Petrology, Rock-Eval and facies analyses of the McLeod coal seam and associated beds, Pictou Coalfield, Nova Scotia, Canada

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Coals, cannel coals and oil shales of the McLeod sequence from two boreholes in the Pictou Coalfield, Nova Scotia were analysed using methods of organic petrology and organic geochemistry.

Petrographic composition was determined by maceral and microlithotype analyses. Within the McLeod coal seam, varying amounts of alginite, vitrinite, inertinite, and mineral matter indicate significant changes in the environment of deposition. High amounts of lamalginite and minerals, i.e., clay minerals and pyrite at the base and top of the seam indicate a limnic depositional environment, whereas much dryer conditions are indicated for the middle portion of the seam by better tissue preservation, typical for a wet forest type of swamp. This is confirmed also by results from microlithotype analyses. In the oil shales the predominant maceral is alginite.

Coals, cannel coals and oil shales vary significantly in TOC values and hydrocarbon potentials. Parameters such as hydrogen and oxygen indices and hydrocarbon potentials are in good agreement with results from petrographic analyses.

Methods of organic petrology and organic geochemistry define distinct types of organic matter in coals, cannel coals and oil shales which can be related to facies changes and environments of deposition. From the preliminary results it appears that these methods also can be applied regionally for stratigraphic correlations within sequences of rapid facies changes.

Des charbons, des charbons de spores et pollens, ainsi que des schistes bitumineux appartenant à la série de McLeod et provenant de deux sondages dans le bassin houiller de Pictou (Nouvelle-Ecosse) furent analysés à l'aide de méthodes de pétrologie et de géochimie organiques.

On détermina la composition pétrographique grâce à une analyse des macéraux et des microlithotypes. La variation des teneurs en alginite, vitrinite, inertinite et en composants minéraux au sein du filon charbonneux de McLeod témoigne de changements majeurs dans le milieu de dépôt. Un milieu de dépôt limnique est indiqué par des teneurs élevées en lamalginite et en minéraux, i.e. minéraux argileux et pyrite, tant à la base qu'au sommet du filon. En revanche, une meilleure conservation des tissus, typique des marécages de forêt humide, trahit des conditions beaucoup plus sèches pour la portion centrale du filon. Les résultats d'analyses de microlithotype confirment cet état de chose. L'alginite est le macéral prédominant dans les schistes bitumineux.

Les charbons, les charbons de spores et pollens, ainsi que les schistes bitumineux varient fortement aux plans du COT et du potentiel pétroligène. Certains paramètres, comme les indices d'hydrogène et d'oxygène et les potentiels pétroligènes, confortent les résultats obtenus grâce aux analyses pétrographiques.

Au sein des charbons, charbons de spores et pollens, et schistes bitumineux, les méthodes de la pétrologie et de la géochimie organiques définissent des types distincts de matière organique qui peuvent être liés aux changements de faciès et aux milieux de dépôt. A partir de ces résultats préliminaires, il semble qu'on puisse utiliser ces méthodes à une échelle régionale pour réaliser des corrélations stratigraphiques à l'intérieur de séries montrant des changements rapides de faciès.

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INTRODUCTION

Upper Carboniferous strata of the Pictou Coalfield, Nova Scotia, Canada are characterized by the occurrence of up to 45 coal seams (Hacquebard, 1978). The coals grade laterally and vertically into cannel coals and oil shales reflecting rapid changes in depositional environments. The coal facies of the Pictou Coalfield is believed to have been formed in a swamp type environment along lakeshores, whereas lacustrine conditions resulted in the deposition of the oil shale facies.

Previous petrographic studies on the coal/oil shale sequence of the Pictou Coalfield (Kalkreuth and Macauley, 1987) showed that the two facies are characterized by distinct types of organic materials. In the coals wood-derived materials such as vitrinite and inertinite macerals are the predominant components whereas in the oil shales the maceral alginite was found to be the major component, and content in inertinite and vitrinite macerals was very low.

The present study focusses on petrographic and organic geochemical analyses of two closely spaced boreholes (Fig. 1), from which the McLeod sequence of the Coal Brook Member (Fig. 2) was sampled in detail over a 10 m interval. In borehole P-29 this interval is characterized by alternating layers of oil shale, cannel coals, coaly shales and coal (McLeod seam). In borehole AP-0371 the sequence consists entirely of oil shales, torbanite and cannel coals. On the basis of marker beds (siderite and calcite bands), the lower part of the cannel coal/oil shale sequence in AP-0371 has been correlated with the McLeod coal seam in P-29. The objectives of this study were to determine variations in organic and mineral matter contents throughout the oil shale/coal sequence, to assess depositional environments, in particular, of the McLeod coal seam in borehole P-29, and to evaluate hydrocarbon potentials of the various lithologies. The analytical methods applied include incident light microscopy (white light and blue light illumination) to determine organic matter types (macerals) and Rock-Eval analyses to determine organic carbon contents, kerogen types and hydrocarbon potentials, particularly in the oil shale lithologies.

SAMPLING AND EXPERIMENTAL

A total of 73 channel samples were analysed from the two boreholes. The stratigraphic profiles along with sample numbers, thicknesses and lithologies are shown in Figure 3 (borehole P-29) and Figure 4 (borehole AP-0371). The lithologic description of the oil shale/coal sequence is based on macroscopic features such as differences in streak, texture, fracture style and toughness (Naylor *et al.*, 1985).

Petrographic Analyses

The samples were crushed, mounted in epoxy, then ground and polished following the procedures outlined by Bustin *et al.* (1985). Maceral analyses are based on 300 counts/sample and were carried out under white and blue light illumination. The latter is necessary to recognize the fluorescing liptinite macerals, particularly in the oil shales. The classification used is that of a slightly modified Stopes Heerlen System (I.C.C.P., 1971, 1975) which distinguishes three main groups of coal macerals, namely the vitrinite, liptinite and inertinite groups. In addition, the maceral alginite was subdivided into telalginite and lamalginite following a proposal by Cook *et al.* (1981). The former consists of discrete algae remains (in the Pictou Coalfield of mainly *Botryococcus* type). The latter consists of lamellar alginite materials interlayered with or coating the mineral matrix.

Rock-Eval Analyses

Rock-Eval techniques applied to oil shales have been described previously (Kalkreuth and Macauley, 1984, 1987) and are hence not discussed here. In the context of the present study important parameters obtained from Rock-Eval analyses are the TOC values (total organic carbon), the hydrogen and oxygen indices for classification of the organic materials, and the hydrocarbon potentials.

RESULTS AND DISCUSSION

Petrographic Analyses

The overall variations in contents of mineral and organic matter for the two boreholes are illustrated in Figure 3 (borehole P-29) and Figure 4 (borehole AP-0371).

Borehole P-29

The oil shale/cannel coal facies in P-29 is characterized by the predominance of mineral matter over organic materials (except sample A-02 at the base), while in the coals mineral matter contents are low (Fig. 3). The distribution of the organic material (mineral matter free) shows that liptinite (alginite) is the predominant component in the oil shales and cannel coals, while in the coals liptinite contents are much lower. In the coals, the major component is vitrinite, while inertinite contents are in the order of 15-20 Vol. % (m.m.f.). In the oil shale/cannel coal lithology clay is the main component, while contributions of carbonates, quartz and pyrite are of minor importance. The coals, in contrast, contain larger amounts of pyrite and quartz.

