EXPLANATION OF PLATE V.

Fig. 1.—60-ft. Raised Beach at Easington. The section shown is about 6 feet in thickness and consists of bedded sands and gravels resting on a wave-cut platform of Magnesian Limestone. In a cutting which was made above the deposit the bedded cemented gravels and sands were proved to be 15 feet in thickness (on the face), overlaid by a few inches of loose shell-bearing sand, above which was reassorted boulder clay. The whole being covered by washed soil.

Fig. 2.—Photographs of cliffs at Easington, showing 60-ft. Raised Beach resting on rock shelf. The cliff is about 75 feet high. Along the part shown the beach rests on limestone, but the course of cemented gravels can be distinctly followed to the south, when it passes on to boulder clay. The platform becomes less uniform and distinct and the gravels thicken downwards. The top of the course, however, keeps on the same level. R. Raised Beach. M. Middle Magnesian Limestone—eastern equivalents of the Reef which forms Beacon Hill immediately behind the coast at this point. (Fig. 3.)

The Carboniferous Limestone Series of West Cumberland.

By Charles Edmonds.

Introduction.

THE area under consideration extends from the mining town of Egremont to Scalesmoor Farm in the parish of Lamplugh in West Cumberland, and comprises a tract of country 9 miles in length and rather less than 3 miles in width, running from S.S.W. to N.N.E. It forms the south-eastern margin of the Whitehaven Coalfield, and is the western portion of the "collar" of Lower Carboniferous rocks almost surrounding the older Palæozoic rocks of which the Lake District proper is composed. The area consists

Notes to p. 73.

[1] Mr. E. Merrick informs me this depression can be definitely proved to have occurred.

[2] Some of the clay with boulders (unstriated or occasionally striated) which is often called boulder-clay is not of direct Glacial origin, but is reassorted material. Another term should be used to distinguish it, perhaps "Stony clay" would do.

[3] This statement is true whether we accept the higher beach as proved or not, although in my opinion the extent and mode of occurrence of the leafy clays necessitate the existence of the higher beach. The formation of the beaches was contemporaneous with the deposition of stony and stoneless reassorted non-laminated clays and with leafy clays; and the uplift with extensive erosion of these and earlier Glacial and Fluvio-glacial beds. The Kirmington estuarine deposit was probably laid down at the same time as the leafy clays of the Tyne valley.

[4] I am of the opinion that the sea invaded the area as the ice was melting. The rafted boulders which have been dropped into the deposits were carried by floating ice (no remains of trees are found in the clays), and the contorted sands that sometimes occur (e.g. Ryhope) were probably produced by stranding ice-blocks.

[5] Same as the Purple Clay of Yorkshire.

[6] The Yorkshire Basement Clay is probably slightly later than the Durham. The evidence appears to prove that there was a Glaciation-Interval (Interglacial Period ?) between.

Photo D.W.

FIG. 1.—60 ft. Raised Beach at Easington.

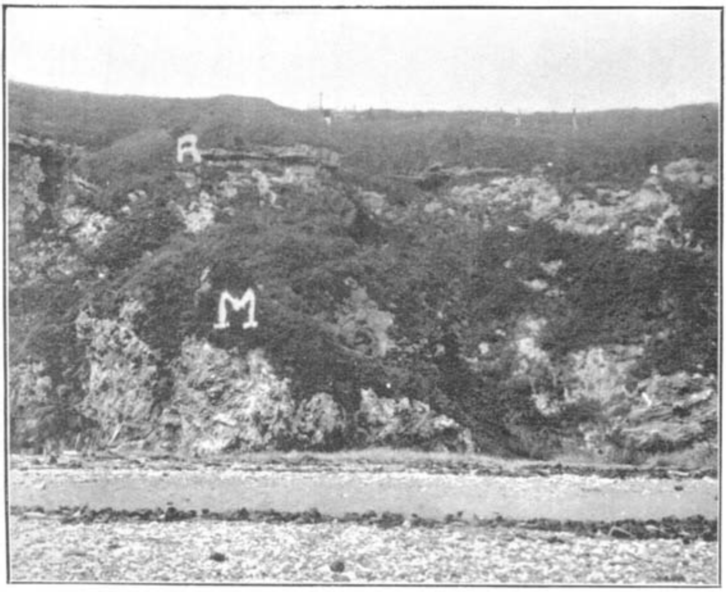

Photo D.W.

FIG. 2.—Photograph of cliff at Easington showing 60 ft. Raised Beach resting on rock shelf.

