THE GEOLOGY OF COAL AND COAL-MINING

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THE GEOLOGY OF COAL AND COAL-MINING

BY

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EDITOR'S PREFACE

THIS book is the first of a series of works on economic geology undertaken by experienced geologists. Other books will shortly follow, dealing with the geology of metalliferous mining, quarrying, water-supply, and precious stones.

The economic aspect of geology is yearly receiving more attention in our great educational centres, and the books of this series are designed in the first place for students of economic geology. It is believed, however, that they will be found useful to the student of general geology, and also to surveyors and others who are concerned with the practical applications of the science.

Dr. Gibson has, as the result of many years' professional work among the coal-bearing rocks of this country and of South Africa, rendered himself peculiarly qualified to write upon the subject treated in the present work.

J. E. MARR.

AUTHOR'S PREFACE

THE limited size of this work makes it imperative that certain portions of the subject should be treated with brevity in order that additional space may be devoted to general principles of practical significance. Many branches, therefore, of strictly scientific or of general interest receive scanty notice. For the same reason simple geological terms in almost daily use by the miner are explained and illustrated, while the terminology used in the petrological descriptions of igneous rocks is not elucidated.

In the account given of the Foreign Coalfields it will be noticed that a geological and not a geographical arrangement has been adopted.

Except in a very few cases, references have been intentionally omitted in the text, and indebtedness is here freely acknowledged for information obtained from the Reports of various Geological Surveys at home and abroad, and from the Final Report of the Royal Commission on Coal Supplies for 1905.

The author wishes to express his thanks to the Council of the Palæontographical Society for permission to reproduce from its volumes the figures of fossils given on Fig. 1, and to the Council of the Geological

Society, London, for the same privilege accorded with respect to Fig. 2. The author is also greatly indebted to Mr. R. Kidston, Dr. A. C. Seward, and Mr. E. A. N. Arber, who have kindly allowed him to reproduce those photographs to which their names are appended.

WALCOT GIBSON.

LONDON, 1908.

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CHAPTER I

INTRODUCTION

THE yearly increase in the demand for coal and the correspondingly greater output have of recent years led to a consideration of the available supply, both in Great Britain and in other countries.

In Europe the areas from which coal could be easily obtained at little expense are either entirely or almost entirely exhausted. New explorations, therefore, are being undertaken in regions often far removed from existing workings, and where the expenditure is necessarily very great before there can be any hope of return.

The working of coal by day-levels in Monmouthshire and eastern Glamorganshire belongs to the past. Such coals as could be easily got by tunnelling into the hills in South Wales, except in the west, have been for the most part worked out, as also have the seams obtained by shallow pits sunk near the outcrops.

In the Black Country of South Staffordshire the exhaustion of coal over a large part of the old coalfields was anticipated many years ago, and new pits have been successfully sunk both to the east and west, and also to the north, far beyond the boundary lines which were formerly considered to mark the extreme limits of the coal-bearing strata in this district.

In Yorkshire and Nottinghamshire the same story is repeated, and new pits creep continuously from the known coal-bearing area on the west eastwards to the unknown, each new enterprise entailing increased initial expenditure and a subsequent costly maintenance.

In Scotland, explorations are now in progress to win the coals beneath the Firth of Forth. Indeed, so valuable has coal become that explorations in search of it are at the present time being pushed forward in the south-eastern counties of England, where for a long time the question of its existence belonged to the realms of pure geological speculation.

Crossing the channel, we find that France is busily engaged in ascertaining the hidden resources of her coalfields in the north, and also in French Lorraine. Belgium enterprise, again, has proved the existence of productive Coal-measures in the Campine, thus enormously increasing the future life of her coalfields in the north.

New methods of utilizing coals of inferior quality are being successfully tried on an extensive scale in Germany and Austria, and seams hitherto considered worthless are now being exploited.

The United States has more than quadrupled the output of coal within the last twenty years, and now produces over 100,000,000 tons per annum more than Great Britain. Explorations in the Pennsylvanian and vast Appalachian coalfields, from which the bulk of

American coal is obtained, are being carried on at a rapid rate, so that the day is not far distant when the United States, like Europe, will have to win the coals at greater depths and in less easily accessible regions.

In South Africa, India, and Australasia the use of coal is continually on the increase. Many local industries of great importance depend to a large extent on the proximity of coal, and several of the iron industries, such as those of India, can, or it is predicted will shortly, enter into competition in the East with those of Europe, owing to the existence of cheap and suitable coals in close proximity to extensive deposits of iron ores.

Japan supplies her navy with native coal; and China, aware of the national importance of her vast coal supplies, preserves a watchful and guarded interest in the development of her coalfields.