Borehole AP-0371

The oil shale, cannel coal, torbanite sequence in borehole AP-0371 is characterized by a relatively low organic matter content except for some samples at the base of the interval (Fig. 4). Within the organic matter, liptinite (alginite) was found to be the main component. Vitrinite and inertinite contents are in general very low except in the lower part of the sequence, where vitrinite contents are in the order of 24-34 Vol. % (m.m.f.), samples B-02 to B-06, Figure 4. The mineral matter consists mainly of clays and carbonates while quartz and pyrite contents are low, Figure 4.

Averaged values for mineral matter and organic matter contents for the various lithologies shown in Figures 3 and 4 are summarized in Figure 5.

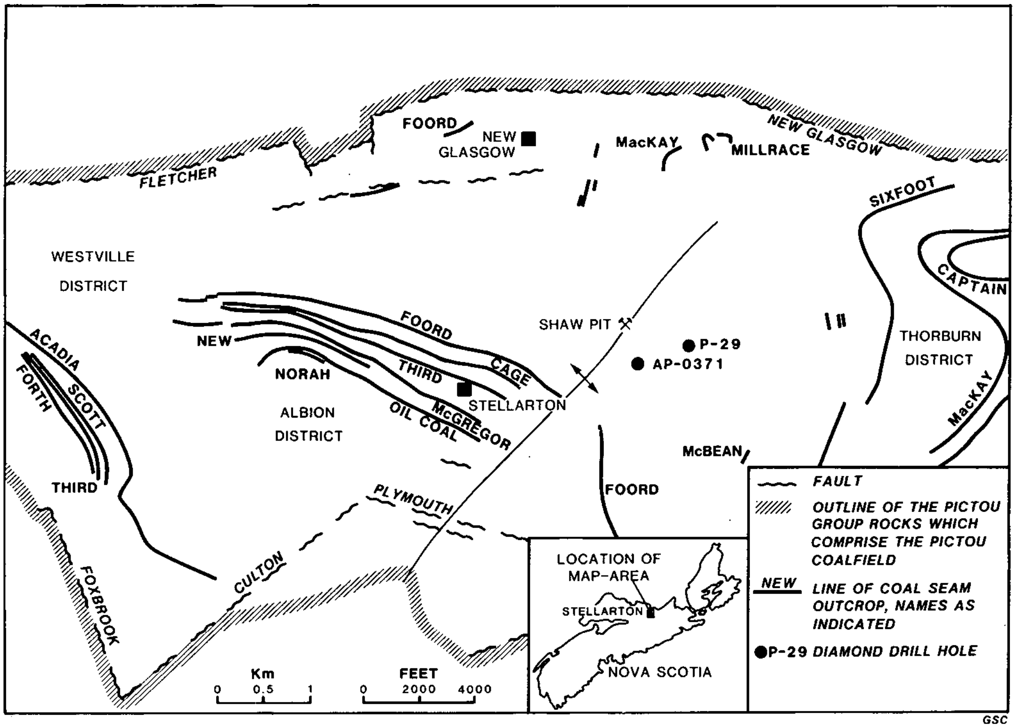


Fig. 1. Study area and location of boreholes P-29 and AP-0371.

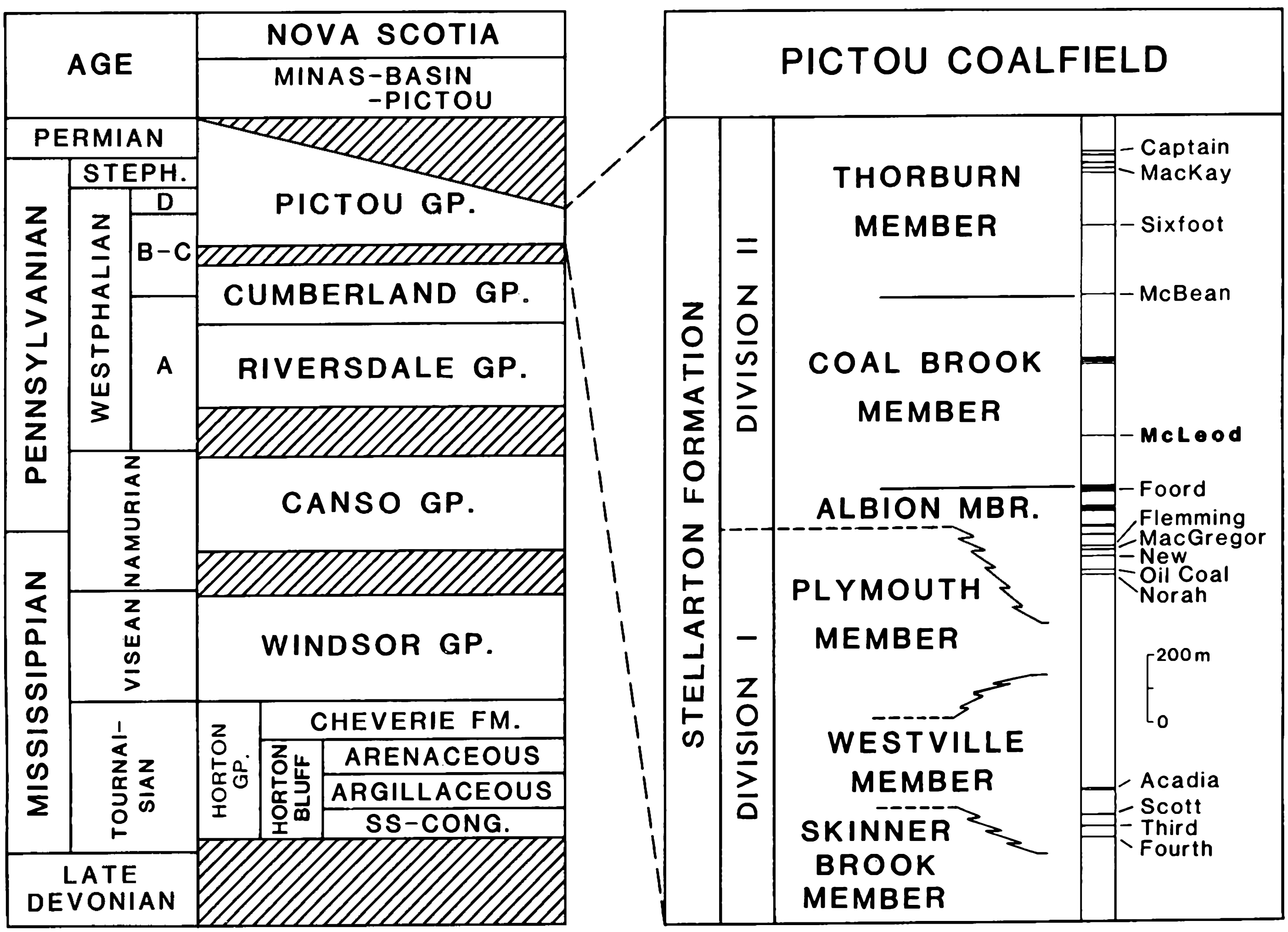


Fig. 2. Carboniferous stratigraphy of the Pictou Coalfield and position of the McLeod coal seam, modified from Bell (1940) and Macauley and Ball (1984).

