub-unit), and Sparky coal. The basal Sparky represents restricted marine deposits. The lower Sparky was interpreted as a cyclic series of shoreface sandstones with marine siltstones and shale which were then disconformably overlain by interdistributary bay shale and crevasse splay sandstones of the A sub-unit. The narrow channel-fill, which originated either during a sub-unit sandstone deposition or pre-Sparky coal deposition, was probably an abandoned crevasse channel. Marsh sediments, with an associated root zone, of the Sparky coal




then were deposited over the entire sequence. Smith (in press) interpreted this sequence to represent part of a wave dominated delta.

In other parts of the study area, the characteristics of the Sparky formation also indicate a wave dominated deltaic sequence. That the basal Sparky was deposited in a restricted marine environment is indicated by the presence of dinoflagellates and foraminifera. In addition, the sedimentary structures and sediments themselves suggest a low energy environment.

Interbedded sandstone, siltstone, and shale of the C and D sub-units are interpreted as shoreface deposits from the presence of vertical burrows, wavy bedding, and wave ripples. In the Wainwright area, however, well sorted, cross-bedded (wave ripples) siltstones/sandstones indicate that these sub-units were deposited in higher energy environment.

In the B sub-unit, the sandstone is thicker and better sorted in the central protion of the Lloydminster Sub-basin. Here the B sandstone is interpreted to be an upper shoreface deposit due to its well sorted character and the occurrence of low angle and parallel laminations. Towards the southwest and northeast, the B sub-unit grades into shale and siltstone with occasional sandstone beds. These deposits may either represent lagoonal or shoreface/offshore deposits. The basin configuration suggests the deposits to the southwest are lagoonal whereas the deposits to the northeast are nearshore/offshore. Cores are lacking in these areas so diagnostic confirmation of the environmental interpretation is difficult.

The northwest-southeast trending oil fields are dissected by northeast trending Channel Facies which are dominately shale-filled. Sandstone-filled channels occur in the region where the thickest B sandstone is developed. These channel-fill sand-