[To face p. 74.

in the main of fairly continuous outcrops, but is much disturbed by faulting. In the unravelling of the tectonics of the district, however, the difficulty caused by excessive faulting is counterbalanced by the multiplicity of the borings that have been made during the exploration and development of the valuable hæmatite deposits associated with the limestones. In no single instance is there an exposure giving a complete section of the sequence, yet with the help of the journals of the "bores" every one of the exposures mentioned in this paper can be placed at its exact horizon with great accuracy.

The area has been mapped by the officers of the Geological Survey.[1] The only memoir dealing with the limestone is that on the hæmatite by B. Smith [2] recently published, in which the names and thicknesses of the various limestones are detailed.

In 1869 W. Brockbank [3] gave some notes on the Aldby Limestone. The horizon is not mentioned, nor are the fossil contents enumerated, which is to be regretted, as this exposure has been covered over with slag heaps. The most important work on the area under consideration is that of Mr. J. D. Kendall.[4] Mr. Kendall describes the succession very minutely, records the general lithological characteristics, gives numerous sections, makes comparisons with sections outside our area, and defines the double system or two systems of faulting. No attempt is made to supply any exhaustive account of lithological details, nor are the fossil contents catalogued with any completeness. Mr. J. G. Goodchild,[5] in a paper on the Limestones of Cumberland and Westmorland, makes mention of our area in pointing out the attenuation of the detrital rocks interbedded with the limestones as our district is approached from the north and north-east. Since then nothing worthy of note has been done, and no attempt at anything like a thorough investigation of the fossil fauna has been made. With the exception of some specimens of *Productus* cf. *giganteus* Mart., one or two other brachiopods, and some very fine specimens of *Lonsdaleia* (all without localities) in the museum of the Whitehaven Scientific Association, there are no public collections of Carboniferous Limestone fossils in the district.

The author began collecting in 1910 with a view to correlating the different beds of the various outcrops; more especially was he anxious to establish definite palæontological horizons in the Egremont portion of the area, where the upper beds with the easily identified Orebank Sandstone are usually denuded, and the interbedded sandstones and shales of the lower portion of the series are not well

[1] Sheet 101 S.W. (New Series, Sheet 28)

[2] Special Reports, vol. viii,—*Iron Ores: Hæmatites of West Cumberland, etc.*, 1919.

[3] *Proc. Manch. Lit. and Phil. Soc.*; GEOL. MAG., Vol. VI, p. 141 (Abstract).

[4] "The Carboniferous Rocks of Cumb. and N. Lancs or Furness": *Trans. N. of Eng. Inst. Min. and Mech. Eng.*, vol. xxxiv, 1885, p. 185.

[5] "Notes on some of the Limestones of Cumb. and Westm.": *Trans. Cumb. and Westm. Assoc.*, No. xvi, 1890–1, p. 134.

slopes coinciding with the dip of the strata, which is usually to the west or south-west.

The drainage of the area is for the most part post-glacial, the Rivers Keekle and Ehen crossing or running along the sides of faults indiscriminately. Two outcrops appear outside the tract of country mentioned. One is at Overend, 1½ miles south-east of Whitehaven, where the First, Second, and Third Limestones have been pushed up through the Millstone Grit and Coal Measures; and the other is at Wilton, a mile east of Egremont, where the Seventh Limestone, isolated amid Lower Palæozoics, has been saved from denudation by slight synclinal folding. The Whitehaven Millstone Grit and Coal Measures border the limestone tract on its western side for the greater portion of its length.

THE CARBONIFEROUS LIMESTONE SERIES AND MILLSTONE GRIT OF W. CUMBERLAND.

TABLE I.—LITHOLOGY.

	Thickness.	S.W. ft.	N.E. ft.
Millstone Grit	Coarse grits with quartz-pebbles and felspar-fragments. Sandy, mottled, and finely laminated black shales, fossiliferous. Thin coal, 4 in.–0	60	120
First Limestone	Dark blue-grey limestone: towards top thinly bedded with sinuous but persistent bedding-planes; lower portion massive. Occasional small veins of barytes	40	60
First Shale	Thinly laminated shale with thin coal and sandstone	12	14
Second Limestone	Dark blue-grey limestone, thick-bedded	14	24
Orebank Sandstone	Fine-grained micaceous sandstones with one or two coarser bands; becomes largely dark shales in N.E.	40	70
Third Limestone	Reddish-grey crinoidal limestone	12	15
Third Shale	Mottled shale, sandy and micaceous	6	8
Fourth Limestone	(For sub-divisions and characters see Table III.)	256	312
Fourth Shale	Green shales, sandy mudstones, and micaceous sandstone	14	24
Fifth Limestone	Upper portion (A) white or reddish-grey limestone usually much jointed; separated from dark blue-grey lower portion (B) by thin mudstone. Pseudo-breccias in (B)	50	70
Sandstone and Shale	Upper portion thinly bedded sandstone, with finely laminated black fossiliferous shale in lower portion	14	24
Sixth Limestone	Blue-grey limestone, thick-bedded, with pseudo-breccias, much divided in places by black shales of variable thicknesses	54	70
Thin Beds	Nodular limestone with thinly bedded limestones, shales, mudstones, and calcite-mudstones	10	20