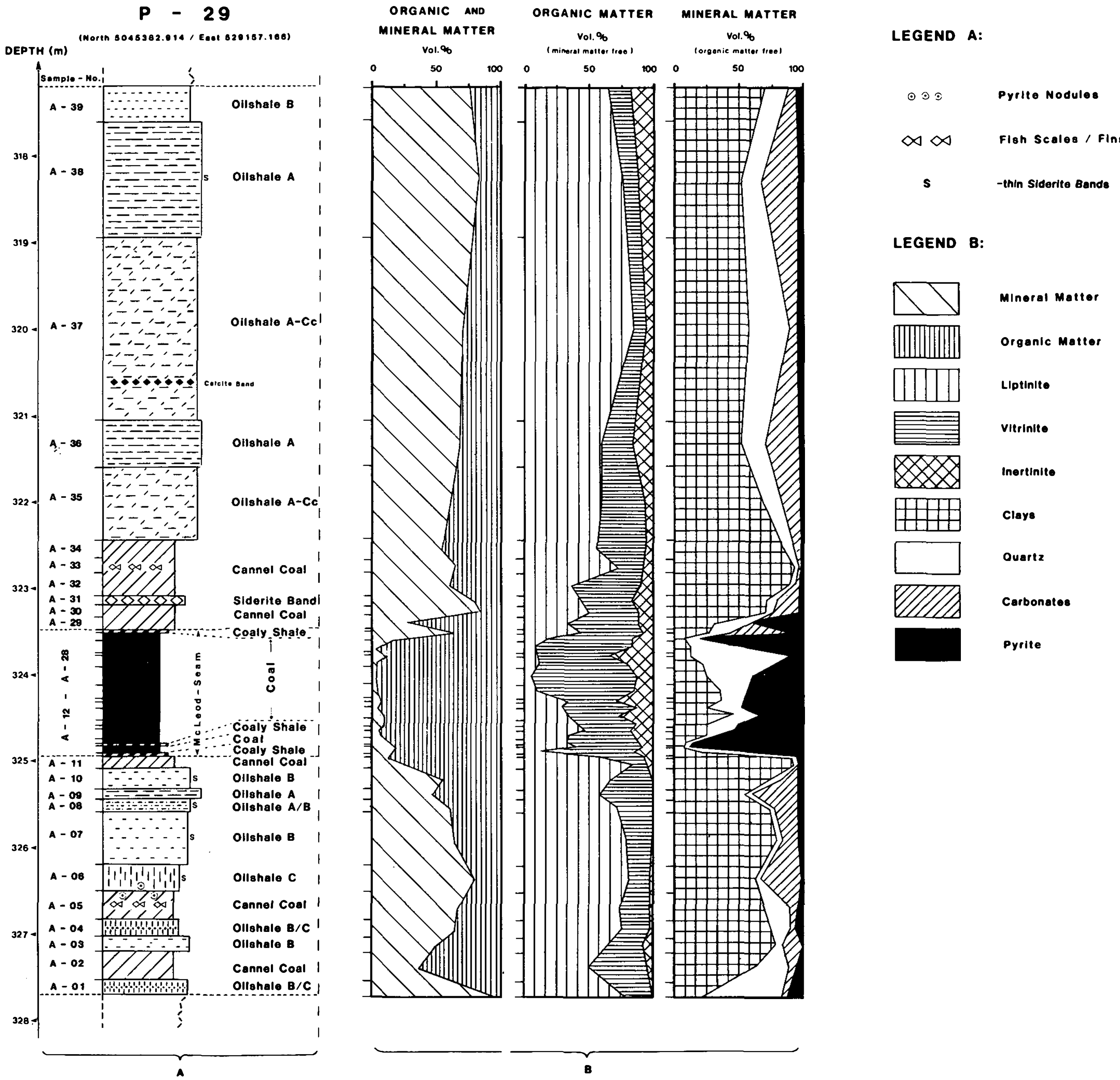


Fig. 3. Lithologic description of the McLeod coal seam and associated beds in borehole P-29 and organic and mineral matter contents for the various lithologies.

Rock-Eval Analyses

Hydrogen and oxygen indices

Hydrogen and oxygen indices derived from Rock-Eval analyses indicate a predominance of kerogen type I and II in the samples. The interpretation of the data are somewhat difficult since the evolution paths of kerogen type I and II are very similar at the maturation levels encountered in these holes. Results for samples from borehole P-29 are shown in Figure 6. The coal samples vary significantly in hydrogen indices (Fig. 6a), which reflect the variations of hydrogen-rich liptinite components. For the coaly shales, a tendency to increasing oxygen indices is indicated by two of the three samples analysed. Cannels coals and the various oil shale lithologies (Fig. 6b, c) do plot in similar areas. Variations in hydrogen indices apparently reflect variations in type of organic matter since the maturation level is the same. A number of oil shale samples show slightly increased oxygen indices (Fig. 6c), which are probably related to release of inorganic CO_2 from carbonate-rich samples. Hydrogen and oxygen indices for samples from borehole AP-0371 are shown in Figure 7. Cannel coals (Fig. 7a) and oil shale lithologies (Fig. 7b) plot in similar areas and are characterized by relatively high hydrogen indices and low oxygen indices. The highest hydrogen indices were determined for the two torbanite samples (Fig. 7a), which were petrographically characterized by high telalginite contents

