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THE PERMIAN SEDIMENTS OF THE LAW GLACIER

Region of the Beardmore Glacier — Antarctica
Observations in the Field (1)

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1. *Introduction*

The author participated in the field investigations of the 1969-1970 "U.S. Antarctic Programs" as a Belgian Exchange Scientist. This participation was rendered possible through a generous invitation of the "U.S. National Science Foundation" addressed to the "Belgian Antarctic Expeditions" and through a co-operative arrangement between the "Belgian Antarctic Expeditions" and the "Belgian National Centre for the Study of Coal-Bearing Formations".

In the field, Dr. J. SEKYRA (Prague) and the author enjoyed the hospitality of a research team headed by D. H. ELLIOT of "Ohio State University", which, fors several seasons, investigated the Beardmore glacier area.

The main objective of the study was a detailed sedimentological and stratigraphical investigation of the Permian coal-bearing Formation.

After briefly recalling the essential features of Antarctic sedimentation, the present note sums up the field observations made in the area bordering on the Law Glacier in the Permian Formations accessible at the Coalsack Bluff, at the foot of Mount Sirius and on the flanks of Mount Ropar. The sediments were examined according to the methods adopted by the "Centre National de Géologie Houillère", Brussels; cleering the rocks by trenching for the purpose of sampling and describing continuous sequences of the greatest possible thickness. The detailed results of palaeontological determinations, of chemical analyses and petrographical investigations will form the subject of subsequent comments. An examination of five coal samples was, however, undertaken by R. NOEL (Institut National des Industries Extractives — Liège.) The results of this first investigation are included in this Report.

Thanks are due to Dr. K. N. MOULTON and Dr. P. SMITH of the National Science Foundation, Dr. D.H. ELLIOT of Ohio State University and the U.S. Naval Support Force Antarctica.

2. *The Geological Background*

According to a schematic lay-out, the Antarctic sediments are divided into three major structural stages:

- at the base, a Precambrian crystalline basement folded and leveled,
- on this basement, Lower Palaezoïc, likewise metamorphosed, folded in Caledonian times and then leveled,
- on this complex, subhorizontal sediments of the "Beacon Strata", from Devonian to Jurassic age, where sandstones frequently predominate, conferring a very particular character to the landscape.

Important igneous phenomena perturb these sediments.

(1) Paper read at the Meeting of October 30th, 1970 of the "Société belge de Géologie".