		Thickness. S.W.	N.E.
		ft.	ft.
Seventh Limestone	Evenly-bedded grey limestones with diagonally-bedded sandstones near base and summit; chinastone-limestone and pseudo-pisolite; chert nodules at one or two levels. Dolomite-mudstones and calcite-mudstones with black shales at base	60	160
Basement Bed	Dark-grey shale, sandy, and conglomeratic in parts, with small comminuted quartz-pebbles throughout	3	6

TABLE II.—PALÆONTOLOGY.

Millstone Grit	Coarse grits and sandstones contain plant-impressions. Black shales contain Goniatites in abundance, *Pterinopecten sp.*, *Lingula sp.*, and many gastropods.
First Limestone	*Productus giganteus* Mart., *P. latissimus* J. Sow., *Schellwienella crenistria* (Phill.), *Athyris planosulcata* (Phill.), and *Orbiculoidea nitida* Phill. are the chief brachiopods. Corals abundant: *Dibunophyllum muirheadi* Thom., *Aulophyllum fungites pachyendothecum* Thom. em. S. Smith, *Koninckophyllum magnificum* Thom., *Caninia* cf. *sub-ibicina* McCoy, and *Lonsdaleia floriformis* (Mart.) mut. *laticlavia* S. Smith are chief forms.
First Shale	Plant-impressions and indeterminable casts of lamellibranchs.
Second Limestone	*Productus latissimus* J. Sow., *P. semireticulatus* Mart., *Dibunophyllum sp.*, *Zaphrentis* cf. *disjuncta* Thom.
Orebank Sandstone	Plant-impressions in many bands.
Third Limestone	Fauna sparse, *Zaphrentis enniskilleni* Edw. & H. and *Diphyphyllum lateseptatum* McCoy are chief corals.
Third Shale	No fossils.
Fourth Limestone	(For palæontology of Fourth Limestone see Table IV.)
Fourth Shale	No fossils.
Fifth Limestone	*Productus* cf. *maximus* McCoy, *P. semireticulatus* Mart., *P. cora* d'Orb. mut. D_1, *Chonetes papilionacea* (Phill.) are characteristic and abundant brachiopods. Coral fauna contains a maximum of *Cyathophyllum murchisoni* Edw. & H., *Koninckophyllum sp.*, *Carcinophyllum sp.*, *Dibunophyllum* θ Vaughan, with *Lonsdaleia duplicata* (Mart.) mut. *melmerbiensis* S. Smith highly characteristic.
Sandstone and Shale	Sandstone contains worm-tracks, rain-prints, etc. Black shale is crowded with *Chonetes hardrensis* (Phill.), *Leptœna analoga* Phill., *Productus longispinus* Dav., and many lamellibranchs.
Sixth Limestone	*Productus maximus* McCoy, *Chonetes* aff. *papilionacea* (Phill.), *Dibunophyllum* θ Vaughan (rare), *Carcinophyllum* θ Vaughan, *Lithostrotion martini* Edw. & H. characteristic and abundant.
Thin Beds	Nodular bed probably algal. *Spiriferina* cf. *laminosa* McCoy abundant. *Pugnax pugnus* Mart. and *Seminula ficoidea* Vaughan. Fish teeth fairly common. Calcite-mudstones contain *Spirorbis*-

	like annelids, small gastropods, *Calcisphæra*. Shales contain lamellibranchs, *Aviculopecten* cf. *plano-clathratus* McCoy and *Modiola sp.*
Seventh Limestone .	*Productus maximus* McCoy, *P. cora* d'Orb. mut. S_2, *P. corrugato-hemisphericus* Vaughan abundant and characteristic. *P. scabriculus* Mart., *Dielasma* cf. *sacculus* (Mart.), *Seminula* cf. *ficoidea* Vaughan, *Cyrtina sp.*, *Cyathophyllum* cf. ϕ Vaughan, *Nematophyllum minus* McCoy, *Carcinophyllum sp.* near θ Vaughan, *Caninia* cf. *patula* Mich. *Syringopora* sp. [a distinct form].
Basement Beds . .	Plant impressions and casts of *Productus*.