So easily, and without any special geological knowledge, has coal been got in the past, and to the early miner so great must have seemed the visible supply compared to the output, that the possibility of exhaustion of the known coal areas, and the consequent extension of the workings into regions which, a century ago, were condemned as barren ground, could never have been considered.

Wherever individual enterprise was successful, and could be maintained without co-operation, those concerned in the working of any one colliery were naturally satisfied with a knowledge sufficient to understand the geological circumstances governing their particular enterprise.

It, therefore, happens that much information, so readily obtained at the time, and which would now prove of such inestimable value in the interpretation of the difficulties met with in exploring fresh areas, has never been recorded, and new enterprises start very much on the same basis as did the older explorations.

Unrivalled sections, obtained during the sinking of new pits and in underground workings, are being almost daily made; but the character of the new ground receives little attention either from local geologists or mining engineers, and much valuable information is still being undoubtedly lost.

If the knowledge of the geological features of many of the older coalfields is far from satisfactory, it is still more difficult to obtain reliable information about the coalfields of new and only partially explored countries, and even about those districts where coal-mining has been in operation for several years.

In no case is reliable information more wanted than in that of the distribution of the fossils of the coal-bearing Carboniferous rocks of Europe and America, since the best coals of the world are found among these strata, and the fossils of which some geologists believe will prove of great service to the miner in the identification of horizon. Many stratigraphists and mining engineers still ignore the value of fossil evidence, except on the more general lines, in spite of repeated instances where even a slight knowledge would have prevented mistakes being made.

The amount of such knowledge required is not really great, nor is it difficult to attain, and, leaving aside the practical aspect of the inquiry, the search for fossils will ever exert a fascinating influence.

In the account of the coalfields chief attention will, however, be given to those fossils of greatest use to the miner, without reference to their scientific interest. Undue importance must not, however, be attributed to palæontological evidence, for the determination of horizons by means of fossils must conform to stratigraphical sequence and geological structure.

In coal-mining, as in metalliferous mining, geology necessarily takes a prominent place in the curriculum of the engineer; but coal—what it is, how it occurs, how it is distributed, and in what quantities—must, from its preponderating influence on modern civilization, form a branch of inquiry interesting to every nation.

CHAPTER II

VARIETIES—CHEMICAL AND PHYSICAL CHARACTERS

THE term 'coal' includes those solid combustible substances which have resulted from the decomposition and alteration of once living vegetable organisms, now occurring in a fossil state in geological formations of various periods. Since the stages reached in the decomposition and alteration vary within wide limits, and the changed vegetable matter is more or less mixed with foreign material, it is obvious that what is coal and what is not coal cannot be satisfactorily defined. Solid bitumens, soluble in naphtha or benzene, and whether of organic or of inorganic origin, are excluded.

Coal in the state in which it commonly occurs is mainly composed of oxygenated hydrocarbons, together with hydrocarbons free of oxygen. Free carbon is inferred in anthracite, though some chemists dispute its existence in a free state in any coal.

Sulphur in combination with iron is usually present, and there are always certain mineral impurities, consisting of silica, iron oxides, silicates of alumina, potash, and soda, constituting the ash.

Plant tissues and coal agree in the essential constituents of both being some combination of carbon, hydrogen, oxygen, and nitrogen, the carbon being largely in excess of the other elements.

The main bulk of plants, whether of a high or low organization—a forest tree or a moss plant—consists of woody fibre, remarkably uniform in composition. In each of these plants, separated so widely in organization, the carbon percentage of the woody fibre varies between 48 and 51, the hydrogen between 5·9 and 6·5, and the oxygen and nitrogen between 41·8 and 44·5. From this it is inferred that the chemical nature of woody fibre has been the same throughout geological time.

While woody fibre throughout the vegetable world possesses a remarkably uniform composition, other parts of a plant vary greatly in chemical constituents, and the same part of one plant may differ in the proportion of its chemical components from the corresponding part in another plant. It is found, for instance, that leaves, leaf-stalks, and bark are richer in carbon, but poorer in hydrogen and nitrogen, and contain more ash than spores, seeds, and cuticles. A coal formed out of spores may therefore differ *ab initio* from one derived from the alteration of bark and leaves.

Ordinary coal usually consists of obviously distinct layers—one bright and glistening, termed 'bright coal,' and another dull black, silky, and fibrous, known as 'mineral charcoal' or 'mother of coal' (*fusain, houille dalöide, faserkohle,* of continental writers). These layers correspond to the laminæ of all ordinary sedimentary rocks, like shale or sandstone. Along the dull layers fragments of charred vegetable tissue, either leaves, leafstalk, bark, or wood, are often clearly distinguishable. In the bright layers organic structure is not so evident, but, as in the Better Bed Coal of Yorkshire, these bright layers can be seen under the microscope to consist largely of spores. The difference in chemical composition of the two layers, the dull and the bright, agrees with that of the materials composing them; the layers of mineral charcoal, or dull layers, are richer in carbon, but contain more ash than the bright layers. In assuming, however, that coals in which spores are abundant have entirely originated from spores, the fact must not be lost sight of that the spores are the more conspicuous element owing to their greater resistance to destruction.