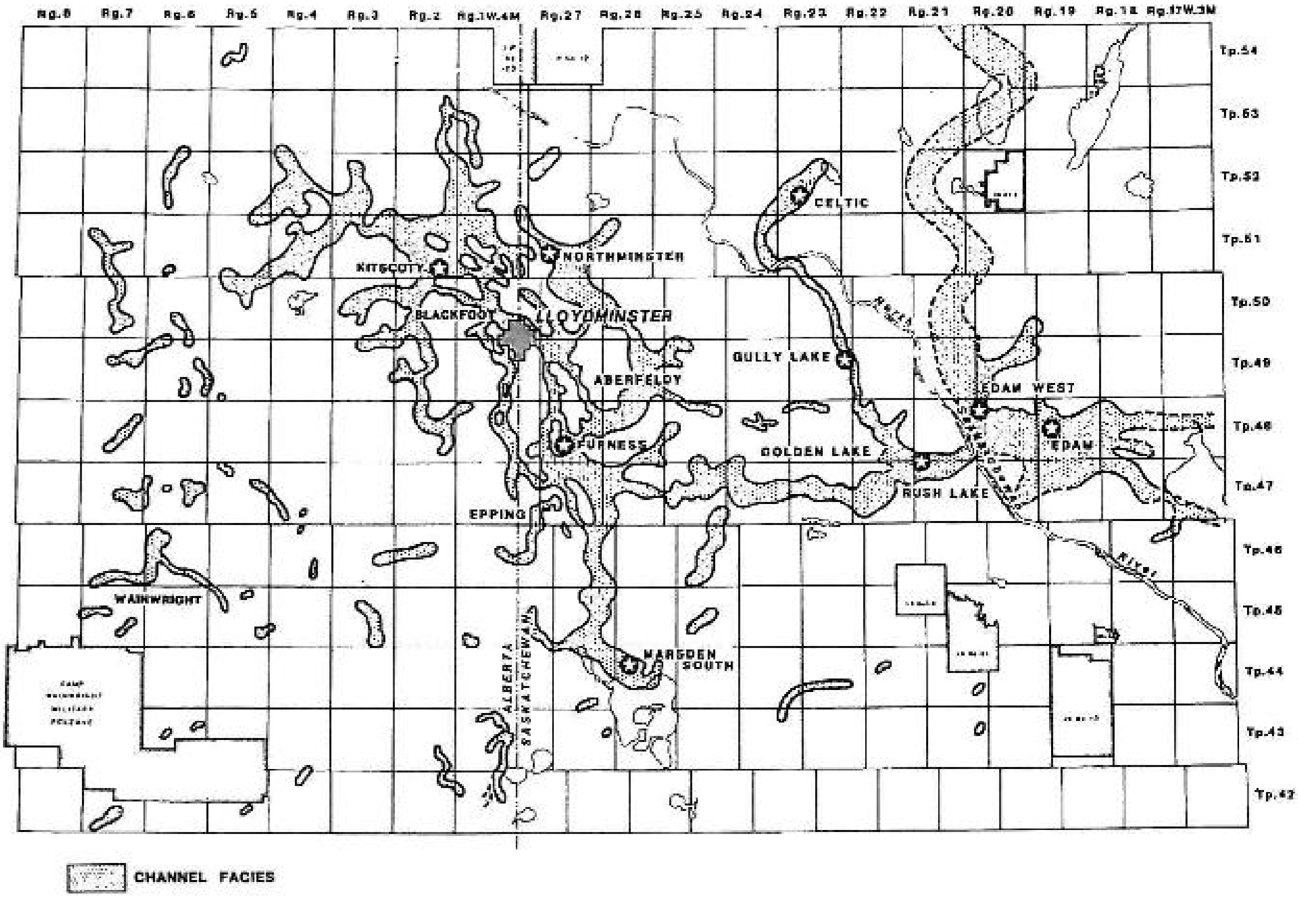



Fig. 14 - Distribution of the Channel Facies with the major channel-fill sandstone deposits highlighted. All the well logs in the study area were reviewed to determine the log signature for grouping into the two major facies within the Sparky formation. The dashed lines indicate possible channels that are defined by only a few thick Channel Facies wells.

stones may be distributary channels and/or tidal inlet deposits. The shale-filled channels may represent abandoned distributary channels or portions of a lagoonal environment.

The A sandstone is commonly developed in the Aberfeldy and Golden Lake Fields. Major channels are in close proximity to these sandstone occurrences which are probably crevasse splay deposits. Elsewhere, the A sub-unit's shales and poorly sorted, silty sandstones are probably interdistributary bay deposits between distributary channels or lagoonal sediments behind thick shoreface sandstone. In proximity to the edge of the Prairie Formation, the Channel Facies has more numerous and thicker sandstone-filled channels with a greater areal extent than sandstone-filled channels to the west, suggesting a possible estuarine origin for these deposits.

Marsh deposits, represented by the Sparky coal, cap the entire sequence. To the northeast and east, the absence of the Sparky coal corresponds with the Prairie Formation depression, implying that the paleo-low influenced the Sparky coal's distribution.

(d) **Depostional Model**

The Sparky formation represents a regressive phase within the Mannville Group of the Lloydminster area. The basal Sparky is continuous across the Lloydminster Sub-basin implying that restricted marine conditions existed over the entire region after deposition of the General Petroleums formation. During C and D sub-unit deposition, areas of slightly higher relief, such as the Wainwright Ridge, had clastic sediments reworked by wave action into well sorted shoreface siltstones/sandstones (Fig. 15A). Interbedded sandstone, siltstone and shale were deposited throughout the remainder of the Lloydminster Sub-basin and indicate areas of slightly deeper shoreface to near shore sedimentation. During B sub-unit deposition (Fig. 15B), either lowering of sea level or an increased sedimentation rate resulted in northeastward progradation of shoreface deposits towards the area of the city of Lloydminster. Thick shoreface sandstone bodies were deposited in a general northwest-southeast trend. Distributary channel and/or tidal inlets dissected these thick shoreface deposits. Lagoonal mud and silt occur to the southwest of the shoreface deposits. In the Prairie Formation depression to the northeast and east, nearshore/offshore mud, silt and occasional sand beds accumlated. The final phase of the regression (Fig. 15C) had crevasse splay and overbank deposits filling interdistributary bays and/or lagoonal mud, silt and occasional sand occurring in the lee of shoreface deposits. Major sand-filled channels developed in the eastern part of the sub-basin and are possibly of estuarine origin. An extensive marsh environment existed over most of the Lloydminster Sub-basin but was absent to the northeast and east, probably due to continued marine conditions in the Prairie Formation depression. The depositional characteristics of the Sparky formation suggest a wave-dominated deltaic environment in the Lloydminster area.