General Lithological Description of the Series.

The series consists of a number of massive to thinly bedded limestones interspersed with beds of sandstone, shale, or mudstone (see Tables I and III).

The limestones are most commonly of standard type, viz. with a standard marine fauna. Their texture ranges from coarse granular crinoidal rocks to very fine-grained or porcellanous "calcite-mudstones",[1] which include "chinastone-limestones". In colour they vary from white through reddish-grey and blue to almost black, beds on the same horizon differing according to the presence or absence of hæmatite in the vicinity.

The shales and mudstones range in colour from pale green or grey through reddish-grey to purple and black; in thickness from paper-thin partings to beds 12 to 14 feet in thickness. The mudstones associated with the Fourth Limestones are mottled (white, red, and purple), and are either purely argillaceous (weathering to a crumbly clay) or sandy-argillaceous; they are known in the district and are recorded on the Vertical Sections published by the Geological Survey as mottled shales. The shales in the upper limestones are carbonaceous. Mica is usually present in the sandy shales, but is absent from the mudstones. The sandstones intercalated between the limestones are generally stained red and purple, and, with the exception of one or two coarser bands in the Orebank Sandstone, are mainly fine-grained. Mica is usually present. No limestone exactly like the Bryozoa Bed (Hor. *a*) of Bristol is present, but rocks somewhat resembling it occur near the base and summit of the Seventh or Bottom Limestone and again near the top of the Fourth Limestone. A rock suggesting the "Seminula Pisolite" of the Avon Section occurs near the summit of the Seventh Limestone.

Subsequent dolomitization occurs locally in many of the limestones; it is frequently associated with hæmatite. Dolomite-mudstones are common at the base of the series, but no contemporaneous dolomitization has been observed. A fine-grained calcite-mudstone, about 2 feet thick, weathering white and fracturing conchoidally, like the "chinastones" of the S.W. Province, occurs midway in the Seventh Limestone, whilst other calcite-mudstones,

[1] The terms "calcite-mudstones" and "dolomite-mudstones" are used for rock-types similar to those described by Mr. Dixon (*op. cit.*, pp. 516–17).

with ostracods, small gastropods, and *Spirorbis*-like annelids, occur at two or three horizons. Purely crinoid limestone, suggestive of "petit-granite", occurs rarely (one or two bands), but crinoid-ossicles are abundant in most of the limestones. Foraminiferal limestones are almost universal, but foraminifera are specially abundant and attain considerable dimensions in the "Spotted Beds" near the middle of the Fourth Limestone. *Saccammina* characterizes a particular horizon of this limestone throughout the area. Limestones that are more or less definitely algal [1] occur at three or four separate levels. *Girvanella sp.* is abundant in a particular band of the Fourth Limestone throughout the district, and the white limestones immediately below are particularly rich in what appear to be algal remains.

Iron pyrites occurs in the Second Limestone at Overend, and is often abundant in the shales, being remarkably ubiquitous in the shaly Basement Conglomerate. Small veins of barytes occur in the First Limestone at Langhorn, and in many of the beds at Kelton Head; it is often associated with hæmatite. Hæmatite is found in variously formed masses and irrespective of any particular horizon, but whilst it has been found in all the limestones an analysis of the occurrences proves that there are three horizons where hæmatite deposits are more general than at other levels. The first is at the base of the First Limestone, the second rests on what is known locally as the Fourth Shale (the shale at the base of the Fourth Limestone), and the third lies on the Basement Shale. Crystals of calcite are abundant throughout, West Cumberland having supplied many specimens to museums all over Europe. Fluorspar is found more sparingly. "Pseudobreccias," similar to those described by Dixon and Garwood from the D Zone of the South-West and North-West Provinces, are present at many levels, and are well developed in the Fourth Limestone; "spotted beds" are confined to that level. Chert occurs in nodules near the base and towards the top of the Seventh Limestone, and sparingly along the bedding at the top of the Fourth Limestone. Some of the nodules show concentric zoning. Beekite and other forms of silica replace corals and brachiopods in some beds.