Besides the organic compounds, all plants, as before stated, contain mineral salts, which are not only different for distinct plants, but also vary greatly both in quantity and nature in different parts of the same plant. *Lycopodium clavatum*, one of the commonest of the British club mosses, contains 4·7 per cent. of ash, and a closely allied species, *Lycopodium chamæcyparissum*, as much as 6·7 per cent., while the ash contained in forest trees rarely exceeds 2 per cent. The spores of the *Lycopodiaceæ*, however, contain an appreciably smaller quantity of ash than the other tissues.

The character of the ash is most marked in *Lycopodium* and in the common bog moss *Sphagnum*. Both these plants, it has been ascertained, possess the power of dissolving alumina out of the soil. From its insolubility in water, alumina remains after the plant has rotted, and after a large proportion of the other soluble mineral constituents has been dissolved out and carried away. Salts of iron and lime, though more soluble than alumina, are less so than alkalis and lime salts. The sulphur present in all plants unites to form more or less insoluble compounds. Thus, in a mass of decaying vegetation certain mineral salts which existed in the living plant will be concentrated, while others will be carried away in solution.

Apart, then, from the mineral matter introduced from extraneous sources to the spot where the decaying vegetable matter was accumulating, some of the inorganic salts present in coal will be due to the aggregation of the insoluble salts present in the living matter from which the coal was derived. It is interesting to note that the ash present in the mineral charcoal of the Bette Bed Coal contains from 28 to 33 per cent. of alumina.

Changes affecting the decayed vegetation subsequent to its burial beneath sediments, and those resulting from earth pressure and other geological agencies, will be dealt with in a succeeding chapter. Sufficient has been said to show that coal has its origin in vegetable matter, and that one coal may differ in composition from another coal as much according to the parts of the plant as to the kind of plant from which it originated.

In describing the different varieties of coal, as commonly designated, it is usual to commence with those coals of which the vegetable origin is the least obscured, and then to pass to those in which the original organic structure is partially, or it may be wholly, indistinguishable even under the microscope. Peats and lignites, though excluded from the coal series, will be considered first, since these two kinds of vegetable fuel occur in a fossil state, and illustrate the earlier stages through which woody fibres and tissues may pass during their conversion into coal.

Peat.—The purest, thickest, and most extensive accumulations of vegetable débris at the present day occur in peat-bogs and swamps. These are most prevalent in the Northern Hemisphere, and extend up to the polar limit of vegetation, the 56th degree north parallel forming the chief zone.

In Ireland peat-bogs cover an area of over 3,000,000 acres, and in some places the peaty accumulations attain a depth of over 50 feet. France contains large tracts of peat, and Russia the largest of all. There are few peat-bogs of any size in the tropics except in Madagascar.

The swamps of Virginia and those in the deltas of the Ganges and Brahmaputra afford examples of areas where decaying vegetation is accumulating at the present day. Swamps differ from peat-bogs by the presence of free circulating waters, and this, as will be shown later on, has some effect on the decay of the plants.

The rate of growth of peat varies considerably. It is stated to be as much as 26 inches in a century, but immersion and low temperature tend to retard the accumulation. The upper layers in a peat-bog are light coloured, and the vegetable origin is obvious; but deeper down the layers become darker in colour, until near the bottom they are almost black, and have lost to a considerable degree all visible signs of organic structure.

In the 'Red Bogs' of the central plains of Ireland the organic matter, partly in a living state, forms a layer from 2 to 6 feet in thickness, termed the 'clearing'; beneath this comes a layer of 'white turf,' passing down into 'brown turf,' and thence downwards, till at the bottom of the bog comes the 'black' or 'stone turf.' Each layer consists of laminæ, increasing in the number per square foot from above downwards. The 'black turf' is the most valuable for fuel purposes, giving out a strong heat and brilliant light.

The percentage of ash is usually highest in the 'black turf,' but much interesting work remains to be done as to the composition of the different layers of Irish peat.

Mosses, monocotyledonous, and, more rarely, dicotyledonous plants, enter into the formation of modern peats. The composition varies within wide limits. The percentage of carbon ranges from 50 to 60, of hydrogen from 5 to 6, and of oxygen and nitrogen from 28 to 50. A large quantity of moisture is usually present, air-dried peat containing as much as 15 per cent.

Fungi and bacteria are considered to have taken an active part in the elimination of the oxygen and hydrogen from the original woody tissue. The ratios of carbon to the hydrogen and the oxygen being 9·8 and 1·8 respectively, as compared with 7·2 and 0·9 for woody fibre, represent the change in the proportion of these elements effected during the conversion.