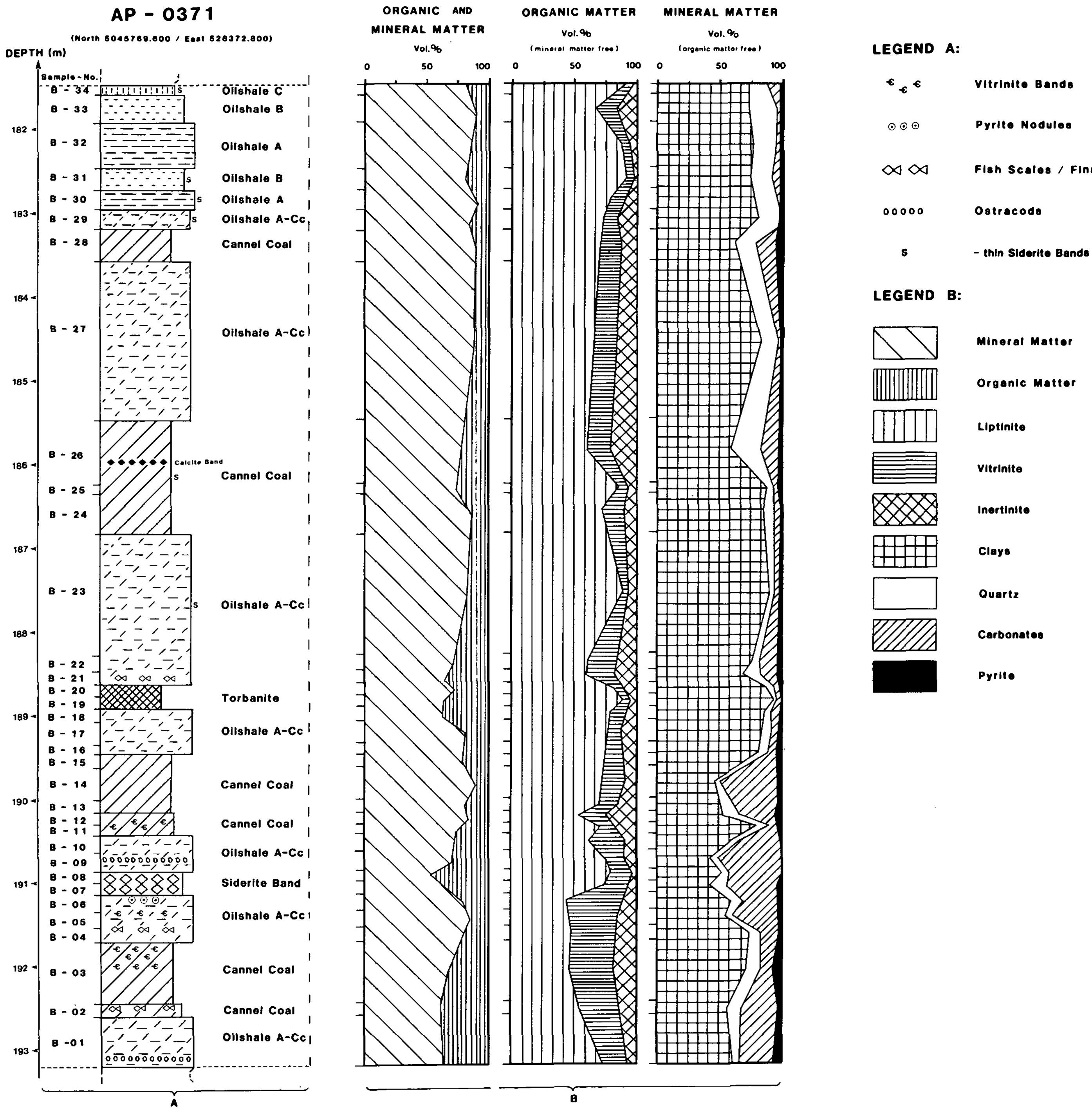


Fig. 4. Lithologic description of the McLeod sequence in borehole AP-0371 and organic and mineral matter contents for the various lithologies.

of 47 and 52 Vol. % (m.m.f.) respectively, whereas in the other oil shale lithologies the most common liptinite maceral, in general, was lamalginite.

TOC values

The McLeod coal seam and associated beds are characterized by large variations in total organic carbon contents. Lowest values were determined for the oil shale C lithology (2-3 wt. %). The TOC values gradually increase to values of up to 12 wt. % in the cannel coals (Table 1).

Petroleum potentials

The results determined for the various lithologies are shown in Figure 8. Lowest petroleum potentials were determined for the oil shale C lithology (4.2-8.8 mg hydrocarbons/g of rock), while oil shale A and cannel coals yielded 36.2-54.8 mg hydrocarbons/g of rock. Yields >40 kg/t of rock, which are presently considered of economic interest (Macauley, 1987), are generated from

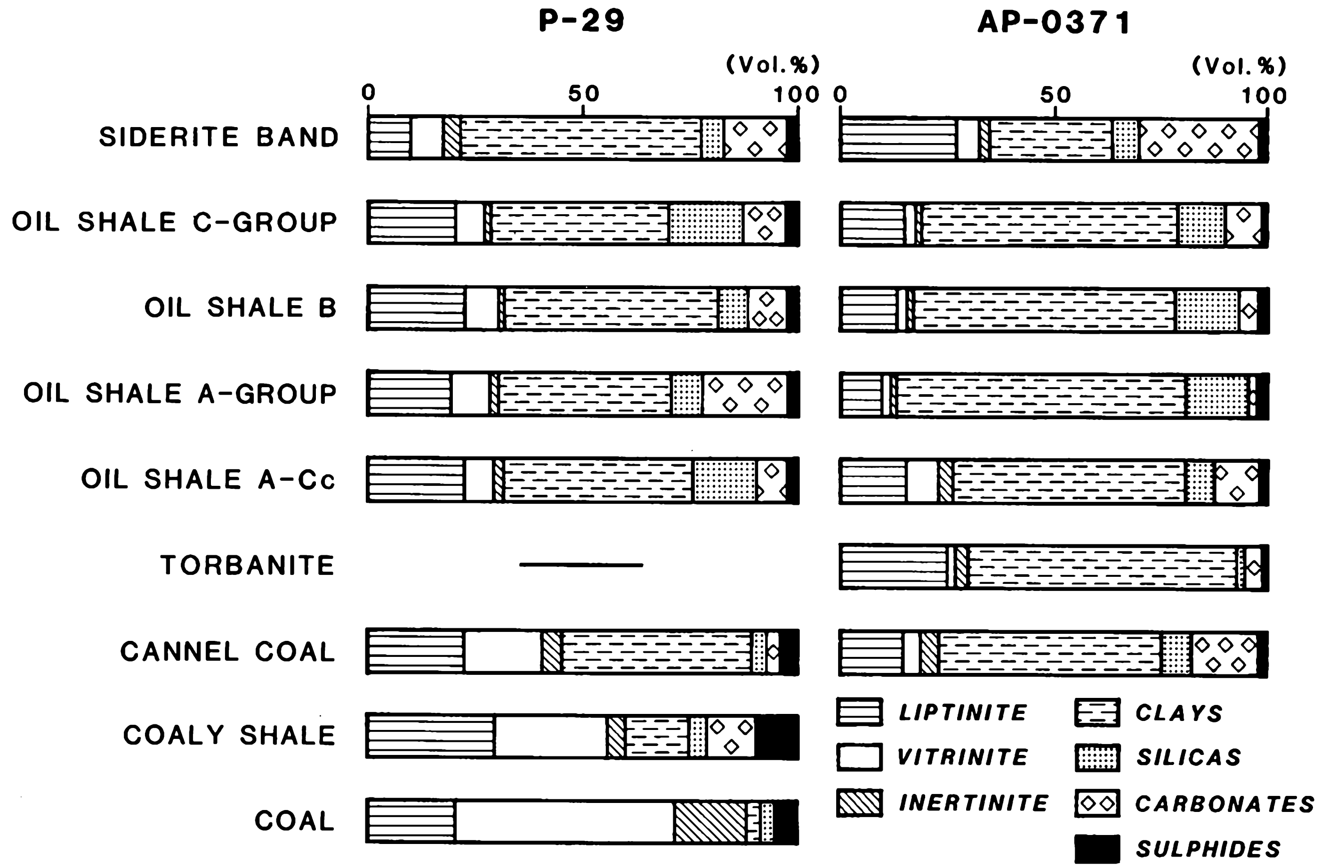


Fig. 5. Averaged mineral and organic matter contents for the lithologies in boreholes P-29 and AP-0371.