## TYPE OF HYDROCARBON TRAPS

### INTRODUCTION

Heavy oil in the Lloydminster area has accumulated in stratigraphic and/or structural traps. Four main trap types are recognized in the Sparky formation:

Type A The Regional Facies abutting up-dip against the shale-filled Channel Facies (Vigrass, 1977),

Type B Structural reversal caused by salt disslution of the underlying Devonian Prairie Formation (Orr *et al.*, 1977),

Type C Sandstone-filled Channel Facies either abutting up-dip against non-reservoir rocks of the Regional Facies or shale-filled portions of the Channel Facies,

Type D Lateral pinch-out of the Regional Facies sandstones.

Types A and B are the two most important trapping mechansims.

Typically, heavy oil pay in the Regional Facies varies from 3 - 14m thick (Fig. 2). These area lie in the central part of the study area between the Paleozoic ridges and the Devonian Prairie Formation depression. Sandstone bodies in proximity to, and overlying, the Pre-Cretaceous ridges are thinner but can be productive, as is the case in the Wainwright field. Sandstone sub-units in the Prairie Formation depression are also thinner but are generally water-bearing. The sandstone-filled Channel Facies may have oil pays up to 40m thick (i.e. Home Oil's Kitscoty EOR Project: S/2 2-51-2W4M).

Sandstone/siltstone reservoirs in the Sparky formation have the following characteristics:

| | |
|---|---|
| Porosity | 27-33%; generally 30% |
| Permeability | 500-8000 md; generally 1000-5000 md |
| Water Saturation | 15-35%; generally 14-18° |
| API | 10-25°; generally 20% |
| Viscosity | greater than 1000 cps; generally 3,000-10,000 cps |

### TYPE A: SHALE-FILLED CHANNEL FACIES

The shale-filled Channel Facies acts as the up-dip permeability barrier to hydrocarbon movement (Vigrass, 1977) within sandstones/siltstones of the Regional Facies (Fig. 11). They are primarily Sparky channel-fills. Waseca shale-filled channels (Fig. 13), however, have also eroded through part of all of the Sparky formation in some areas such as the Freemont Pool, Saskatchewan (Dunning *et al.*, 1980) and provide the up-dip trapping mechanism.

As illustrated in Figure 11 from the Aberfeldy Field, the Sparky shale-filled Channel Facies has eroded down into the lower portion of the General Petroleums formation and forms the up-dip trap for Regional Facies sandstones in both the Sparky and General Petroleums formations. The 3B7-20 well, from the Aberfeldy steamflood pilot, is a typical well log from the field, even though the area has been previously subjected to waterflooding. Regionally, oil is present in all four Sparky sub-units although this varies from pool to pool. The better development of reservoir quality sandstone/siltstones in the B and C sub-units results in these being the more productive sub-units.

### TYPE B: DEVONIAN PRAIRIE FORMATION EDGE

Salt dissolution of approximately 160m of Devonian Prairie Formation has formed a reversal of dip (Orr *et al.*, 1977) in the eastern part of the study area (Fig. 4). This is the major trapping mechanism for the Celtic, Westhazel, Standard Hill, Rush Lake and Edam Sparky Fields. Structural relief in the order of 90m has caused oil trapping in other Mannville formations besides the Sparky formation. Figure 4 shows the southwesterly dip, and the thinning of the Prairie Formation salt to the east. In the areas of thin or no Prairie Formation the overlying formations are structurally low, causing hydrocarbons to be trapped in the structurally high areas.