Peats belong to the Quaternary or latest period in the geological record. A few thin bands are Pre-Glacial and some Inter-Glacial, but the most extensive areas of peat are of recent formation, though at the present time peat is not being formed to any appreciable extent.

Lignite.—This variety of fuel forms the connecting link between peat and the bituminous coals, but is not, as we have stated, classed with true coals. The term is sometimes restricted to those varieties presenting the appearance of woody tissue; the other kind, in which the woody character is more or less obscure, being termed 'brown coal.' Classified according to external characters, lignites are divided into—(1) woody or fibrous brown coal, possessing the form and structure of wood; (2) earthy lignite, compact and easily rubbed into a powder; (3) common brown coal, with the woody structure indistinct, possessing a slaty cleavage and always black or dark brown in colour; (4) bituminous lignite or 'pitch coal' ('peckkohle,' 'glanzkohle'), having a conchoidal fracture, pitch-black in colour and frequently resembling coal, and sometimes even anthracite.

Lignites contain fragments of leaves, bark, tissues, spores, macrospores, and pollen grains, all in an advanced stage of decomposition. They were formed in shallow waters in which infusoria could live, and in which fungi and bacteria were abundant.

Like peats, the chemical composition of lignites varies. The carbon percentage ranges between 53 and 73, that of hydrogen between 3 and 6, and that of oxygen between 19 and 37. There is always a large amount of moisture and ash present. The carbon-hydrogen and carbon-oxygen ratios are respectively 12 to 6 and 3 to 6.

Lignites are chiefly met with in the Tertiary formation, and form an important source of fuel on the Continent and in other countries, sometimes constituting the only source of fossil fuel. They are of rare occurrence in this country, those of Bovey Tracey being the best known. In Russia the Blatter Kohle and Papier

Kohle are regarded as lignites of Lower Carboniferous age, and show how long some vegetable débris will resist alteration.

Coal.—As popularly understood, coal includes the several varieties of fuel intermediate in physical appearances and in chemical composition between brown coal and the stone-like, but combustible, substance called anthracite. The different kinds of coal are known under the several names given on a succeeding page, and are classed according to their chemical composition or commercial qualities. We are here concerned with the varieties based to a large extent on physical characters and appearances.

Ordinary coal is a more mineralized substance than lignite, and, except in the layers of mineral charcoal, usually shows few visible signs of its organic origin. The amount of carbon, oxygen, and hydrogen differ in the several varieties, but that of carbon is higher in coal than in lignite, while that of oxygen and hydrogen is lower.

Cannel.—In association with true coal, or else existing as a bed by itself, a dull, black, lustreless variety, breaking with a conchoidal fracture, is often met with. Cannel coal, as this variety is called, burns readily without melting, and emits a bright candle-light flame, whence it derives its name. It is frequently capable of taking a fine polish and, like jet, which is a variety of cannel found in the Upper Lias clays on the Yorkshire coast, is made into ornaments. A cannel found in the Midlothian Coalfield burns with a crackling noise, and is termed 'parrot coal.' 'Horn coal,' found in South Wales, is a cannel emitting an odour like burning horn.

The composition of cannel consists of: carbon, 81 to 86 per cent.; hydrogen, 5 per cent.; oxygen, 3 to 8 per cent.; and ash, 1 to 8 per cent. Sulphur is also usually present.

Cannel coal is a valuable source of gas, a ton of Wigan cannel yielding 14,111 cubic feet of gas of 39 candle-power, as well as a large percentage of by-products of much value. Jet and cannel coal contain ethane gas occluded in the pores of the coal.

Cannel always occurs in lenticles, and was evidently laid down in water which was very little subject to disturbance, and in which fish and other animals must have lived, since they are often found in an almost perfect state of preservation in the cannel coal itself.

Under the microscope some cannels are seen to be rich in the fructification of trees and other vegetable débris; some are rich in the fructifications of cryptograms; and some are without any visible structure.

Boghead.—Boghead coal, or Torbanite, as it is sometimes called, from its occurrence in Torbane Hill, is regarded by some authorities as a variety of cannel coal, but others dispute its right to be included with the coals; indeed, such a dispute led to a long lawsuit during the past century. Some bogheads contain no oxygen, and these cases represent the total deoxygenation and partial dehydrogenation of the original vegetable matter; others, again, contain a small percentage of oxygen. All are rich in volatile hydrocarbons, that of Torbane Hill containing over 70 per cent. The ash percentage is high, due, no doubt, in a great measure to the foreign substances introduced during the accumulation of the organic material, for bogheads, like cannel, were deposited in water.

Algæ are said to enter largely into the composition of some bogheads.

