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The Sydney coalfield of Nova Scotia, Canada

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ABSTRACT

In size, production and remaining resources, the Sydney coalfield is the largest field in eastern Canada. It is nearly entirely submarine and extends from northeastern Cape Breton Island to almost as far as Newfoundland, occupying an area estimated at 36,300 km^2. During 205 years of mining, some 410 million t have been produced and the total remaining "demonstrated" resources, present in ten seams, have been calculated at 1,800 million short tons, T (1 short ton=0.907 t). Of this in situ tonnage about 300 million may be suitable for metallurgical purposes and 1,500 million T can be classed as thermal coal. Some 82% of the total estimate is contributed by four seams, of which the Harbour seam is the main producer. The present annual production is between 3 and 4 million T and all mining is done in the submarine area. The main problems with submarine mining are ventilation and haulage time. The latter increases with the distance from the shore and results in reduced production.

A west to east cross-section through five seams illustrates the development of coal and shows the phenomenon of depositional splitting and rejoining, caused by the interaction of fluvial sedimentation and peat accumulation. Fossil rivers forming "wants" or "wash-outs" in the coal seams are the principle geological obstructions to mining. Structural difficulties are minor as the field is only gently folded and no main faults are present. All coal of the Sydney field is classed as high volatile A bituminous, but there are significant changes within and beyond this category. These are related to the observation that the coalification is essentially post-deformational. This has resulted in an increase in rank with depth, as well as regionally from west to east within the same seam. Coke stability data indicate that these rank changes are economically favourable, because the coking characteristics of the coal improve with depth and towards the east.

Petrographically, a normal, banded bright coal is represented, consisting of alternating bands of vitrite, clarite, clarodurite, durite and fusite. Durite bands occur sporadically, rarely exceeding 3 cm, and are present as "inertinite-rich" durite and "exinite-rich" durite. The latter consists of a groundmass of matted exinite and some of these bands could be traced over a lateral distance of some 50 km within the Harbour seam section. Microlithotype analyses show that, within each seam section, four coal facies types can be recognized, namely: the forest-terrestrial-moor (Ftm), the forest-moor (FM), the reed-moor (RM) and the open-moor (OM) facies. All coal seams of the Sydney field have low ash yields, which range from 5% to 9%. However, the sulphur content is generally high and varies between seams from 2.5% to 6.2%. The average volatile matter content is 36% and calorific value averages 7,524 kcal/kg (13,545 Btu/lb).

INTRODUCTION

Data provided by offshore drilling for oil and gas in 1974 and for coal in 1978 and 1979 (when sixteen test holes were put down) have greatly added to our knowledge of the mainly submarine Sydney coalfield. They have shown that the previously known part of the field, comprising a small land area and adjoining coastal region, actually forms part of an extensive offshore Carboniferous basin. Information on this basin is still limited, but interpretation of the new data in light of existing knowledge has considerably broadened the geological picture, as will be shown in the figures.

THE COALFIELDS OF EASTERN CANADA

Figure 1 illustrates the location, age, production and remaining resources of the coalfields in the Maritime Provinces. All coals of this region were formed during the Late Carboniferous (Pennsylvanian) period. However, within this period, not all coal formation took place at the same time. There were three main intervals, these occurred at the time the Riversdale (Westphalian A), Cumberland (Westphalian B) and Pictou Groups (Westphalian C, D and Stephanian) were laid down (Fig. 2) (Hacquebard, 1972). The oldest coals are those of the Riversdale Group. These coals are of rather limited extent, and only a few mineable seams are present, namely at St. Rose and Port Hood. From the two areas only 2 million T have been extracted. The Cumberland Group coals are confined to Cumberland County, and include the coals of Springhill and Joggins-Chignecto coalfields. Figure 1 shows that some 43 million T have been removed. The coals of the Pictou Group are the youngest

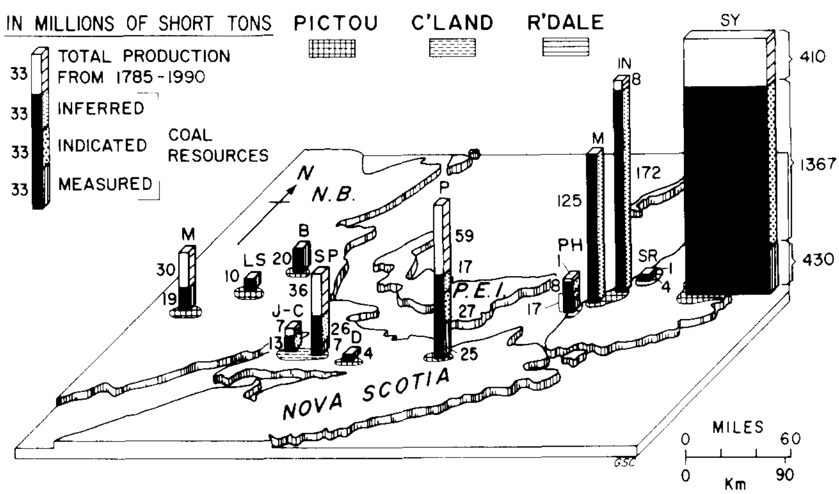

Fig. 1. Location, age, production and remaining resources of the coalfields of the Maritime Provinces of Canada. Coalfield index: *M* = Minto; *LS* = Lake Stream; *B* = Beersville; *J-C* = Joggins-Chignecto; *SP* = Springhill; *D* = Debert; *P* = Pictou; *PH* = Port Hood; *M* = Mabou Mines; *IN* = Inverness; *SR* = St. Rose; *S* = Sydney. Age: C'LAND = Cumberland; R'DALE = Riversdale) (after Hacquebard, 1979; updated).