Diagonally Bedded Sands.—A feature to be noticed occurs in the Seventh Limestone at two distinct horizons, one about 20 feet above the Basement Conglomerate and the other at the top of the limestone. Grains of red and brown quartz enter the limestone in "diagonal" (cross) bedding, forming diamond-shaped "frames" that enclose masses of almost purely crinoidal limestone. *Spirifer*, *Dielasma*, *Seminula* cf. *ambigua*, and other brachiopods persist upwards through the sands, and are preserved as casts in the sandstone itself. The lower of the sandy episodes consists of bands of a few inches thickness, whilst the one at the top of the Seventh

[1] Attention has been drawn by Garwood and Reynolds to the importance of algæ as rock builders of Carboniferous and other limestones.

Limestone developes in places into a sandstone, 6 to 10 feet thick, with numerous plant-impressions. On a weathered surface the sand-grains stand out as brown lines, and give the rock a striking appearance. The walls on either side of the Rowrah to Kirkland road are built of this limestone and show up the diagonal bedding to perfection. This feature, when present, distinguishes the Seventh or Bottom Limestone, being absent from all the other limestones.

The Fourth Limestone.—The Fourth Limestone (Tab. III) can be subdivided into several distinct beds, and the intercalated mudstones, shales, and sandstones are persistent over an area extending beyond the limits of the district under consideration. This limestone, which is highly fossiliferous throughout its thickness, affords the best exposures throughout the district, and is the one most frequently quarried; indeed, at present (1921) no quarry is being worked in any other limestone. The thicknesses usually given in vertical sections are 256 feet in the vicinity of Clints and 312 feet at Yeathouse, but by direct measurement the thicknesses are slightly less. The best exposures are at Kelton Head and Rowrah Head, where the full sequence can be seen and studied. Other good exposures, but lacking some of the top beds and their connexion with the Third Limestone, are at Rowrah Hall, Salter Hall, Postlethwaite's Eskett, Yeathouse, and Clints Quarries. The junction of the D_1- with the D_2-subzone occurs about 50 feet above the base of this limestone; it is distinguished by a thin calcite-mudstone lying between shales with plant-impressions. The calcite-mudstone contains *Spirorbis*-like annelids, small gastropods, beside *Girvanella sp.* and similar algæ. *Girvanella sp.* also occurs encrusting small fossils and crinoid-fragments in the limestone immediately above the calcite-mudstone.

THE FOURTH LIMESTONE.

TABLE III.—LITHOLOGY.

	Thickness.	S.W. ft.	N.E. ft.
Black Chert Beds .	Dark blue-grey limestone with chert nodules along bedding; middle bed calcite-mudstone . . .	10	15
Shale	Mottled mudstone, with concretions .	1	2
Junceum Beds . .	Thick-bedded blue-grey limestone with platy crinoidal band towards top. Chert (Kelton Head). Little shale along bedding planes which are usually concretionary towards top but absent in massive lower portion	55	65
Saccammina Beds .	Greenish-grey limestone separated from above by 1–2 feet of mottled shale or mudstone	18	25
Upper Algal (?) Band.	Micaceous sandstone (Clints); nodular and porcellanous limestone	2	5
Pot-holes Bed . .	Thick post of light-grey limestone without shale partings. Pot-holes abundant and persistent.		

	Thickness.	S.W. ft.	N.E. ft.
	"Spotted," the "spots" being large patches of pink staining on light-grey matrix.	20	30
Shale, mudstone, or sandstone.	Shale and mudstone (Clints); sandstone (Frizington)	2	3
Spotted Beds	Thickly-bedded light-grey limestone with two or three thin shales or mudstones; "spots" mainly dark-grey ("matrix" light-grey), more or less circular in one or two bands, about 1 in. in diam. in lower portion, increasing upwards	30	35
Thin Mudstone			
Rough Beds	Dark-grey limestone with pseudo-breccia structure and "wavy" bedding planes; highly bituminous towards base	50	60
Shale	Shale, mudstone, and calcite-mudstone	1	2
White Beds	White limestones in 5 or 6 beds with 3 or 4 mottled mudstones 1–10 feet thick. Middle beds much worn by contemporaneous channelling; true limestone-breccias in the mudstones; lower beds faintly spotted. Persistent evenly-bedded limestone-breccia at base	55	65

THE FOURTH LIMESTONE.

TABLE IV.—PALÆONTOLOGY.