The boghead coals of Torbane Hill and Armadale in Scotland, and those of Russia and the United States, are all of Carboniferous age. Those of Autun in France, at Ermelo in the Transvaal, and in New South Wales, belong to the Permian and Permo - Carboniferous periods.

Anthracite.—Coals of this class are stone-like in appearance, or have a semi-metallic lustre, and can be handled without soiling the fingers. They burn with a feebly luminous but smokeless flame, and are much less easily combustible than any other variety of coal. The amount of volatile matter is under 10 per cent., and the carbon percentage in true anthracites is over 93, while the amount of ash is very small. Many coals classed as anthracites, however, contain a considerable quantity of ash, and if the ash is included in the analysis, the carbon percentage is, in consequence, lowered. This is notably the case in anthracites which can be proved to have been formed from bituminous coals by the action of heat due to igneous intrusions.

Anthracites contain immense quantities of occluded gas, especially marsh gas, which is retained in the coal owing to its dense structure, unlike the gas occluded in less coherent coals, which often rushes out in great volumes from the working face.

By the nearly total elimination of the volatile constituents, anthracites may pass into graphites, though it is by no means certain that all graphites have been formed from vegetable matter.

Anthracites are the least widely distributed of all the varieties of coal. The purest and most free from ash occur in South Wales. Pennsylvania possesses large quantities (p. 271), and immense beds are reported to exist in Shan-Si in China, but of which little is known, though recent explorations confirm the reports of early travellers.

In greatly disturbed and folded regions where the seams of anthracite have been subjected to great pressure, as in Pembrokeshire, the coal has been crushed into a fine powder, which is called 'culm.' This powder, after being artificially kneaded or compacted, is used as a fuel, which burns very slowly.

A few rare varieties of coal, or of combustible substances which have at times been mistaken for coal, occur in various parts of the world. One of these, known as 'Anthraxolite,' is a coal-like substance of variable composition found in the older formations of Quebec and Ontario, and is usually regarded as a form of inspissated petroleum. 'Albertite' is another combustible mineral similar in appearance to anthraxolite, but considered to be a mineral asphalt. The carbonaceous deposit in the Laxey lead-mine is probably some form of one of these minerals. The term 'Byerite' has been given to a bituminous coal from the Middle Parks, Colorado. The mineral 'Huminite,' obtained from Östmark, in Sweden, is some form of hydrocarbon. 'Tasmanite' is a carbonaceous shale of a brown colour met with on the River Mersey, in Tasmania, in a bed from 6 to 7 feet thick. It is allied to the White Coal of Australia, of Tertiary age. The carbonaceous matter of both these varieties is composed to a great extent of spores. In White Coal the ash attains a percentage of over 68, and it is also very high in Tasmanite.

Analysis and Sampling.—The value of an analysis of coal depends in the first instance on the method adopted in the selection of the samples. This is evidently of the utmost importance, and frequently falls into the hands of the geologist or the pioneer in new countries.

A seam of coal is generally made up of layers possessing different properties, and a small piece chosen from one thin band would give very misleading results where the analysis of a thick seam is required. In selecting a sample for analysis the following method should be adopted:—

A sample of about 20 pounds in weight is taken from each of at least two of the working faces situated as far apart from each other as possible. A cut about 3 inches wide is made from roof to floor across the seam, neglecting the bands not sent to market, but including those taken out and sold with the coal. If a sample of 20 pounds is too bulky for transport, it is reduced by breaking up all the material of the sample into small pieces, thoroughly mixing them, and making four portions of the broken material, and then taking alternate quarters and again mixing and halving. This process, which is called quartering, is continued until the requisite amount is arrived at; but whenever possible this breaking, mixing, and quartering should be left to the analyst.

Classification.—Coals may be classified according to their suitability for certain purposes, or according to their chemical composition, or a scheme of classification may be propounded, fitting both commercial properties and chemical composition. In this latter case a classification based on the ultimate composition of coal—

that is, the percentage of carbon, oxygen, and hydrogen—is considered to be most satisfactory. It is found that the amount of volatile matter, on which the commercial quality of coals so largely depends, is proportionate, though not directly, to the hydrogen ratio in most coals in which the percentage of carbon is over 84, but the hydrogen ratio is not so reliable when the carbon percentage is less. In the following table the connexion between the hydrogen ratio and volatile matter is obvious:

	Carbon.	Hydrogen.	Volatile Matter.
True anthracites	over 93·0	3·0 to 4·0	3·0 to 8·0
Dry or smokeless steam coals	93·3 to 91·2	4·0 to 4·5	8·0 to 14·0
Semi-bituminous coals ...	93·3 to 91·2	4·5 to 5·0	14·0 to 24·0
Bituminous coals	91·2 to 84·0	5·0 to 5·8	22·5 to 48·c

According to the nature of the flame—coking power—distinctions are made between anthracites, dry, lean (*maigre*), non-coking and free-burning coals, and between the bituminous ('fat,' '*gras*') coking coals giving a luminous flame.