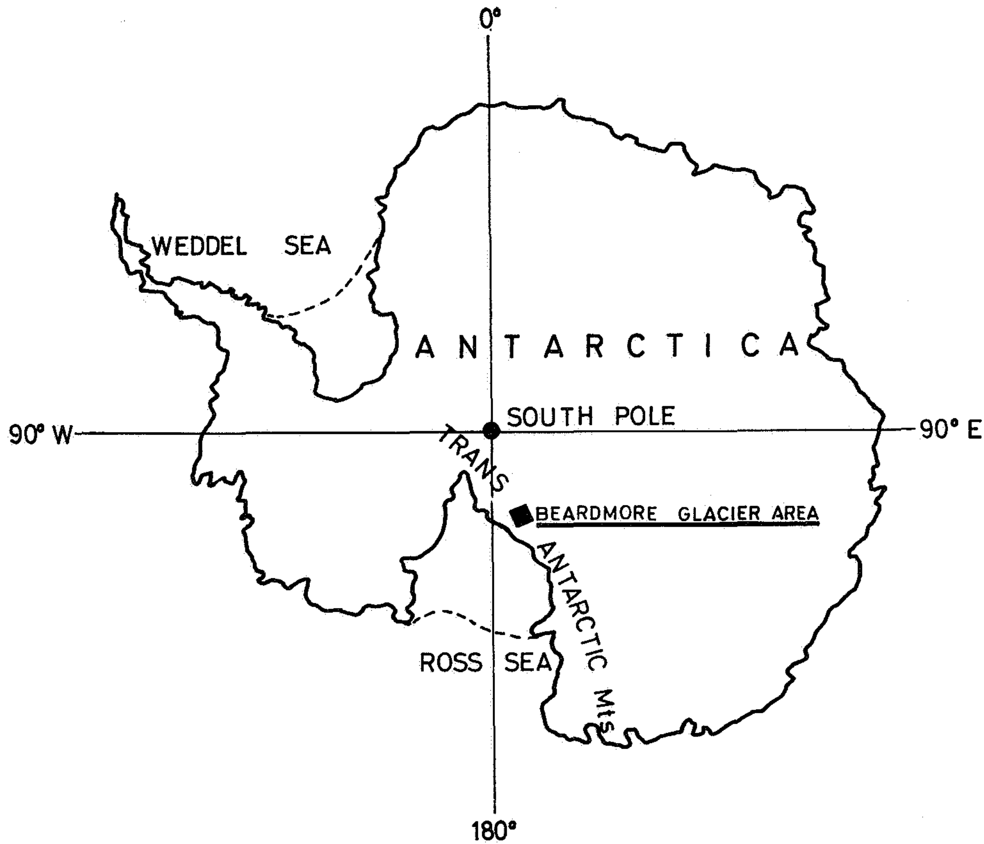


Fig. 1. Site of the Region Visited

The subhorizontal sediments of the "Beacon Strata" formed the main subject of study in the Transantarctic Mountains, from Victoria Land to the Horlick Mountains, in the Pensacola Mountains and the Theron Range. They are present also on the eastern border of the continent, on McRobertson Coast, George V Coast and Oates Coast.

P.J. BARRETT (1969) divides the "Beacon Group" into eight Formations:

At the base of the "Beacon Group", the sandstones of the *Alexandra Formation* rest unconformably on Lower Palaeozoïcs. These sandstones are presumably of Devonian age and are covered by glacial deposits of the *Pagoda Formation*, then by dark shales and fine-grained sandstones of the *McKellar Formation*, and then by arkosic sandstones of the *Fairchild Formation*, and finally by sandstones and shales with coal seams of the *Buckley Formation*. The four Formations Pagoda, McKellar, Fairchild and Buckley are considered Permian. The Fairchild and Buckley sediments have yielded a characteristic flora of that age.

The Permian is covered over by sandstones and shales of the *Fremouw Formation*, whose Triassic age is proved by the discovery of bones of terrestrial reptiles and amphibians (BARRETT et al. 1968, ELLIOT et al. 1970) and of *Dicroidium odontopteroides* (RIGBY and SCHOPF 1967). The upper part of the Fremouw Formation contains seat earths, and even coal seams. The *Falla Formation* which comes next consists of alternate layers of shale and sandstone in the lower part and especially of tuffs in the upper part. It contains also a Triassic flora.

At the summit, the *Prebble Formation* is represented by conglomeratic mudflows with elements of volcanic origin and by tuffaceous sediments. Its age, Triassic or Lower Jurassic, has not been determined yet.

The *Kirkpatrick Basalt*, whose flows cover the *Prebble Formation*, and the *Ferrar Dolerite*, which is to be found in the form of dykes and sills of various thicknesses in the Beacon, form the *Ferrar Group*, whose emplacement goes back to the Jurassic. This age is ascertained not only by the discovery of Lioestheridae in sediments intercalated between two basalt flows (ELLIOT and TASCH 1967), but also by the age determinations effected by the potassium-argon method (McDOUGALL 1963, WADE et al. 1965).

According to BARRETT, the total thickness of the Beacon sediments in the region of the Beardmore Clacier is 2,600 metres, of which 2,200 metres relate to the Permo-Triassic.

3. *Occurrence and Accessibility of the Permo-Triassic Bordering on the Law Glacier*

Two distinguishing features dominate the landscape and condition the geological studies: the quasi horizontality of the strata and the considerable importance of doliritic intrusions.

The strata are very generally horizontal or dip slightly westward. They appear in the shape of long tabular blocks extending over a length of several hundred metres to over several kilometres (Plate I, Photo 2), bordered by dolerite sills and dykes of such thicknesses that they crop out by themselves over vast sectors. Locally, packets of strata have been toppled over by the lava's progress. This appears to be the case of the Triassic sandstones forced into a vertical position on the western flank of the Coalsack Bluff.

The baking action of the intrusive material on the sediments is quite visible on the terrain. Near the Coalsack Bluff's summit, shales in contact with the dolerite are transformed into hornfels over a thickness of several metres. On the flank of the same mountain mass other fine shales included in a sedimentary sequence 200 metres thick are porcellanized. At Mount Ropar, a sill 0.60 m thick has inserted itself between a coal-seam and its roof, and has transformed this coal into natural coke. Such thermal effects are frequent, others, less apparent, can be only observed under the microscope.