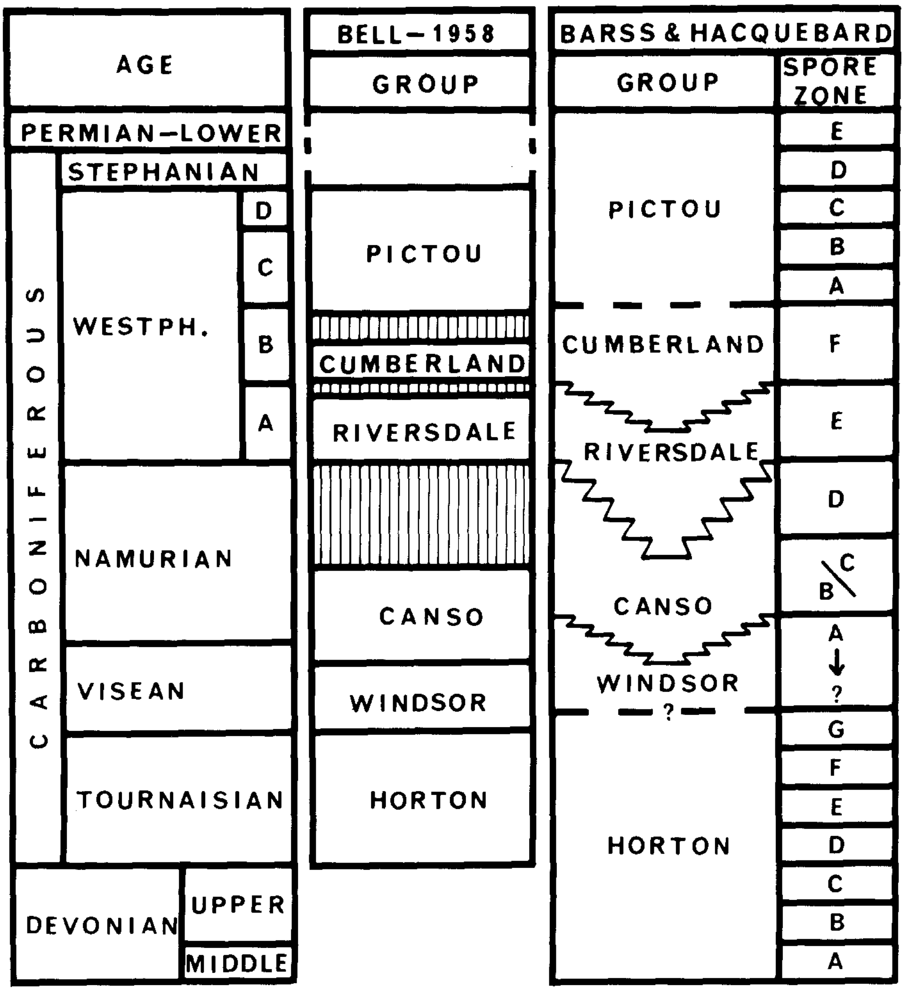

Fig. 2. Stratigraphic subdivisions and age of Upper Paleozoic rocks in eastern Canada (after Hacquebard, 1972).

and most abundant, both in actual number of seams and in regional distribution. Here belong the coals of the Sydney, Inverness, Mabou, Pictou, Debert, Beersville, Lake Stream and Minto fields. Their total production amounted to 507 million T or 92% of the Maritime total of 552 million T.

Figure 1 shows that in size, production and resources, the Sydney coalfield is by far the largest field of the region. During 205 y of mining some 410 million T have been produced and the total remaining "demonstrated" resources have been calculated at 1,800 million T. With the exception of the coalfields of St. Rose, Minto and Sydney, all mining has ceased in the area. At present, three mines are in production at Sydney.

LOCATION, AGE AND STRATIGRAPHY

The Sydney coal basin is situated in northeastern Nova Scotia on and offshore of Cape Breton Island (Fig. 3). It consists of two parts: a small land area of about 520 km^2 (200 mi^2) and a region where mining is carried out below the sea. Both form part of a large Carboniferous basin that extends almost as far as Newfoundland, occupying some 36,300 km^2 (14,000 mi^2). It is referred to as the Sydney Basin and its extent was determined by King and MacLean (1976) using shipboard geophysical and acoustic methods. The structural style of the basin is relatively simple and, except for local folding, essentially saucer-shaped with the beds dipping towards the deeper and central parts of the basin.