No term is perhaps more loosely applied than that of 'steam' coal. In the highest class of steam coal the carbon percentage, neglecting ash and moisture, lies between 91·2 and 93·3, and the volatile matter between 14 and 24 per cent. Coals having the same carbon percentage, but with volatile matter between 8 and 14 per cent., pass over to the anthracite class, but for commercial purposes are retained among the steam coals. In the north of England a coal having 84 to 87 per cent. of carbon is considered to furnish a good steam coal.

The marketable value of a coal depends to a great extent on the amount, chemical composition, and fusibility of the ash, and its liability to attack the material with which it comes in contact. Sulphur, always deleterious, frequently renders a seam worthless, and, even in small quantities, often causes a seam to be practically useless for many metallurgical purposes. Phosphorus is always present in coal, but in varying quantities, and forms an injurious constituent in coals used for steel-making and in the manufacture of calcium carbide. Arsenic commonly contained in the 'brasses' or pyrites of coals, when used for malting, is a dangerous quantity when it rises to $\frac{1}{13}$ or $\frac{1}{8}$ of a grain per pound.

Commercial Properties.—The properties of coal of chief practical importance are the calorific power, the specific gravity, the nature and quantity of the coke, and the friability.

The heating power of coal chiefly depends upon the amount of carbon and hydrogen. To ascertain the calorific power of a coal, a known weight is burnt under the most favourable circumstances so as to insure complete combustion. The unit of heat adopted is either the calorie or gramme degree—that is, the amount of heat required to raise one gramme of water, one degree C.; or that of the British Thermal Unit which expresses the amount of heat needed to raise one pound of water, one degree F. The calorific power, therefore, expresses the number of units of heat produced by the combustion of unit weight of fuel. The calorific power expressed in British Thermal Unit per pound may be converted into calories per gramme by multiplying by 5 and dividing by 9.

Supposing the ash and any water existing in the pores of the coal to be removed, a pound of ordinary coal gives out during combustion about 14,000 British units of heat. Anthracites possess a higher calorific power than ordinary bituminous coals, and these than lignites.

The specific gravity of coal becomes of importance where the storage space is limited, as on railway-engines and in ship's bunkers. In anthracites the specific gravity varies from 1·33 to 1·48, and in bituminous coals from 1·26 to 1·31.

Friability, depending largely on the pressure to which coals have been subjected, naturally varies from place to place, but is an important factor where the coal has to be transported long distances and also transhipped several times. Some seams yield a large amount of 'smalls' and slack, others give a good proportion of 'large' coal. Modern coking-ovens permit the utilization of the slack of many seams to form coke. Bituminous coals usually yield coke, except when the volatile matter exceeds 40 per cent.

Coal, it will now be understood, affords many varieties differing in physical characters, chemical composition, and the uses to which they can be applied. A district may possess only one class of coal, or it may yield several kinds. The physical and chemical characters determine to a great extent the uses to which the coals of any district can be put; but it is only providing a sufficient number of samples can be secured, and that proper precaution is taken in selecting them, that the value of a seam or seams as a whole can be arrived at, otherwise the estimated value of a new coalfield may be misleading.

CHAPTER III

COAL AS A ROCK

FROM considering coal as a mineral, we have now to study it as a rock in its relation to other rocks.

In whatever region of the globe, or in whatever formation coal occurs, it is always found in connexion with sediments which have been laid down under water, but whose lithological characters and fossil contents show the close proximity of land.

Among these sediments coal forms a distinct layer or bed, varying from a few inches up to as much as 300 feet in thickness, but usually occurring as a bed from about 4 to 6 feet thick.

Coal-bearing strata often much exceed 5,000 feet in thickness, and throughout this great mass of sediments the coal seams occur at different horizons. Usually several seams are grouped together, but others again may be separated by several hundred feet of barren strata. In all cases, the coal forms only a small proportion of the sediments, and the united thickness of the different seams rarely amounts to more than a few hundred feet, and is usually less.

Coal.—The 'floor,' or bed of rock on which the coal rests, is commonly a white or pale grey clay—'underclay,' 'seat-stone,' 'warrant,' 'spavin'—but not infrequently consists of conglomerate or sandstone (Garw Coal, Beaufort, South Wales), occasionally of limestone (Fifeshire), of volcanic rocks (Central France), or of granite and schist, without any trace of an underclay, or merely by a layer an inch or less in thickness. In deep workings, where the pressure exerted by the overlying strata is enormous, the nature of the floor becomes of considerable importance: a floor of clay or soft shale swells up, and increases the difficulty of keeping open the underground roadways.

The 'roof,' or bed of rock immediately overlying a seam, is usually shale or sandstone, but may be a conglomerate, clay, or limestone.