Black Chert Beds	*Productus semireticulatus* Mart., *P. latissimus* J. Sow. *Athyris planosulcata* (Phill.), chief brachiopods. Corals not abundant; *Aulophyllum pachyendothecum* Thom., *Syringopora reticulata* Goldf., with *Chætetes depressus* in wide-spreading flat sheets.
Junceum Beds	Fauna particularly abundant; some of the chief forms: *Productus giganteus* Mart. in a distinct band near top of this bed, *P. concinnus* J. Sow., *P. scabriculus* Mart., *P. fimbriatus* J. de C. Sow. *Martinia glabra* (Mart.), *M. ovalis* (Phill.), *Spirifer grandicostatus* McCoy are common. *Lithostrotion junceum* (Flem.) in many distinct bands with *L. portlocki* (Bronn) and *L. maccoyanum* Edw. & H., *Lonsdaleia duplicata* (Mart.) mut. *alstonensis* S. Smith, *Cyathophyllum regium* Phill., *Michelinia tenuisepta* (Phill.), *Dibunophyllum splendens* Thom., *Clisiophyllum* cf. *keyserlingi* McCoy, *Aulophyllum fungites* (Flem.) mut. *cumbriense* S. Smith, *Heterophyllum Lyelli* Duncan, and a large form of *Diphyphyllum sp.* are not found in any of the other beds. *Saccammina carteri* Brady occurs at base.
Thin Mudstone	Is crowded with *Saccammina* at Clints.
Saccammina Beds	Standard D_2-fauna but macroscopic fossils not abundant. *Saccammina carteri* Brady [throughout], but most plentiful in a band midway in the beds. *Orionastræa ensifer* S. Smith only from here.

Upper Algal (?) Band.	Algæ (?) (Frizington); plants in the sandstone.
Pot-holes Bed . .	Standard fauna, D_2 corals abundant; *Saccammina* in upper beds.
Mudstone . . .	Mudstone unfossiliferous; plants in sandstone.
Spotted Beds . .	Brachiopods particularly abundant in top beds; foraminifera abundant, large *Textularia sp.* characteristic. *Lonsdaleia sp.* [var. in which many septa reach theca]. *Lithostrotion irregulare* Phill. abundant.
Thin Mudstone . .	No fossils.
Rough Beds . .	Typical D_2-fauna abundant, with many lamellibranchs in lower portion. *Chonetes* cf. *comoides* occurs in band near base, and *Girvanella sp.* occurs encrusting crinoid stems and coral fragments in a band at the base and is found in the calcite-mudstone immediately below. Chief associated forms are: *Productus edelburgensis* Phill., *P. maximus* McCoy, *Chonetes compressa* Sibly, *Pugnax pleurodon* (Phill.), *Spirifer bisulcatus* J. de C. Sow., *Dibunophyllum θ* Vaughan, *Caninia denticulata* Thom., *Lonsdaleia floriformis* (Mart.) mut. *crassiconus* S. Smith, *Carcinophyllum sp.*, *Zaphrentis sp.*, *Cyathophyllum murchisoni* Edw. & H., and *Lithostrotion irregulare* Phill.
Calcite Mudstone .	*Spirorbis*-like annelids, *Girvanella sp.*, and many small gastropods.
White Beds . .	Brachiopods abundant in upper beds; *Productus cora* d'Orb. mut. D_1, *P. hemisphericus* J. Sow., *Schizophoria resupinata* (Mart.), *Cyrtina septosa* (?) Phill. A gastropod, *Straparollus acutus* (Sby.), is common. Corals abundant, especially in lower beds, and typical of D_1: *Cyathophyllum murchisoni* Edw. & H., *Carcinophyllum θ* Vaughan, *Dibunophyllum θ* Vaughan, *Caninia* cf. *derbiensis* Vaughan, *Lonsdaleia duplicata* (Mart.), and a Clisiophylloid *Lithostrotion*.

(*To be continued.*)

The Petrology of the Pennant Series, East of the River Taff.

By A. Heard, M.Sc., F.G.S., University College of South Wales and Monmouthshire.

ALTHOUGH much geological research has been done on the Coal Measures of South Wales, little detailed work on the petrology of the series, east of the River Taff, has been published. This work has been undertaken in the hope that the petrology of the district may give a foundation for a reliable correlation or may give a clearer conception of the conditions of deposition and the source of the sediments than is obtained from a study of the coal-seams alone.

The Coal Measures of South Wales are divided into three main groups: the Lower Coal Series, the Pennant Sandstone, and the Upper Coal Series. The upper boundary of the massive sandstone series known as the Pennant Grit, is defined by the Mynyddislwyn