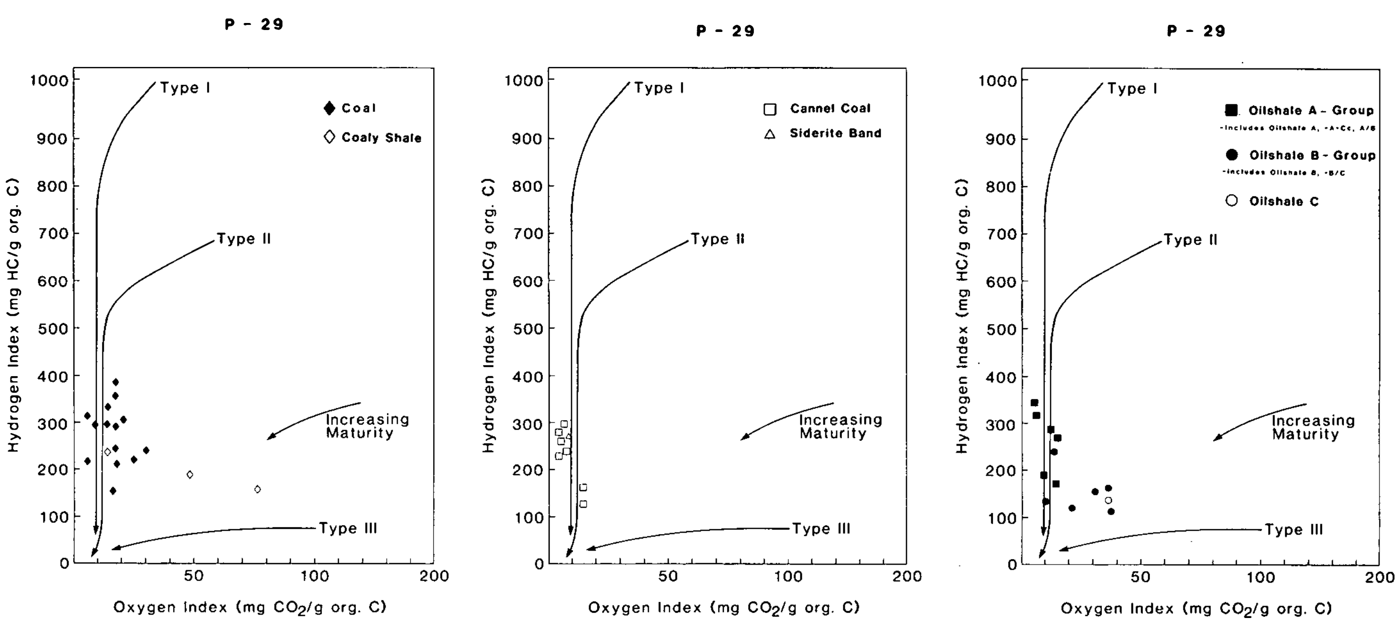


Fig. 6. Hydrogen and oxygen indices for samples from borehole P-29.

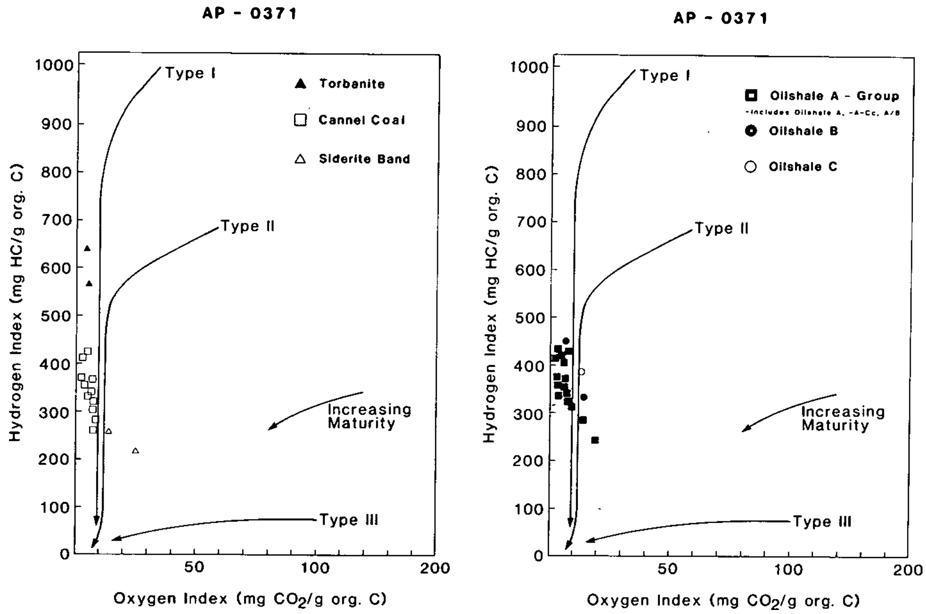


Fig. 7. Hydrogen and oxygen indices for samples from borehole AP-0371.

Table 1. TOC values for oil shales and coals in boreholes P-29 and AP-0371.

	P-29	AP-0371
	TOC (wt. %)	
Siderite Band	10	6
Oil shale C-group (includes O-C and O-B/C)	2	3
Oil shale B	4	4
Oil shale A-group (includes O-A and O-A/B)	7	5
Oil Shale A-Cc	12	10
Torbanite	-	12
Cannel Coal	24	14
Coaly Shale	13	-
Coal	35	-

samples having >10 wt. % TOC (some oil shale A, torbanite and cannel coal samples). Highest petroleum potentials are indicated for the coal samples from the McLeod seam averaging 108.5 mg hydrocarbons/g of coal.

Depositional Environment, McLeod Seam, Borehole P-29

Maceral and microlithotype analyses on the coal samples from the McLeod seam showed systematic vertical trends within the seam profile (Fig. 9). Most striking changes appear to occur in the vitrinite A versus vitrinite B contents, in the variations in lamalginite contents (increasing amounts in samples from the base and top of the seam) and in the variations of pyrite contents. An assessment of the depositional environments under which the samples from the McLeod seam accumulated was attempted using petrographic data obtained from maceral and microlithotype analyses. Figure 10 is a ternary diagram in which three facies (limnic, telmatic and limno-telmatic) are outlined. Macerals and minerals believed to have been enriched in these three facies are shown under A, B and C respectively. Samples enriched in components characterized by cell-tissue preservation (vitrinite A, semifusinite and fusinite) plot in an area representative of telmatic (terrestrial forest swamp) types of environments (samples A-22-26, Fig. 10). The remaining samples appear to be more heterogenous, with some indicating a more limnic depositional environment (higher lamalginite and pyrite contents). Others show increasing amounts of vitrinite B and inertodetrinite most likely indicating a wet forest/reed-moor type of deposition (limno-telmatic). A somewhat better resolution is obtained using the results of microlithotype analyses (Fig. 11). Sample A-12 from the base of the seam is enriched in carbominerites and is consequently plotted in the corner representative for limnic conditions. The depositional environments gradually change to dryer conditions as indicated by increasing amounts of vitrinite-rich microlithotypes (samples A-14-19 and sample A-21, Fig. 11). The dryest conditions during peat accumulation are indicated for samples A-20 and A-22-27, which are enriched in vitrinite and inertinite-rich microlithotypes. A return to a limnic environment of deposition is indicated for sample A-28 (Fig. 11). Gelification and tissue preservation indices (Diessel, 1986) support the previous interpretations which were based on maceral and microlithotype analyses (Fig. 12). Gelification indices (GI) and tissue preservation indices (TPI) indicate that accumulation of the McLeod coal seam began under limnic conditions. Dryer conditions are indicated for samples A-13 to A-21 (most likely reed