The coal-bearing rocks belong to the Pictou (Morien) Group, which, on the basis of the megaflora and spore florule, has been assigned a Westphalian C, D and Stephanian age (Bell, 1938; Barss and Hacquebard, 1967). The maximum thickness of the Morien Group in the onshore portion is 1966 m (6450 ft), to which an additional 271 m (890 ft), encountered in the offshore wells can be added, making a total thickness of 2237 m (7340 ft). The coal-bearing sequence contains thirteen seams that are 0.9–4.3 m (3–14 ft) thick, eight of which occur in Westphalian D (Fig. 4). All but the youngest three coals (of Stephanian age), which do not outcrop in the land area, have been

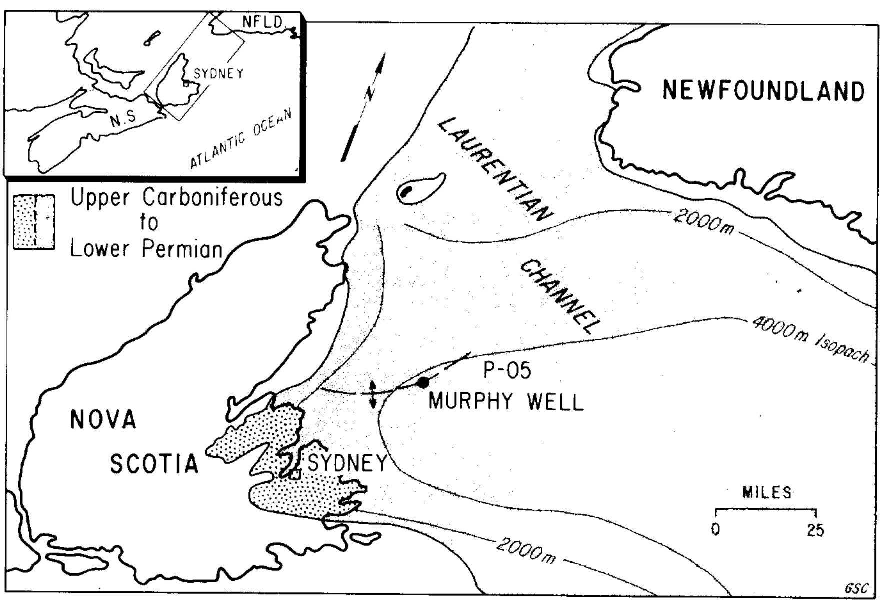

Fig. 3. Sydney coalfield and adjacent Carboniferous basin with isopachs showing thickness of Upper Carboniferous to Lower Permian sediments (after King and MacLean, 1976; in Hacquebard, 1979).

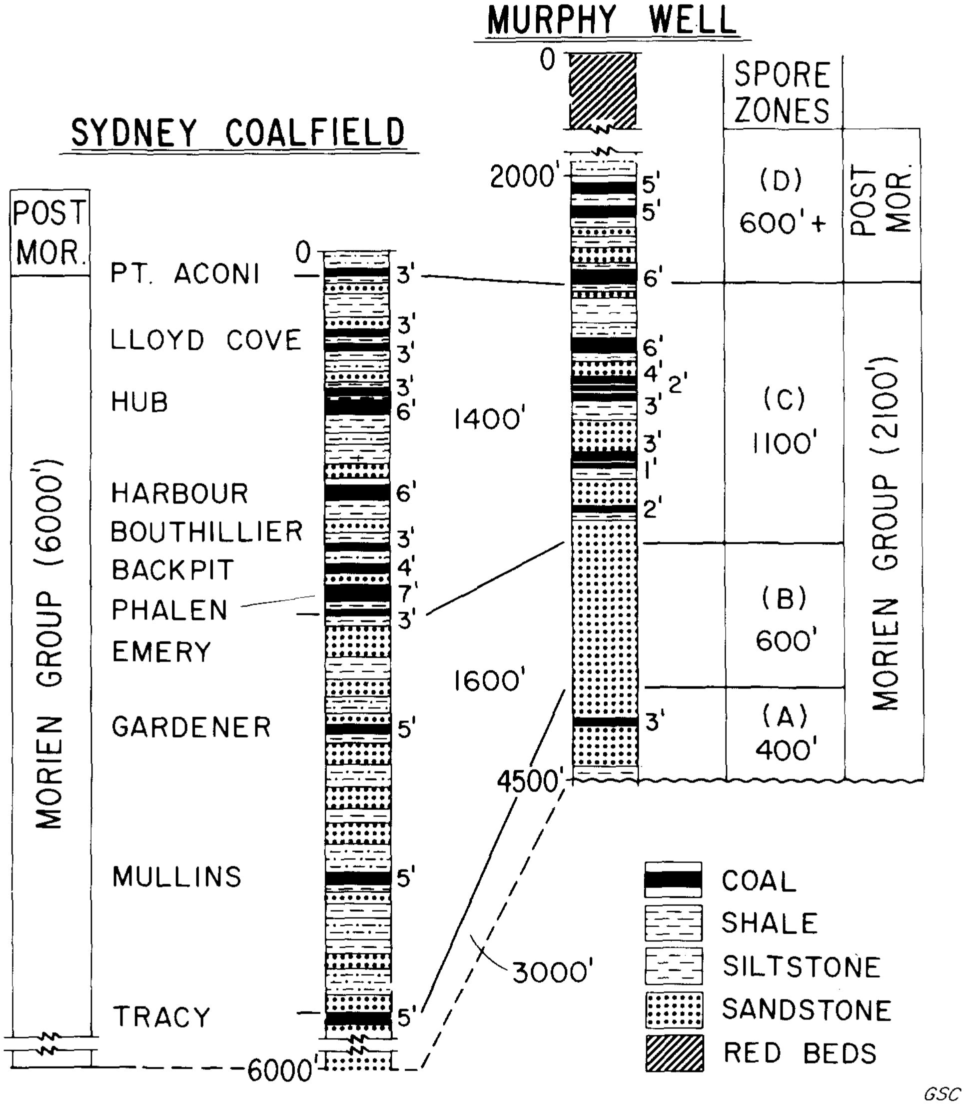

Fig. 4. Coal-bearing sequence of Sydney coalfield and correlation with Murphy et al. North Sydney P-05 well (Fig. 3) (after Hacquebard, 1976, 1979).

mined in the past. At present, submarine operations are being carried out only in three seams.