The sedimentary sequences examined crop out over sections of slopes dipping at 20 to 40° being separated by cliffs of dolerite or coherent sandstones. The accessibility of these slopes can generally be achieved on foot. From the end of November, the small amount of snow which has not been cleared by the violent wind melts and evaporates immediately owing to solar action and the great dryness of the air.

When present, the movable overlay is generally of small thickness. It consists of a decimetric film of rock disaggregated or exfoliated in small fragments, strewn with dolerite blocks, polished, fluted or honeycombed by the wind. Save at the foot of the cliffs where the scree thickens, the beds of sandstone, shale and coal can then be freed with the help of an ice-pick or a trenching spade, working round those blocks too large to be displaced, as well as the rare ice lenticles too.

In these circumstances, it is possible to describe sequences of beds extending from several tens of metres to several hundreds in a continuous and detailed manner.

4. *Macroscopic Analysis of the Sedimentary Sequences*

Three sedimentary sequences have been examined bed by bed, while others have formed the subject of more cursory inspection. The three first sequences are situated at the Coalsack Bluff, at Mount Ropar and at Mount Sirius. Additional observations were carried out at Mount Picciotto, in the upper portion of Mount Ropar and in the outcrops situated between the Coalsack Bluff and Mount Sirius. The principal points visited appear on the map of Figure 2. At the start of our sojourn in the Antarctic, a number of preliminary observations were made from McMurdo (Mount Gran, Victoria Land).