### TYPE C: SANDSTONE-FILLED CHANNEL FACIES

Within the Channel Facies, sandstone-filled portions have locally developed and traps from either against the shale-filled portions of the Channel Facies (Fig. 13) or against non-reservoir shale/siltstones of the Regional Facies. The oil in these sandstones is typically heavier than oil in the Regional Facies due to increased biodegradation of the oil. The Channel Facies sandstones are typically thicker, slightly coarser grained, better sorted, and have less clay than the Regional Facies sandstones but the increased viscosity of the oil and the presence of waterlegs have generally made them uneconomical to produce at this time. For this reason, many of these pools have sparse well control, making it difficult to ascertain the size and geometry of the sand body. Figure 14 depicts areas in which the authors have identified Sparky related channel-fill sandstones with oil pay.

A structural cross-section (Fig. 13) through the Rush Lake area of Saskatchewan illustrates the major characteristics of this type of trap. The Sparky coal overlies all the wells and the Channel Facies extends down into the Rex formation and in places, into the top of the Lloydminster formation. A local channel-filled sandstone has developed at the base of the Channel Facies and is encased by shale-filled portions of the Channel Facies and shales of the Rex formation. Local sandstone bodies and thin sandstones, stratigraphically equivalent to the Sparky B, C and D sub-units, occur in the upper part. As previously mentioned, they may represent late sand influxes during channel abandonment or migration of the Sparky sub-units over an in-filled channel.

### TYPE D: LATERAL PINCH-OUT OF REGIONAL FACIES SANDSTONE

This type of trap is of minor importance and is more common locally within pools where one or more sandstone sub-units grade laterally into non-reservoir shale/siltstone. At Marsden, Saskatchewan (Fig. 16), the Sparky B, C and D sub-units grade up-dip into non-reservoir shale/siltstone with minor tight sandstone beds. Down-dip at A6-10-44-27W3M, the Sparky C and D sub-units are completely wet and the Sparky B sandstone sub-unit is tight.

## SUMMARY

The Base of Fish Scale Zone to pre-Cretaceous unconformity surface isopach map thickens to the northeast and east into a structural low caused by salt dissolution of the underlying