DEPOSITIONAL ENVIRONMENT AND SEAM DEVELOPMENTS

Although no distinct marine horizons have been identified in the Sydney succession, the coals clearly have the same characteristics of those known from paralic basins; such as the occurrence of normal-banded autochthonous coals, the phenomenon of seam splitting and rejoining, the presence of fossil rivers, etc. (Hacquebard and Donaldson, 1969).

The development of the major coal seams of the Sydney field is shown by the cross-sections in Fig. 5, which are based on actual seam measurements taken at numerous underground locations. The different patterns that are presented reveal the ever changing interaction between fluvial sedimentation and peat accumulation. Some of the seams, notably the Phalen and Hub seams, show the influence of a very active river by their extensive splitting, rejoining

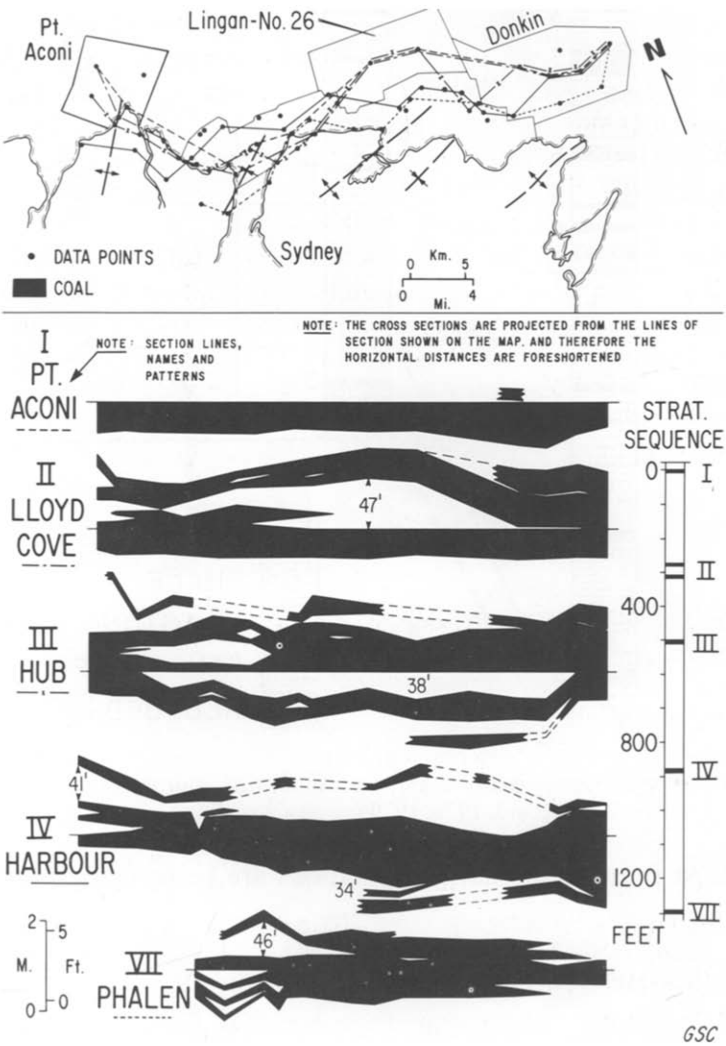

Fig. 5. Cross-sections through five upper seams of the Sydney coalfield (after Hacquebard, 1983).

and digitation. Others, like the Harbour and Point Aconi seams, were much less affected. However, a common characteristic of all these autochthonous coal seams is their termination by the process of subdividing and eventual "pinching out" of individual benches. This splitting often has a detrimental effect on mining, because when the benches become less than 1.2 m (4 ft) thick in submarine workings, extraction is no longer considered economically feasible.

The vertical (stratigraphic) arrangement of the seam sections in Fig. 5 shows two significant depositional features, namely:

(1) A general westward extension from older to younger seams, reaching a maximum coverage of the coalfield from the Harbour seam upwards. This includes four seams below the Phalen seam that are not shown in Fig. 5, but which all have their nucleus of coal deposition in the eastern part of the coalfield. The western seam extensions are related to the transgressive nature of the upper zones of the Morien Group (containing the younger coals), which overstep the lowest zone to the west. The oldest coal deposition started in the eastern part of the coalfield, where the basin was initiated.

(2) The four uppermost seams, from Harbour to Point Aconi, all have their greatest development in the Donkin area. Here, the different benches join together, resulting in individual seam thicknesses of 3.3 m (10 ft) and more. The formation of this favourable area of coal accumulation was initiated during the deposition of the Harbour seam. The total "demonstrated" coal resources of the four seams in the Donkin reserve area amount to 911 million short tons (827 million t).

COAL QUALITY

The quality of the high volatile A bituminous coal of the productive seams is shown in the representative analysis of the Harbour seam (Swartzman, 1953) given in Table 1. All coal seams of the Sydney field have low ash yields, which range from 5% to 9%. However, the sulphur content is generally high and varies between seams from 2.5% to 6.2%. The sulphur occurs mostly as finely divided pyrite, predominantly in the roof and bench coal. It is not related to marine incursions, because marine beds overlying the coals have not been clearly identified. The onshore and nearshore parts of the field are considered to represent the uplands region of a paralic basin. In the onshore hinterland of this basin gypsum deposits occur, which predate the coal measures, and were, therefore, probably a suitable source for sulphur-bearing solutions entering the peat swamps, and causing pyrite precipitation.