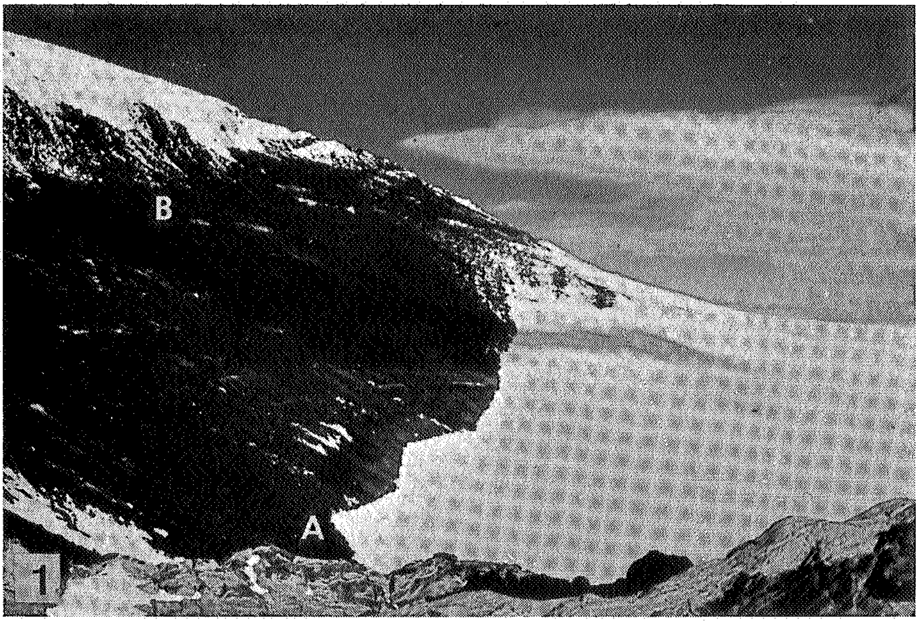


PLATE I

Photo. 1 Coalsack Bluff, AB sequence 176 m thick

Photo. 2 Typical landscape, permian horizontal strata

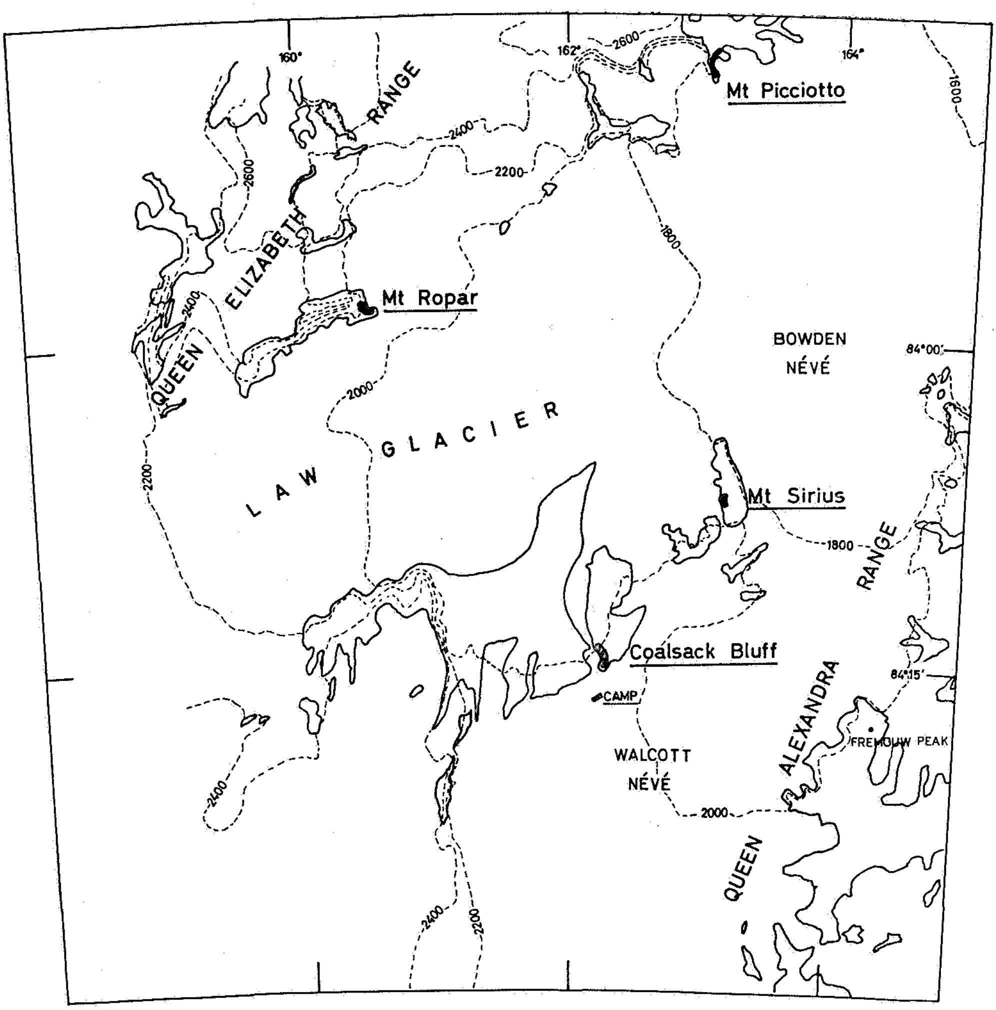


Fig. 2. Schematic Map of the Approaches of the Law Glacier

4. 1. The Sequence at the Coalsack Bluff

One hundred and seventy-six metres thick, the Coalsack Bluff sequence starts at the roof of a dolerite sill which crops out at the foot of the slope; it finishes at the base of the scree which underlies the sill.

It is in the first unit of sandstones encountered above this sill that D.H. ELLIOT discovered a bone bed in the course of the first day on the field, a bone bed which was to provide E.H. COLBERT, J. JENSEN and their collaborators (ELLIOT et al. 1970) with the remains of terrestrial reptiles and amphibians of Triassic age. The sequence, briefly described below, contains a Permian flora; it is representative of the upper part of the Permian, of which a few metres only of the summit are missing.

The sequence, which was examined, disclosed in order of importance shales, sandstones and coaly complexes more or less rich in coal content.

The shales, silty or sandy, seldom clayey, represent nearly 65 % of the bulk of the sediments.

The sandstones represent an aggregate thickness of 43 metres, about 24.4 % of the whole. A few thin layers only are encountered of fine-grained sandstone, often greenish, isolated in the shales. The coarse-grained sandstones, thickly bedded and cross-bedded, widely prevail: one unit of these sandstones attains a thickness of 27 metres.

Eleven coaly seams or complexes have a total thickness of 26 metres. Omitting the shaly partings, the coal, more or less heavy in ash, represents approximately 10 % of the sediments. All the rocks of the sequence, moreover, contain coaly material, event the sandstones whitish or yellowish, at the outcrops, which are very frequently grey or dark grey where freshly fractured.