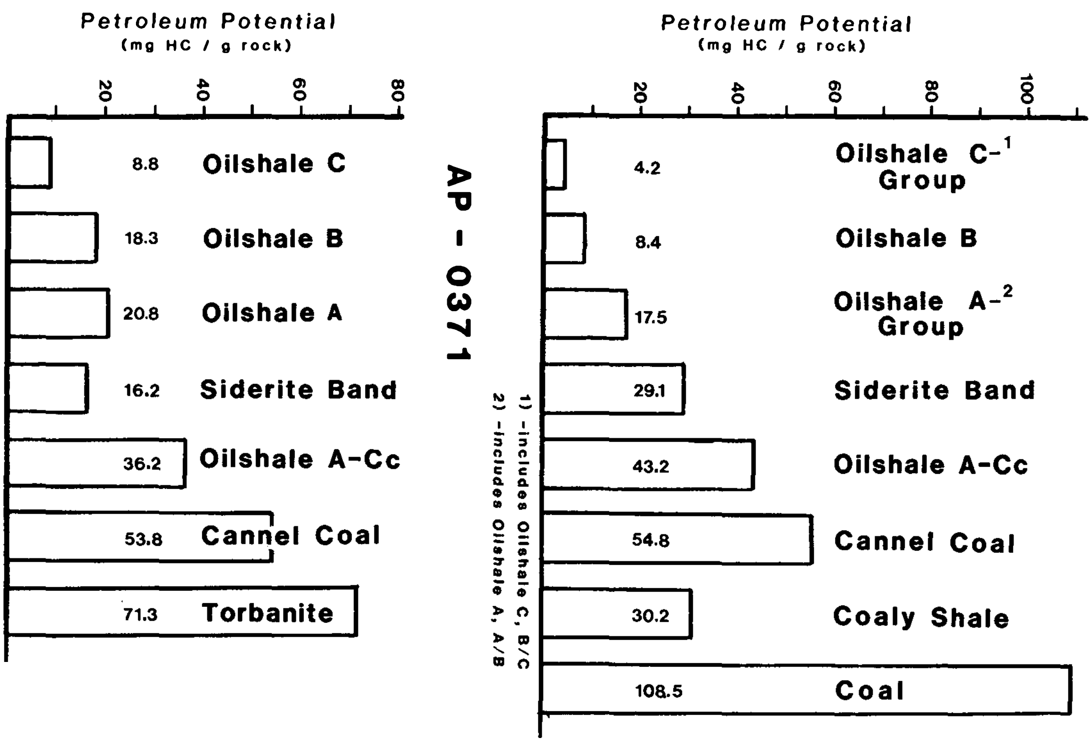


Fig. 8. Averaged petroleum potentials for oil shales and coals in boreholes P-29 and AP-0371.

moor facies), while samples A-22 to A-26 indicate a wet forest swamp type of environment. At the top of the seam at the transition to the overlying cannel coals and oil shales a return to limnic conditions is indicated in the GI/TPI diagram for samples A-27 and A-28.

Correlation of the McLeod Horizons in P-29 and AP-0371

Based on the occurrence of siderite and calcite bands (see Figs. 3, 4), the McLeod coal seam of borehole P-29 has been correlated with a cannel coal sequence (sample B-03, Fig. 4) in borehole AP-0371. The correlation based on these marker beds is supported by results from maceral, Rock-Eval analyses and a density-log. Figure 13 shows an attempt to correlate the McLeod coal seam and associated beds based on vitrinite, inertinite, lamalginite and telalginite contents. In particular, the increasing vitrinite and inertinite contents in AP-0371 appear to correlate well with the McLeod coal seam in P-29 (Fig. 13). The same is true for the trends in lamalginite contents as shown in Figure 13. A relatively good correlation is also shown by parameter obtained from Rock-Eval analyses (TOC and S2 - Peak, Fig. 14). Both TOC and S2 - peaks are increased considerably in the McLeod sequences of the two boreholes. They also show similar patterns in the overlying cannel coal and oil shale beds (Fig. 14).

Conclusions

Petrographic analyses

The organic matter in oil shales, cannel coals and torbanites of the McLeod sequence is characterized by the predominance of liptinite macerals, i.e., lamalginite and telalginite. Vitrinite and inertinite contents are, in general, low to moderate. In the coals, vitrinite and inertinite macerals make up the major portion of the organic material. Liptinite contents are in general low except in samples from the base and top of the seam. Mineral matter in the oil shale and cannel coal lithologies is made up of mainly clays and carbonates whereas in the coals the most abundant minerals are clays, quartz and pyrite.

Rock-Eval analyses

Hydrogen and oxygen indices place the organic material of the oil shale/cannel coal into kerogen types I/II. Averaged TOC-values range from 2 wt. % in the oil shale C lithology to 12 wt.% in oil shale A and torbanites and up to 24 wt. % in the cannel coals. Petroleum potentials (S1 + S2) range from 4.2 mg (oil shale C) to 54.8 mg hydrocarbons/g rock (cannel coals). Rock units having petroleum potentials greater than 40 mg hydrocarbons/g are considered attractive for the production of shale oil. Among the suite of samples studied, some of the oil shales, cannel coals and torbanites fall into this category.

Depositional environment, McLeod coal seam

Maceral distribution and microlithotype variations within the McLeod seam indicate significant changes in depositional environments during peat accumulation. For the initial phase a limnic environment of deposition is indicated followed by a change to much dryer conditions (wet forest swamp). Peat accumulation was terminated by a return to limnic conditions, followed by the deposition of cannel coals and oil shales.

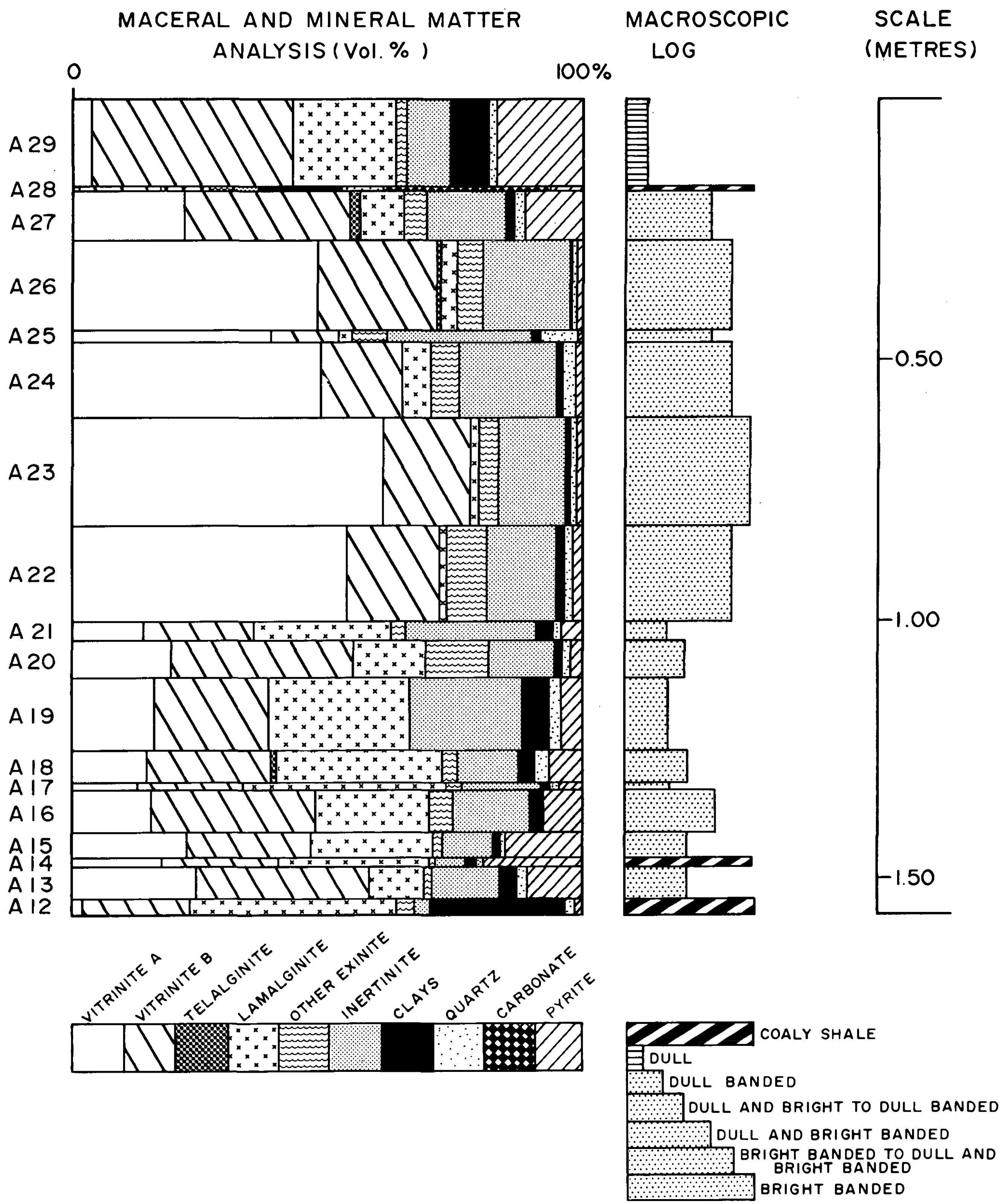


Fig. 9. Seam profile of the McLeod seam showing mineral and maceral contents of individual layers.