A high volatile A bituminous coal is represented, but as mining proceeds seaward and the depth below sea level increases, a medium volatile coal will become available (Fig. 6).

TABLE 1

A representative analysis of the Harbour seam showing the quality of the high volatile A bituminous coal

Property	Value (as received basis)
Moisture	4.0%
Ash	5.2%
Volatile matter	36.1%
Fixed carbon	54.7%
Sulphur	2.9%
Calorific value	7,524 kcal/kg (13,545 Btu/lb)

From Swartzman (1953).

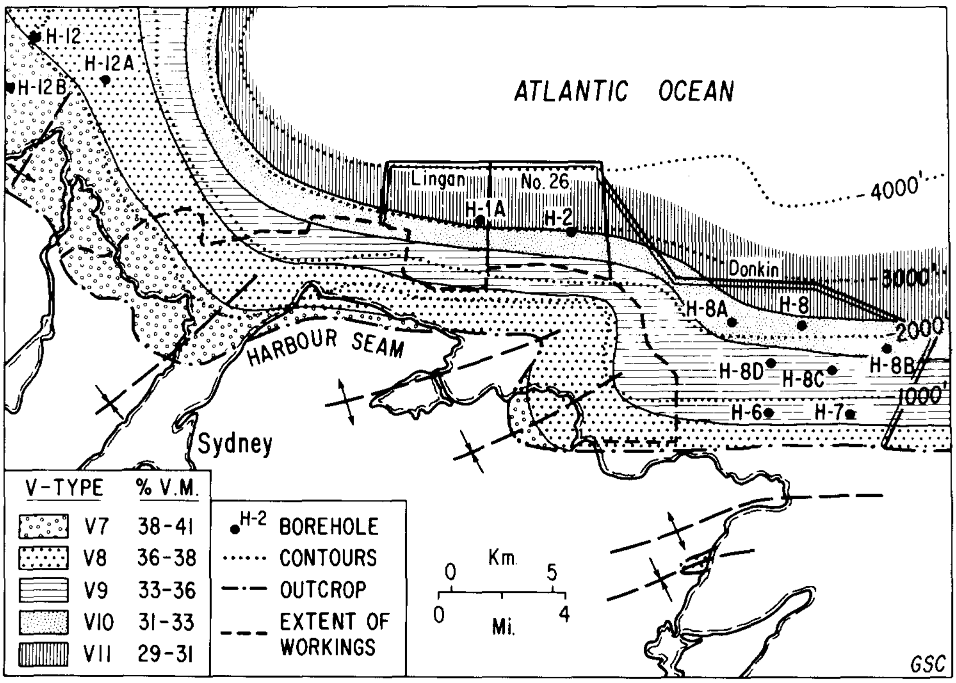

Fig. 6. Iso-reflectance rank map of the Harbour seam, with seam contours relative to sea level, Sydney coalfield, Nova Scotia (after Hacquebard, 1983).

COALIFICATION AND RANK VARIATIONS

The Sydney coal, as mined in the past, as well as the present, is classed as high volatile A butiminous. However, within and even beyond this broad category there are significant changes in rank. These changes are related to the observation that the coalification is essentially post-deformational in origin. Hacquebard and Donaldson (1970) showed that the rank of coal increases with the present depth below the surface, but does not alter in surface exposures in relation to the stratigraphic position (Fig. 7). In addition to the vertical changes in rank, a regional increase from west to east also exists, although it is less pronounced. This double effect is illustrated in Fig. 6 with an iso-reflectance rank map of the Harbour seam.

In the Lingan mine, the vertical rank increase (down dip) is of the order of two reflectance levels or two V-types (from V-9 to V-11) over a depth of 564 m (1850 ft). A more rapid increase occurs in the Donkin area, where only 480 m (1577 ft) is required to obtain an increase of two V-types. A V-type represents a reflectance level; for example, V-9 means 0.90–0.99% $R_{o\ max}$.

Regionally, the Harbour seam changes in rank from V-7, in the extreme west, to V-9, at Donkin. This change occurs in coal that lies at about the same