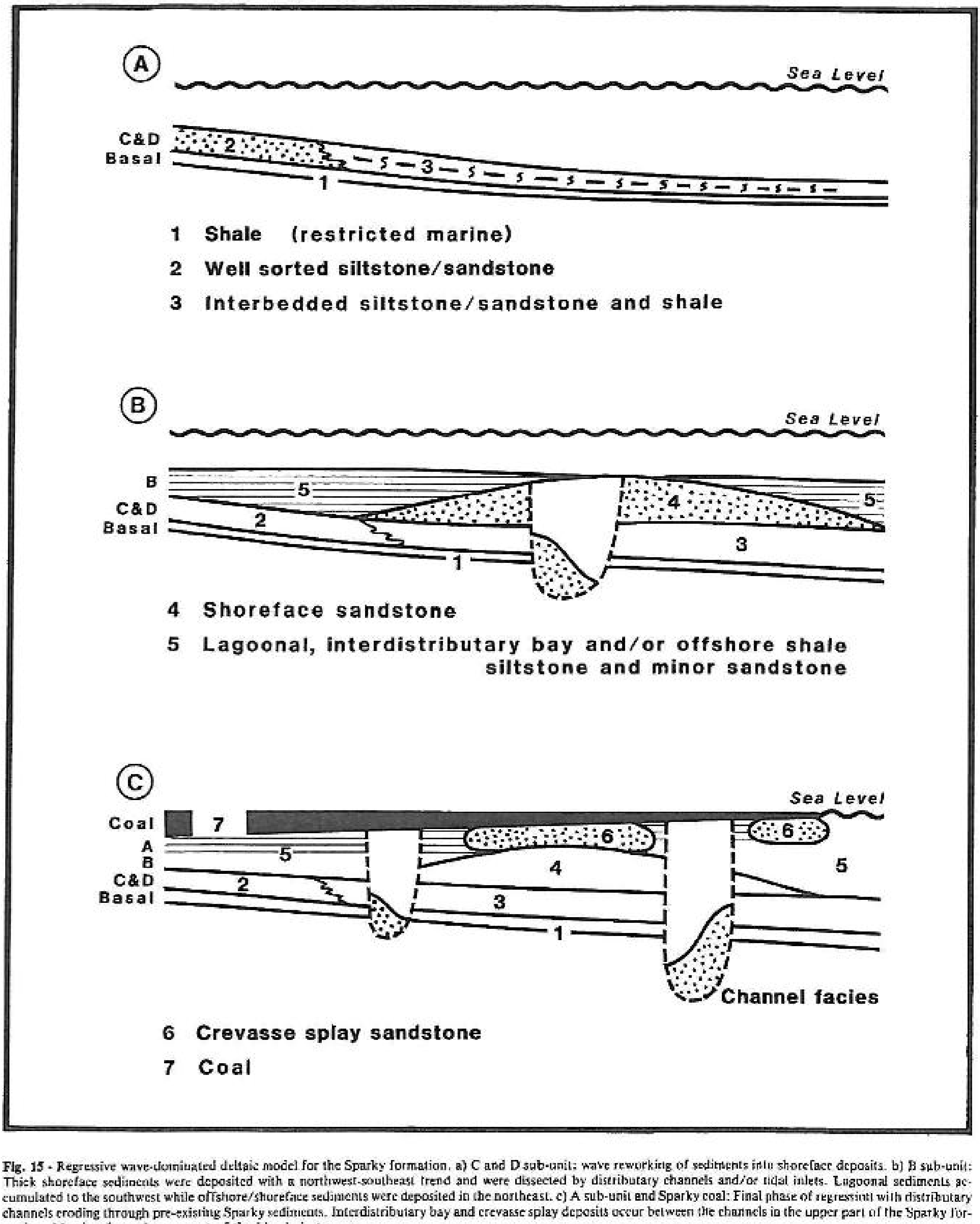
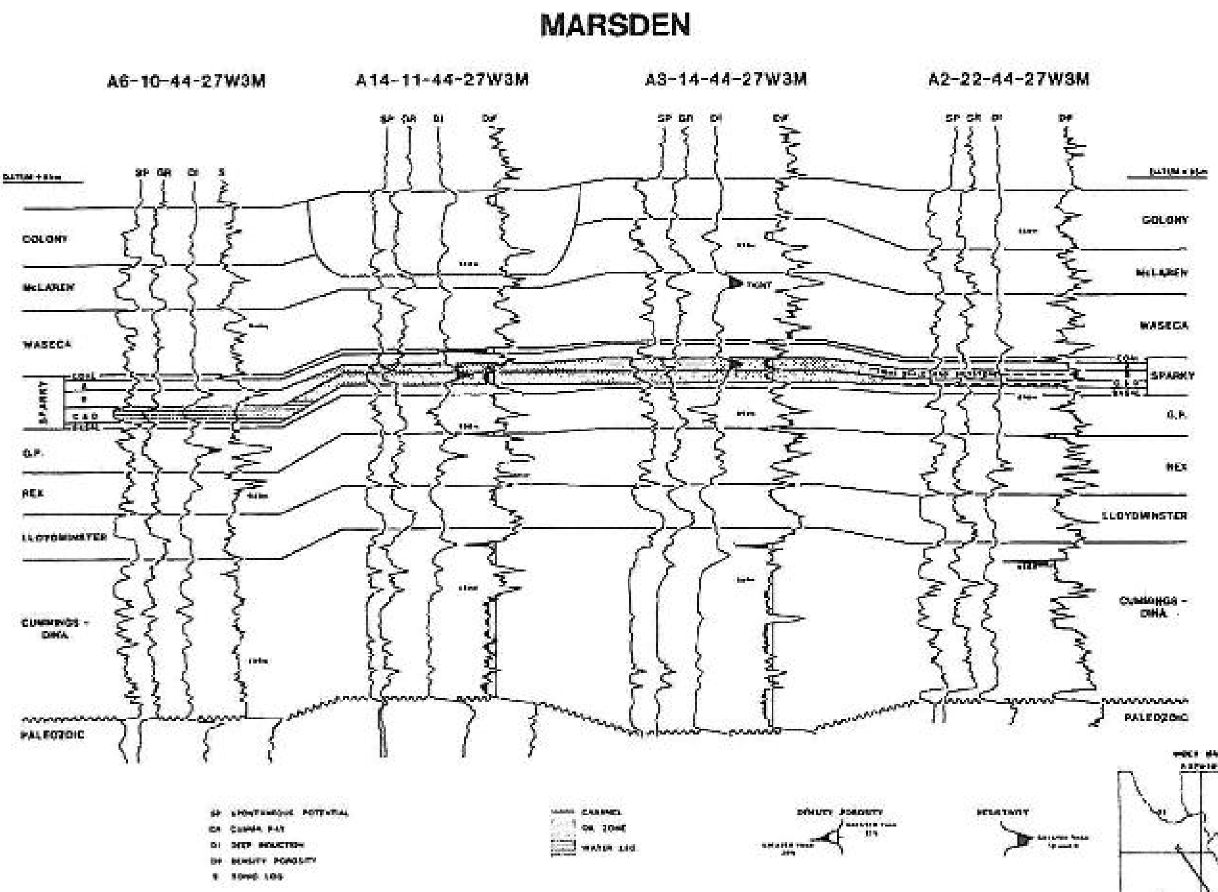