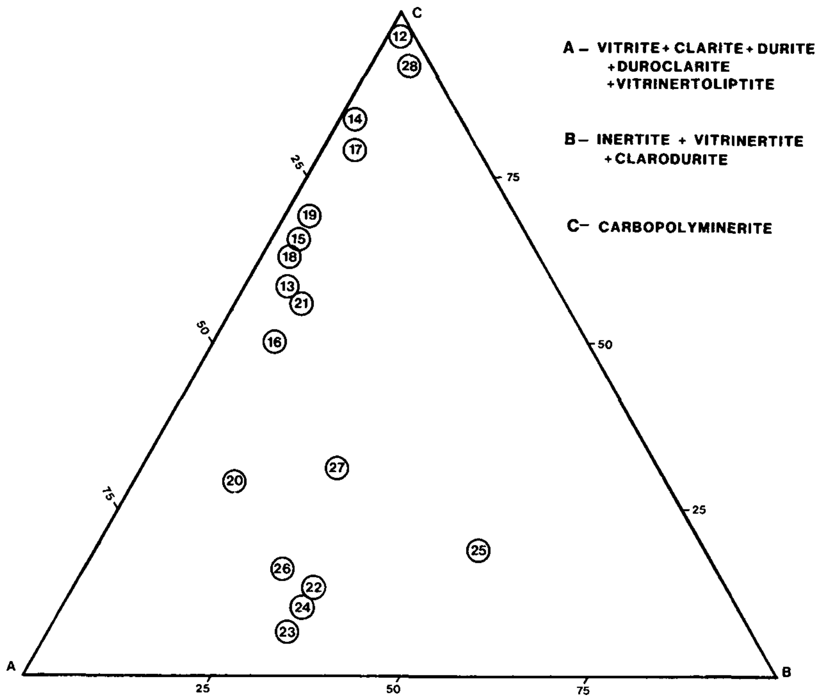


Fig. 10. Ternary diagram illustrating depositional environments of the McLeod coal seam based on maceral analyses (vol. %, mineral matter fee).

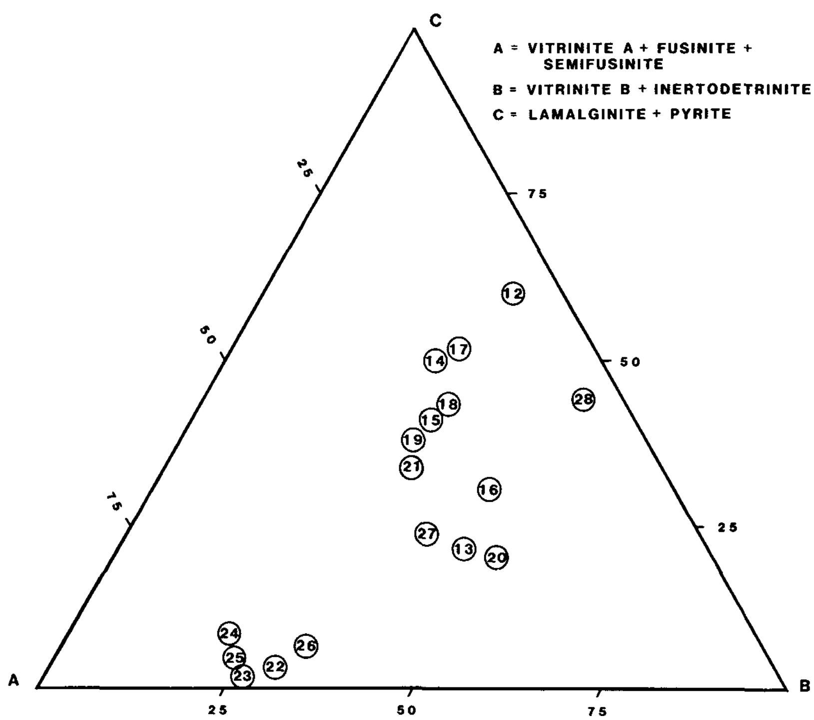
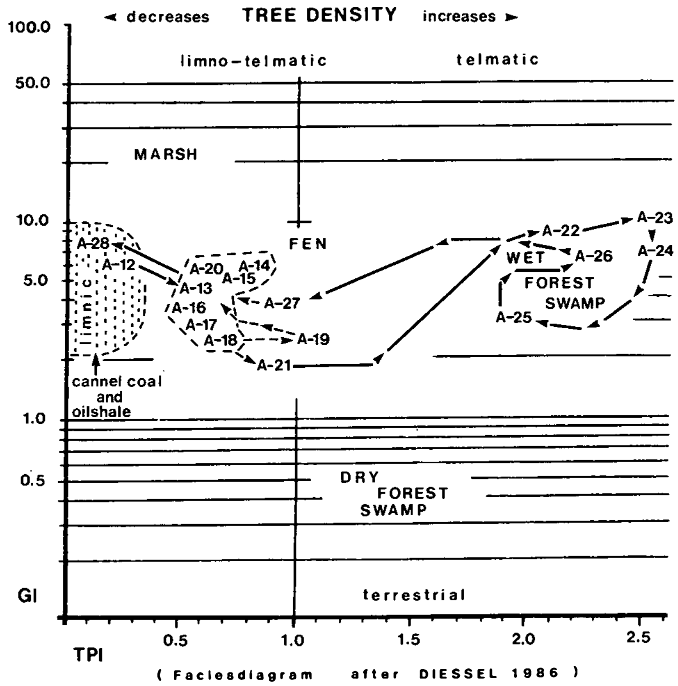


Fig. 11. Ternary diagram illustrating depositional environments of the McLeod coal seam based on microlithotype analyses (vol. %, mineral matter fee).

Correlation

Although coal is not developed in borehole AP-0371, it appears that a cannel coal interval within the section can be correlated to the McLeod coal seam in borehole P-29. This cannel coal interval is characterized by vitrinite, intertinite and TOC contents which are significantly higher than the average values for this lithology.



Gelification Index:

$$GI = \frac{\text{Vitrinite} + \text{Macrinite}}{\text{Semifusinite} + \text{Fusinite} + \text{Inertodetrinite}}$$

Tissue Preservation Index:

$$TPI = \frac{\text{Telinite} + \text{Telocollinite} + \text{Semifusinite} + \text{Fusinite}}{\text{Desmocollinite} + \text{Macrinite} + \text{Inertodetrinite}}$$

Fig. 12. Depositional environments of the McLeod coal seam based on Gelification (GI) and Tissue Preservation Indices (TPI), modified from Diessel (1986).