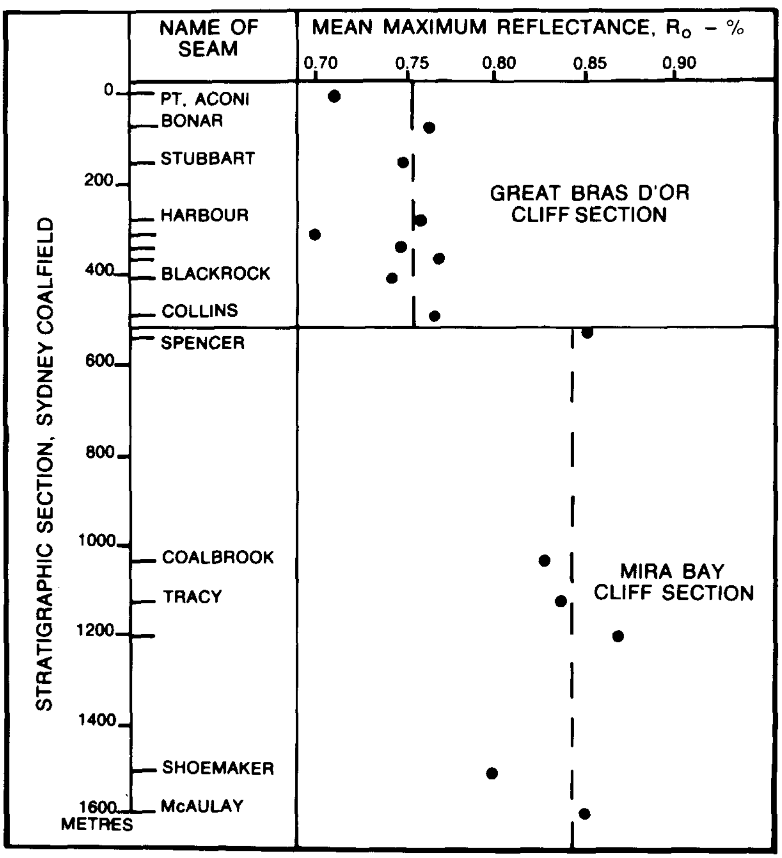

Fig. 7. Coal rank changes in surface exposures in relation to stratigraphic sequence (after Hacquebard and Donaldson, 1970).

depth below the surface. It also is apparent by comparing data obtained in the offshore area at greater depth. The Harbour seam intersected at 914 m (−3000 ft) below sea level in borehole H-1A at Lingan, has a rank of 1.11% R_o, whereas, at −707 m (−2321 ft) in borehole H-8 at Donkin, it reached a rank of 1.13% R_o. This means that it requires 207 m (679 ft) less depth of mining at Donkin than at Lingan to encounter medium volatile bituminous coal. This is an economically significant observation when considering the production of metallurgical coking coal.

COAL PETROGRAPHIC CHARACTERISTICS

The Sydney coals can be classed as normal banded bituminous coal. Such coals consist of the following microlithotypes or banded ingredients, which are identified microscopically (Hacquebard, 1950): vitrite, clarite, clarodurite, durite and fusite (Fig. 8). Each microlithotype is composed of coal macerals, which are derived from the original plant tissues. In the photomicrographs the macerals can be recognized as follows: vitrinite (v), light grey, occurring in bands and as groundmass; inertinite (i) as white, well delineated bodies; fusinite (f) and semifusinite (sf) as white units with distinct cellular structure; exinite (e) as dark grey elongated bodies, representing either microspores or megaspores.

The microlithotypes occur at different positions and concentrations in the seam section, as is illustrated in Fig. 8. Typical of the Sydney coals is the abundance of clarite, which together with vitrite constitute the so-called bright-coal components. A bright-banded coal therefore is represented. It is occasionally interbedded with well defined layers of clarodurite and durite. The latter are sometimes referred to as splint bands and some of these have great lateral continuity, and are useful for inter-seam correlations.

Coal petrological data provide information on: (1) origin and deposition of coal; (2) properties of metallurgical coke by quantitative maceral analyses and vitrinite reflectance determinations; (3) coal rank and oil maturation levels through reflectance measurements; (4) nature and distribution of mineral matter in coal; (5) correlations of coal seams.

The facies changes within and between coal seams are the result of environmental changes that occurred in the peat swamps. They can be deduced from the petrographic composition, particularly from the distribution of the microlithotypes through the seam section. The procedure followed has been described in the 1969 publication of Hacquebard and Donaldson, who translated specific microlithotype combinations into vegetation zones that originated in four different peat environments, namely forest-moor (FM), forest-terrestrial-moor (FtM), reed-moor (RM) and open-moor (OM). In these environments the level of the groundwater played a most important role in the preservation of the plant debris, and therefore in the formation of the