We did not meet with any clean limestone and the clay ironstones are rare.

No remnants of fauna were encountered. On the other hand, some ten levels yielded debris of plants, generally identifiable (*Glossopteris* and *Gangamopteris* flora), their occurrence extending over the entire height of the examined sequence. Three seat earths were traced, one of the earths contains roots or stumps in a position of life, more or less silicified, with a diameter of 15 to 30 cm. On the parts exposed to the atmosphere, one notices in particular the presence of two-coloured growth rings from one to several millimetres thick. In the sandstone 27 metres thick, one identifies the debris of floated stumps and rootlets.

4. 2. The Mount Ropar Sequence

This sequence forms part of a thick stratigraphical succession on the eastern slope of Mount Ropar. Allowing for the possibilities available at the time, we were able to sample and describe 132 metres of sediments bed by bed and to undertake a number of observations in overlying deposits of a thickness of about 150 metres.

The sequence of a thickness of 132 metres is situated between two sills of dolerite, the lower one crops out level with the glacier descending from the "Peletier Plateau". The strata dip a few degrees westward. This sequence, as well as the overlying sediments which were observed, is attributed by BARRETT to the Buckley Formation. We are of opinion that it belongs to a Permian succession below that of the Coalsack Bluff.

At Mount Ropar the sandstones are far and away the most plentiful sediments. In the sequence described bed by bed they represent 61 % of the sediments examined. They are coarser than at the Coalsack Bluff, and one meets there with lenticles of conglomerates with small rounded pebbles of white quartz reaching 15 mm diameter. Over a total thickness of 81 metres of sandstones, one encounters three units of 10 to 25 metres' thickness whose crossbedded stratification is striking. These sandstones contain "clay galls" of fine sandy shale spread over several levels.

The mostly sandy shales represent 31 % of the total sediments, whereas the seamlets and seams of coal, ten in number, exceed slightly more than 7 %. The proportion of shaly partings included in the seams is far lower than at the Coalsack Bluff, being 1.5 % instead of 5 %. The percentage of coal in quite distinguishable layers with regard to the sediments taken as a whole remains, however, patently less at Mount Ropar: 5.5 % instead of 10 % at the Coalsack Bluff.

In the roof of the thickest coal-seam, silto-sandy shale, 12 metres thick, contains lenticles and beds of carbonate.

The profusion of sandstones and sandy shales yields, on the other hand, a greater rarity and a bad preservation of plant remains: one *Glossopteris* bed only has been found following the detailed study of the sequence, while two other with *Glossopteris* and stems of Equisetales have been identified in the upper sequence, subjected to a more cursory examination. A seat earth has been identified also in each of these sequences; the lower seat earth appears on photograph 6 of Plate III. At the top of the inspected sequence, a thick stratum of sandstone contains remarkable floated stumps and rootlets.