Both the roof and floor of the same seam often change rapidly. A sandstone roof may give place to one of shale or clay, and the floor may be at one spot a sandstone or shale, and at another a seat-earth. This variation in the character of the roof, like that of the floor, affects the commercial value of a seam, a good roof rendering the coal safer and less costly to work.

Igneous rocks may form the roof or floor of a coal-seam, but this occurrence can be regarded as accidental.

The seam, as a bed of coal is commonly called, though the term 'vein' is sometimes erroneously used, may be confined to a very limited area, or, as in the case of the Pittsburg Seam of the Appalachian Coal-field, it may extend over an area exceeding 14,000 square miles. In South Wales several seams, though receiving different names, have been traced along the entire length of the coalfield; and in the eastern counties of England individual seams have been followed almost uninterruptedly from Nottingham to near Leeds.

A seam of coal may possess the same character over wide areas, any particular seam being a bituminous, semi-bituminous, or steam coal throughout its lateral extent and for its entire thickness. Generally, however, a seam is composite, being built up of different qualities in separate layers. These layers may be arranged in one order in one place, and in a somewhat different order in another place, though many seams present the same arrangement in the composition of the layers over considerable areas.

Some seams, again, consist of good marketable coal from top to bottom, and retain this character for several miles; then locally bands of clay, shale, or sandstone become intercalated, and finally these bands become abundant, and the seam passes into a worthless mixture of foreign matter, and thin layers of coal. In some cases the introduction of 'dirt' layers takes place in a definite direction, but as a rule they occur irregularly.

The Thick Coal, or 30-Feet Coal, of South Staffordshire affords a good instance of the gradual introduction of foreign material in a definite direction. In the southern district (Thick Coal area) a seam of coal, averaging 30 feet in thickness, splits up northwards into fourteen seams by the gradual introduction of sandstones and shales.

Local inclusions of lenticles of sandstone, shale, or other foreign material into a coal-seam are common, and are termed 'horses,' 'washouts,' or 'rock faults' by the miner.

Lenticular masses of sandstone or shale may in this way entirely replace a seam, or only a portion of the seam; or, again, they may occur as a wedge in the heart of the coal, dying out on all sides. The interruption of the seam may be only local, extending over a few yards, or the foreign material may cover several acres. Sometimes a ridge of sandstone or shale rises up through the floor of the coal, which ends off abruptly against it, forming what is termed a 'roll' or 'swell.'

In the descriptions of many foreign coals the numerous intercalated thin bands of coal, shale, or other material are often included in the total thickness of a seam, and its importance is in this way much exaggerated. Many of the seams in the Transvaal, for instance, are said to attain a thickness of over 20 feet, but in many cases only a comparatively small portion of this is marketable coal.

Of the different varieties of coal given in the preceding chapter, cannel coal is the most inconstant in its occurrence. Sometimes the whole of a seam is cannel, sometimes only a part; but in all cases it occurs as lenticles, either as a seam by itself, or forming part of a composite seam.

Like the seams of coal, the associated sediments occur in layers or beds, constituting the rocks called sandstones, shales, clays, and limestones. These do not, however, occur in any definite relation to the coal seams. Sometimes a sandstone, at others a shale or clay, is in immediate contact with the coal, which yet retains its character, no matter with which of these rocks it may be in contact. When a porous rock forms the roof of a coal, it in some cases permits the volatile constituents to escape, and so the carbon percentage may be increased (p. 41).

Intrusive igneous rocks, again, frequently change the nature of the coal completely by driving off the volatile matter, and not infrequently render a seam valueless.

This is notably the case with intrusions of acid rocks, but is often scarcely appreciable with intrusions of basic igneous rocks such as basalt.

Sandstones.—The prevailing character of the sandstones found in association with most coals is their great variability in thickness and composition. They occur, not as regular beds, but as wedge-shaped masses, commencing suddenly, rapidly swelling out, and as quickly dying away. In composition they vary from a fine-grained, laminated rock to a coarse, thick-bedded sandstone. By the addition of shaly material in grains or layers they lose their individuality, and pass into sandy shales, or a mass made up of sandstones and shales in alternate thin layers.

When closely associated with seams of coal, the sandstones are universally grey or yellow in colour, red sandstones, in which the colouring matter is original, being scarcely ever found in close proximity to coal. It is also a common experience that the red strata of later Palæozoic, Mesozoic, and Tertiary ages are not only remarkably barren of organic remains, but are equally destitute of coal. When coals do occur in red measures they are almost invariably thin and impersistent, and are accompanied by a local development of grey measures in the midst of the red strata.