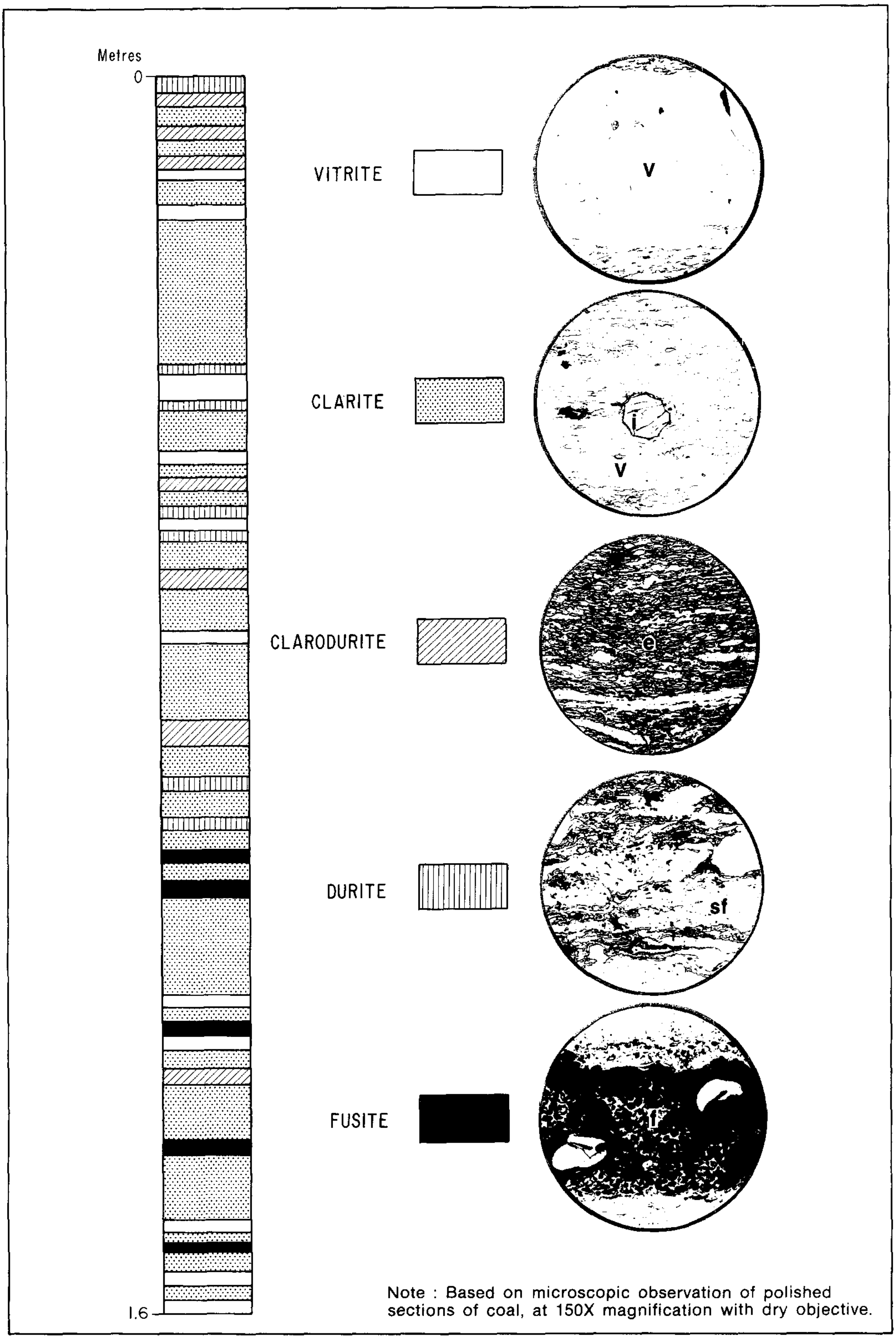

Fig. 8. Petrographic profile of a typical section of the Harbour seam, Sydney coalfield, Nova Scotia.

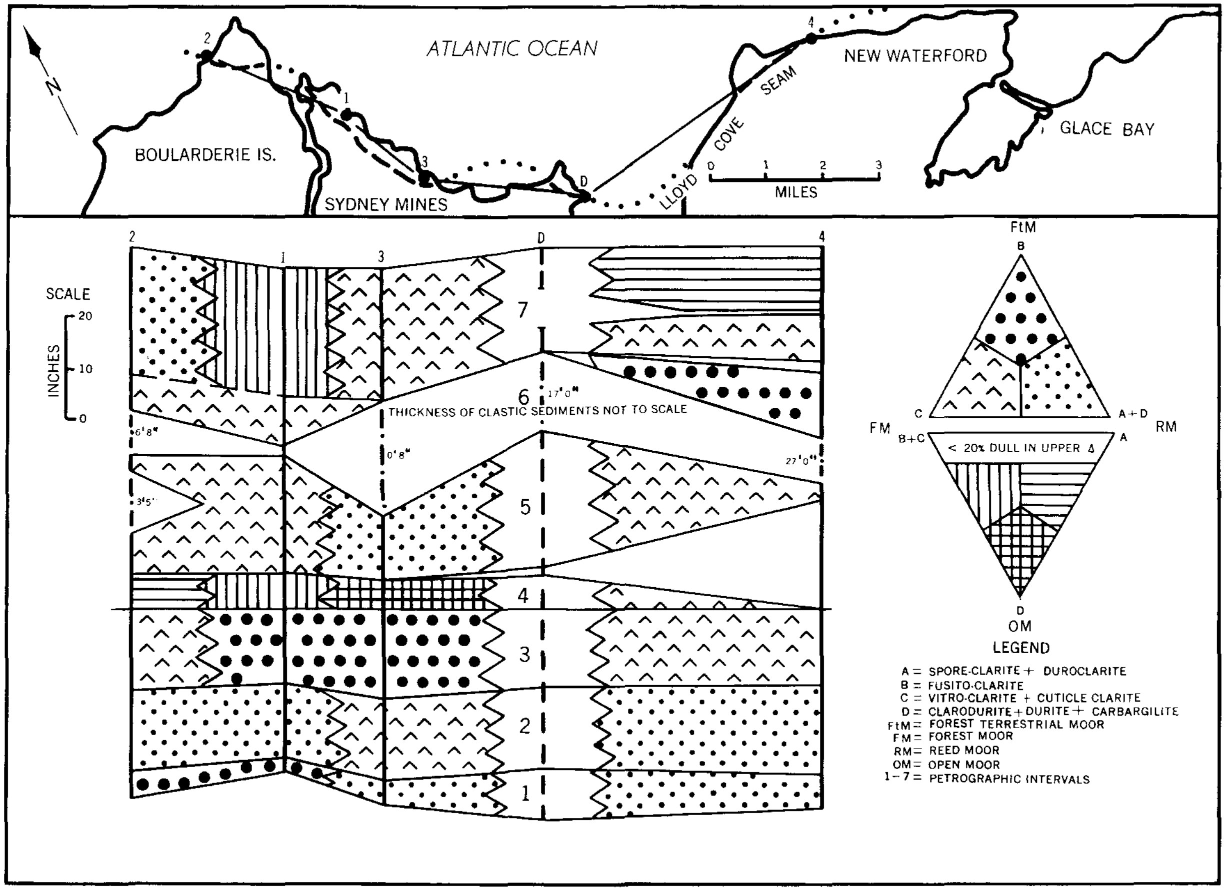

Fig. 9. Facies changes in the Lloyd Cove seam (after Hacquebard and Donaldson, 1969).

different types of coal. Three groundwater zones are recognized, namely terrestrial (above high water), telmatic (between high and low water) and limnic (entirely subaquatic).