4. 3. The Sequence of Mount Sirius

A short Permian sequence crops out on the

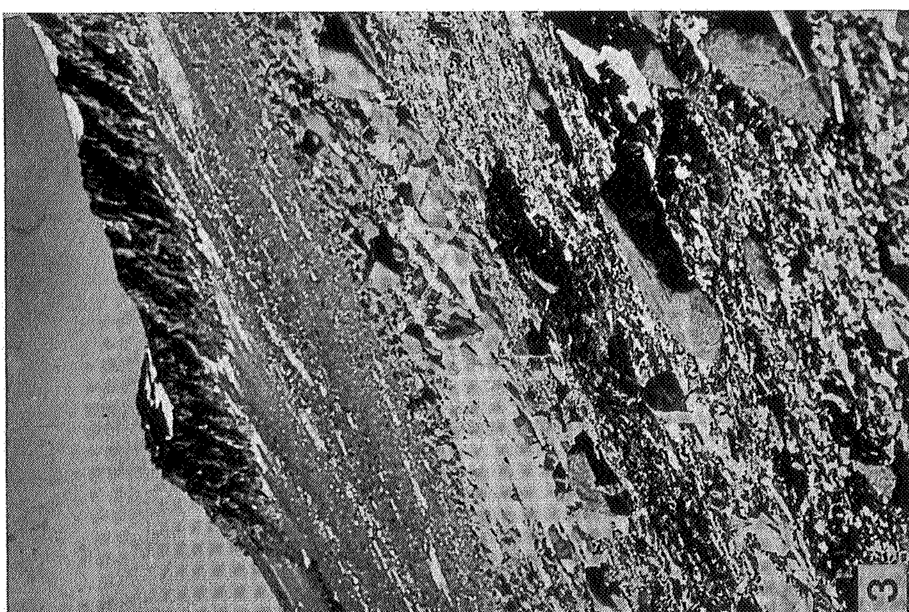


PLATE II

Photo. 3 Coalsack Bluff, doleritic sill on top

Photo. 4 Mount Ropar, cliff 30 m. high

western slope of Mount Sirius, at the foot of the ice flow which joins the Walcott Névé to the Bowden Névé (Fig. 2).

Despite its slight thickness, 22 metres, this sequence is remarkable, seeing that the immediate roof and the upper roof of a coal-seam contain numerous plant remains, among which several species of *Glossopteris* and debris of Equisetales. This floral level is surmounted by a seat earth capped by a few centimetres of shaly coal.

5. *Preliminary Conclusions*

Some conclusions can be reached from observations made in the field, completed by bibliographical data. They are of a preliminary nature and may be regarded as valid only for the region and its surroundings. They must needs be reviewed in the light of the detailed reports of specialists.

5. 1. The postglacial Permian Contains

- — at the base, deposits mostly sandy and free of coal (McKellar and Fairchild Formations, BARRETT 1969),
- — in the lower part of the Buckley Formation, sandstones stil predominate, but coal-seams appear (case of the sedimentary sequence, inspected at Mount Ropar),
- — in the upper part of the Buckley Formation, shales predominate with some sandstones and with coal in larger proportions than in the preceding sequence (case of the upper Permian of the Coalsack Bluff). Be it noted, that a hiatus separates the Permian from the Trias.

This lay-out is found again, in a less pronounced manner, in the Triassic which presents an arenaceous facies more irregularly spread, but which carries coal-seams solely in its summit area (Golden Cap and Fremouw Peak, BARRETT 1969).

Were one to rely mainly on the distribution of the accumulations of organic matter of vegetal origin not only in the sediments but also in the shape of individualized beds, the postglacial Permian and the overlying Triassic each correspond to a "megacycle", characterized by a more or less pronounced scarcity of coaly matter in the lower part and by the increasingly marked presence of such matter in an upward direction.

5. 2. In the absence of coal, the sediments are arranged in simple rhythms, often reduced to the succession of sandy shale, sandstone, sandy shale, sandstone etc.

In the sedimentary sequences striated by coaly episodes, one perceives the presence of cyclothems which are often incomplete.

We have, so far, never come across any remains of invertebraten, which leads us to believe, that, in the event of their presence, it would be in too small a proportion to enable the concept of biophases to be applied, as so often happens in the case of paralic coal deposits in Western Europe.

The virtual cyclothem of the Permian sequences examined consists of the following phases, cited in a descending order:

8 — *coal*, with or without thin partings of shale,
7 — *Clayey shale* (the first phase beneath the coal sometimes contains implanted roots),
6 — *silty shale*,
5 — *sandy shale*,
4 — *sandstone*, sometimes conglomeratic,
3 — *sandy shale*,
2 — *silty shale*,
1 — *clayey shale*.

Under this shale the coal is reached, which, by definition, forms the top of the cyclothem immediately below.

This virtual cyclothem is seldom observable. It often lacks one or more phases. The clayey shales appear exceptional. The groupes of decreasing grainsize phases 5,6 and (7) are often less thick than the base group of increasing grainsize (1),2 and 3: a case of extreme clarity is that of the cyclothem A of Figure 3, which is also represented on the lower two-thirds of photograph 4 on Plate II. The passage from one phase to the next can be progressive (case of phases 1,2 and 3, photo-