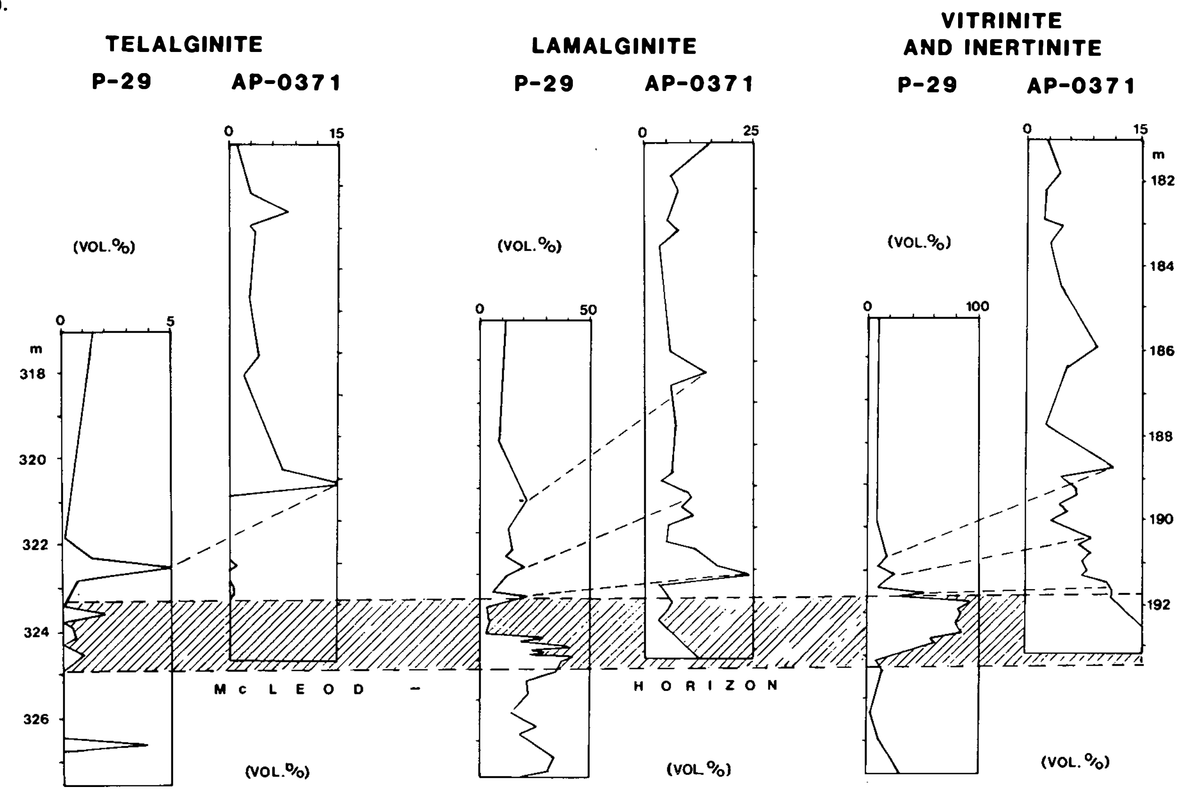


Fig. 13. Correlation of the McLeod sequences in P-29 and AP-0371 based on alginite, vitrinite and inertinite contents.

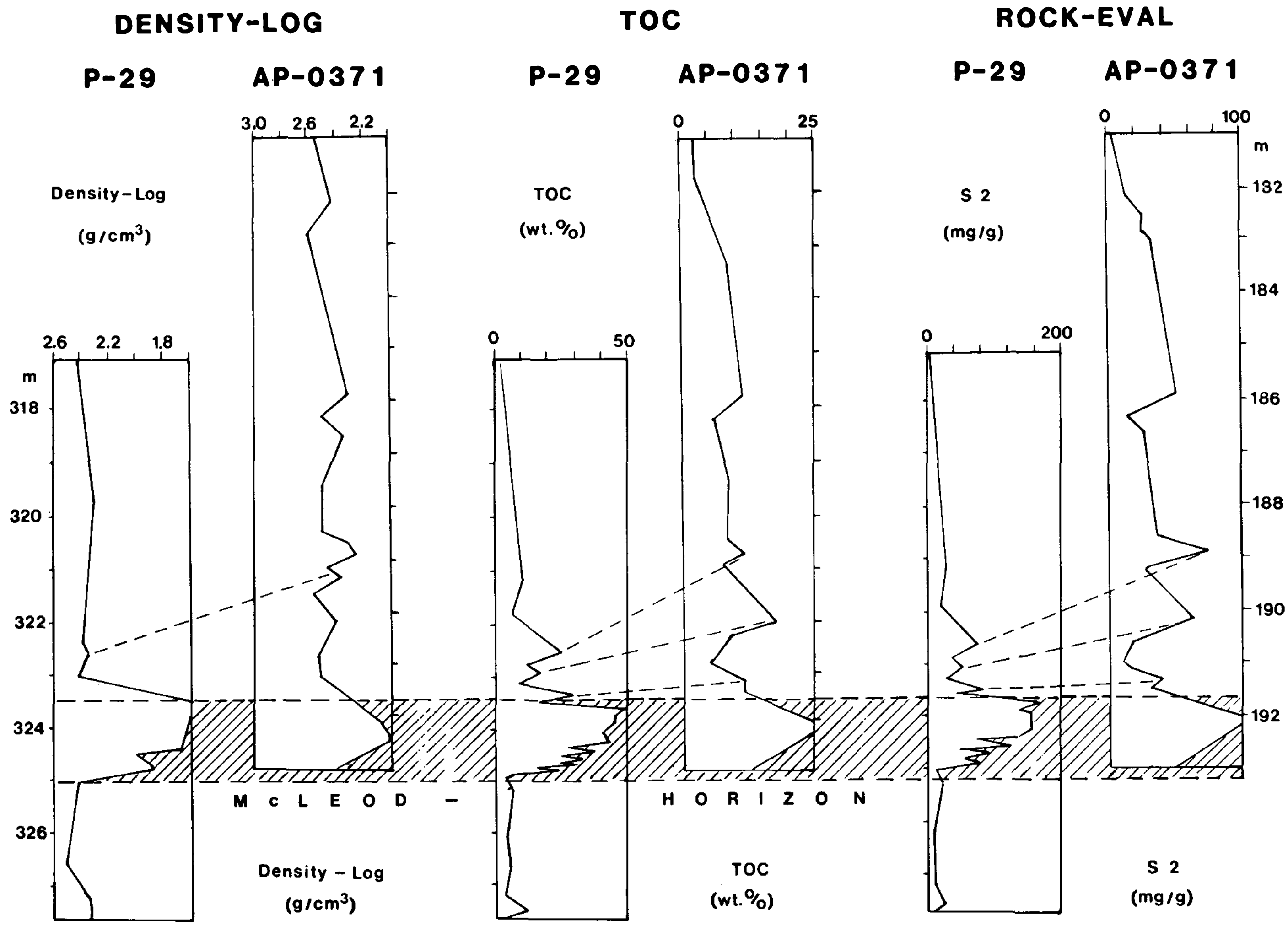


Fig. 14. Correlation of the McLeod sequences in P-29 and AP-0371 based on density-logs, total organic carbon contents and S2-peaks.

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