An example of the facies changes in one of the seams of the Sydney coalfield is presented in Fig. 9. In the Lloyd Cove seam the prevailing environment during intervals 1, 2 and 3 was at first the telmatic RM, which in interval 3 changed into that of the forest-moor. This forest grew under the abnormally "dry" conditions of the FtM environment at the locations of columns 1 and 3. Due to a rise in the groundwater level, the more OM conditions of interval 4 temporarily halted the forest environment, but it returned in the succeeding intervals, where it developed mainly in the telmatic zone. At the location of columns 4 and 1, however, "dryer" (FtM) and "wetter" FM conditions produced different types of peat during intervals 6 and 7. The facies diagrams of the other seams of the Sydney field show comparable patterns, but with characteristic lateral and vertical variations.

MINING HISTORY AND SUBMARINE EXTRACTION

Coal has been recovered at the Sydney coalfield since 1720 when it was utilized by the French during the construction of the fortress of Louisbourg, situated 40 km (25 mi) southeast of Sydney. Continuous, large–scale mining has been in progress for the past 160 yr reaching a peak annual production of nearly 6 million T in 1940. At the present, the annual production from three operating submarine collieries is between 3 and 4 million T. The mines are highly mechanized and both the longwall advance and the longwall retreat extraction methods are used, as well as the room-and-pillar technique in those areas that have less than 305 m (1000 ft) of cover. Nearly all mining in this field has been carried out in the submarine area, which is considered feasible up to a cover of 1200 m (4000 ft) below sea level, or a distance of 8 km (5 mi) from the shore. Access to the seams, which generally dip gently seaward, has been through adits at the outcrop. Only when the vertical distance to the coal is less than 55 m (180 ft) at the shore line can the submarine area not be entered by slope and shaft and rock tunnel is required.

A major problem with submarine mining is related to ventilation, which becomes more difficult with increasing distance from the shore. To place ventilation shafts near the work areas, as is done in mines on land, is too expensive and hazardous in the open ocean at Sydney. Another problem caused by this is the reduction of working time at the coal face. As the face advances, working time lessens because haulage time of men and materials increases, thus contributing to lower daily productions.

Although the mines are beneath the floor of the Atlantic Ocean, water does not create a problem for the mines are extremely dry and free from water of any sort. The presence of underclays immediately below the seams may be responsible for this, because they would act as seals to prevent seawater circulation through fissures in the overlying rocks, caused by subsidence in the old workings.

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REFERENCES

Barss, M.S. and Hacquebard, P.A., 1967. Age and stratigraphy of the Pictou Group in the Maritime Provinces as revealed by fossil spores. Geol. Assoc. Can. Spec. Pap., 4: 267–282.

Bell, W.A., 1938. Fossil flora of Sydney coalfield, Nova Scotia. Geol. Surv. Can. Mem., 155: 1–334.

Hacquebard, P.A., 1950. The nomenclature and classification of coal petrology. Proc. 1st Conf. on the Origin and Constitution of Coal and Crystal Cliffs, Nova Scotia, Nova Scotia Dep. Mines and Nova Scotia Res. Foundation, pp. 8–38.

Hacquebard, P.A., 1972. The Carboniferous of Eastern Canada. C.R. 7th Int. Congr. Carboniferous Stratigraphy and Geology, 1: 69–90.

Hacquebard, P.A., 1976. Appraisal of coals intersected in Murphy off-shore well (North Sydney P-05) of Sydney coalfield, Nova Scotia. Geol. Surv. Can. Tech. Rep. 11-K/G-76-3, 12 pp.

Hacquebard, P.A., 1979. A geological appraisal of the coal resources of Nova Scotia. Can. Min. Metall. Bull., 72 (802): 76–87.

Hacquebard, P.A., 1983. Geological development and economic evaluation of the Sydney coal basin, Nova Scotia. Geol. Surv. Can. Pap. 83-1A, p. 71–81.

Hacquebard, P.A. and Donaldson, J.R., 1969. Carboniferous coal deposition associated with flood plain and limnic environments in Nova Scotia. Geol. Soc. Am. Spec. Pap., 114: 143–191.

Hacquebard, P.A. and Donaldson, J.R., 1970. Coal metamorphism and hydrocarbon potential in the Upper Paleozoic of the Atlantic Provinces, Canada. Can. J. Earth Sci., 7: 1139–1163.

King, L.H. and MacLean, B., 1976. Geology of the Scotial Shelf. Geol. Surv. Can., Pap. 74-31, 31pp.

Swartzman, E., 1953. Analysis directory of Canadian coals. Dep. Energy, Mines Resources, Mining Branch, Rep. 836, 2nd ed.