**Fig. 15** - Regressive wave-dominated deltaic model for the Sparky formation. a) C and D sub-unit: wave reworking of sediments into shoreface deposits. b) B sub-unit: Thick shoreface sediments were deposited with a northwest-southeast trend and were dissected by distributary channels and/or tidal inlets. Lagoonal sediments accumulated to the southwest while offshore/shoreface sediments were deposited in the northeast. c) A sub-unit and Sparky coal: Final phase of regression with distributary channels eroding through pre-existing Sparky sediments. Interdistributary bay and crevasse splay deposits occur between the channels in the upper part of the Sparky formation. Marshes formed over most of the Lloydminster area.



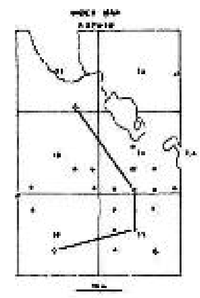



Fig. 16 - Structural cross-section in the Marsden area illustrating hydrocarbons being trapped by lateral pinch-out of the Regional Facies sandstones.

Devonian Prairie Formation and thins over Devonian Woodbend Formation carbonate ridges to the southwest, south, and north. These ridges outline the Lloydminster Sub-basin and are referred to as the Wainwright Ridge, Baldwinton Ridge, and Lindbergh Ridge respectively. It is suggested that deposition of the Sparky formation has been influenced by the basin configuration of the pre-Cretaceous unconformity surface.

The second order residual maps of the pre-Cretaceous unconformity surface and the Sparky formation also depict the major structural elements bordering the sub-basin, suggesting the pre-Cretaceous basin configuration influenced Sparky deposition. The relationship is further illustrated by the edge of the Sparky coal, which generally coincides with the edge of the Devonian Prairie Formation in the east. This structural low was probably present during Sparky deposition and has restricted marsh development due to the continued existence of marine waters. Thickening of the Sparky coal in the Wainwright area occurred in a slowly subsiding lagoon or interdistributary area during the last stage of deposition within the Sparky formation. Extensive channeling in the center of the sub-basin is related to channel migration and abandonment. Thicker and more widespread sandstone-filled channels occur adjacent to the edge of the Prairie Formation salt and may be of estuarine origin. Most of the Sparky oil fields occur in the center of the sub-basin and are interpreted to be shoreface sandstone/siltstones.

Structural and/or stratigraphic traps are present in the Lloydminster heavy oil area. The most important trapping mechanisms for the Sparky formation are:

(a) Shale-filled Channel Facies forming the up-dip seal for the Regional Facies sandstones,

(b) Salt dissolution of the underlying Devonian Prairie Formation has caused structural reversal in the Celtic/Westhazel/Edam area.

Locally, the development of Channel Facies sandstones and lateral pinch-out of Regional Facies sandstones are possible Sparky hydrocarbon traps.

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