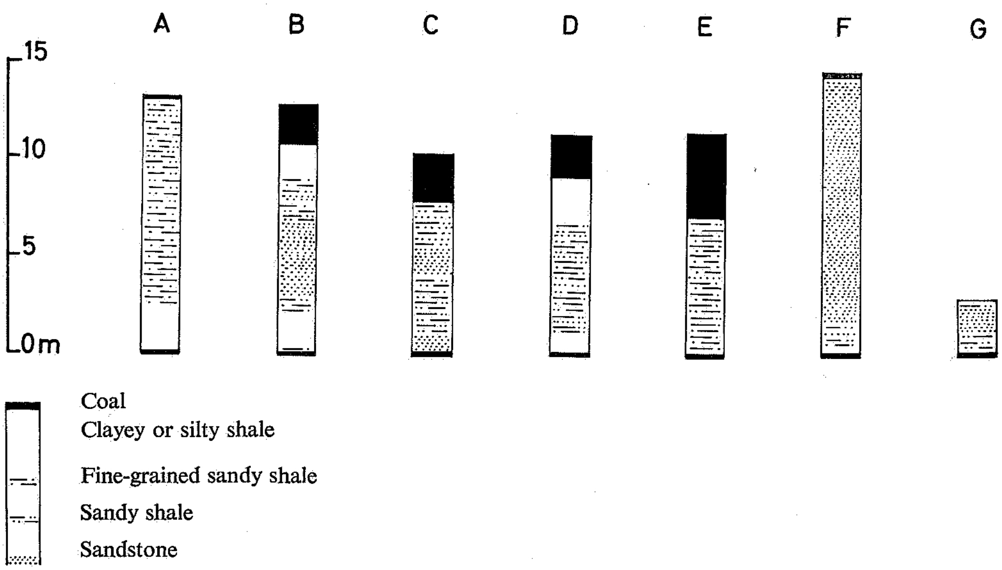


Fig. 3. A few types of Permian cyclothems measured at the Coalsack Bluff and at Mount Ropar

graph 5, Plate III) or abrupt (cyclothem B, Fig. 3; phases 3 and 4. photograph 5, Plate III).

The sandstone phase may be but slightly developed (Cycl. D and E of Fig. 3) or, on the contrary, invade the greater portion of the cyclothem (Cycl. F). The base of this phase can represent a gulley erosion, in which case coarse sediments directly overlay fine sediments, or be somewhat undefinable, when, in the absence of any gulleying, there is a gradual change in the size of the grains. Sometimes, as in the case of certain cyclothems in paralic basins, a layer of isolated sandstone crops in between two cyclothems (Cycl. C, Fig. 3).

Although the average thickness is of the order of 10 to 15 metres, certain cyclothems do not exceed 2 to 3 metres (Cycl. G, Fig. 3).

5. 3. Over a thickness of 330 metres, 23 seams, seamlets and coaly complexes were encountered. They aggregate 29 metres of ashy coal, sometimes grading into coaly shale.

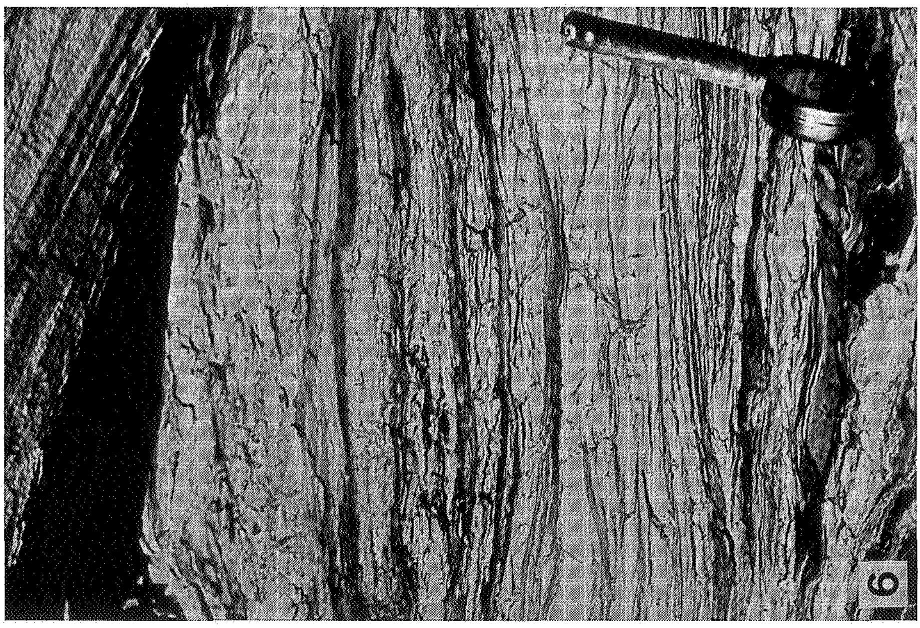
These coals, which have been subjected to the influence of dolerite intrusions, have been systematically sampled and their study has been entrusted to the Institut National des Industries Extractives" Liège (I.N.I.E.X.). R. NOEL has conveyed the preliminary data to us respecting ash content and microscopic observation by reflected light of some samples:

"Five samples formed the subject of investigation. Their ash content (in the dry state) was respectively 15.2 — 40.7 — 42.8 — 64.7 and 89.5 %. One only may be regarded as coal in the full acceptance of the term, the two following are coaly shale, the two last are shales containing coaly matter."

"The coalified matter of the five samples nevertheless gave a similar reflective power, respectively 3.83 — 4.01 — 3.92 — 3.74 and 3.85 % when immersed in oil, which corresponds in normal Carboniferous coal of the Northern Hemisphere to very evolved anthracites whose volatile matter index is between 5 and 6."

"The high percentages of the samples in mineral elements render the analyses of volatile matter very doubtful. The cleanest sample (15.2 % ash), however, provides an indication of theoretical volatiles of 11.06, which appears distinctly high in relation to the reflective power."

"The anisotropy is relatively normal for



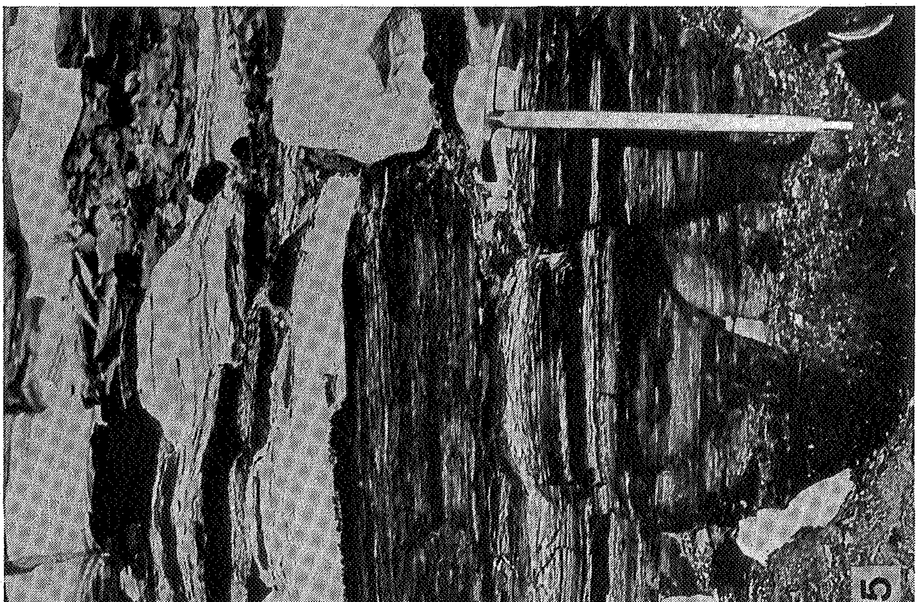


PLATE III

Photo. 5 Mount Ropar, lower part of a cyclothem

Photo. 6 Mount Ropar, seat earth with thin rootlets

" coals of this rank. One of the samples shows " an anisotropy distinctly greater than the " others."

"From the petrographical point of view, " most of the macerals are, unfortunately, no " longer recognisable, taking into account the " high degree of coalification. One distinguis- " hes only collinite, semifusinite and fusinite, " the latter two appear distinctly more plentiful " than in the Carboniferous coals of the Nor- " thern Hemisphere."

"The minerals mainly predominating which " impregnate the coaly mass are clay min- "erals."

5. 4. Besides shales and sandstones mentioned in Chapter 4, it is a matter of interest for attention to be drawn to the presence of indurated layers a few centimetres thick generally encountered in relation with coaly complexes.

The macroscopic characteristics of these indurated layers are very closely akin to those of tonsteins. On the other hand, a preliminary examination in thin slides, carried out by J. THOREZ (Laboratoire de minéralogie of Liège University), has revealed the presence of kaolinite under different aspects in eight of these layers. It therefore appears warranted to assume that tonsteins exist in the Permian of the Antarctic. The detailed petrographic and diffractometric study of these layers is being pursued at the present time and will form the subject of a complementary note.

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