Although an individual bed of sandstone may vary greatly both in thickness and composition, certain groups of sandstones occupy very definite horizons and extend over miles of country. In the coalfields of South Wales and Bristol, for instance, the Pennant Sandstone—made up of sandstones and shales of great thickness—separates a lower coal-bearing series from an upper series, and can be traced over the entire coal-fields.

In other coalfields groups of sandstones occur over considerable areas at definite horizons, and mark the approximate position of seams of coal.

Shales and Clays.—These terms are applied to laminated rocks, in which argillaceous material forms an essential constituent. Unlike the sandstones, the shales and clays occur in regular beds. By the addition of sandy materials these rocks may pass into sandy shales, sandy clays, and so on into sandstones.

The term 'shale' is usually restricted to a finely-laminated rock, and the term 'clay' to an argillaceous rock, in which lamination is more or less indistinct. In this country the laminated varieties are known to the miner as 'binds,' and when sandy material is present they are called 'stony binds' or 'rock binds.' The unlaminated varieties are commonly known as 'soft binds.' A high percentage of carbonaceous matter is sometimes present, when the rock is termed a 'bass' or 'batt.' These carbonaceous shales, however, seldom exceed a few feet in thickness, and are closely associated with seams of coal. They frequently contain mineral oil, and pass laterally into cannel coal.

The shales vary in colour from light grey to black. Among the lighter-coloured varieties the miner applies the term 'soapy binds' to a greasy light-blue shale, and it is found that this term is frequently applicable to the bands of shale in which marine fossils occur.

Shales, or 'binds,' besides forming the roof or floor of a coal-seam, are often interstratified in layers, varying in thickness from a mere film to several feet, with the seams of coal. Sandstones are rarely thus met with, and when they do so occur are of very limited extent.

Fire-clays.—Among the sandstones, shales, and clays there are found thin beds of unstratified clay, seldom exceeding a few feet in thickness, and varying in colour from dark grey to white. They generally form the floor of a coal-seam, and contain rootlets of plants (*Stigmaria*), but more rarely overlie a seam or occur apart from coal. These unstratified argillaceous rocks vary very much in composition. They often consist of clay, but usually contain a large proportion of sand. The different varieties are known as gannister, underclay (when overlain by a coal), fire-clay, and clunch.

The most siliceous form, the gannister, is an intensely hard, close-grained compact stone. When the silica percentage is high (57 to 96), the clay makes excellent fire-bricks.

The terms 'fire-clay' and 'clunch' are very loosely applied. Technically, a fire-clay contains a high percentage of silica, but the term is frequently used for a clay without any test being made as to its composition. The term 'clunch' is indiscriminately used for a pure clay or an underclay, whether a fire-clay or otherwise, while the term 'stone clunch' is often applied to a gannister.

The shales and clays, with the ironstones occurring in them, either as distinct beds or in nodules, contain the more important fossils. These constitute valuable means of identification among the Coal-measure strata of Carboniferous age (p. 52).

Limestones.—These are not of such general occurrence among the coal-bearing strata as either sandstones, shales, or clays, and are seldom found in actual contact with a seam of coal. In the Carboniferous formation of Britain, for instance, the coals in the lower or limestone division are restricted to the north, where the limestones are thin and interstratified with sandstones and shales. In the south, where the limestone is massive, workable seams of coal are unknown, though coal occasionally occurs in pockets and thin layers. In Russia, however, limestones are more general among the coal-bearing strata of Carboniferous age.

Ironstones.—Coal-bearing formations generally contain nodules and bands of ironstone interstratified with the shales and clays, and sometimes with the coals. The laminated bands of ironstone, containing sufficient coal to be self-calcining, are called 'Black Band,' and form valuable beds in North Staffordshire, Scotland, and elsewhere. In many cases the iron of Black Band ironstones can be proved to have replaced carbonate of lime, and they frequently pass laterally into limestones. Nodules of clay-ironstone, composed of a mixture of clay and carbonate of iron, occur in great profusion in nearly all Coal-measure clays and shales. The nodules are either flat, oval, or irregular in shape, sometimes occurring in layers, at others irregularly distributed, and frequently contain a fragment of fern, shell fish, or other fossil.

Conditions.—All the sedimentary rocks associated with coal strata have been laid down in water, but under very different physical conditions. Some have been deposited in the comparatively tranquil waters of lakes, and others in the agitated waters of estuaries and along sea borders. In quiet waters the sediment brought down by rivers quickly sinks to the bottom and is roughly stratified, whereas material carried into tidal waters is spread out and sorted into more definite layers. This difference in the arrangement of the sediments is very marked among the different coal formations of the world.

The lacustrine coal-bearing formations of the central plateau of France are noted for the irregularity in the thickness of the seams of coal and associated rocks; while the regularity of the coals among the more evenly-bedded estuarine and marine sediments in the coal-fields of northern France is remarkable.

We now come to a class of sediments marking the close of the Carboniferous period in many coal regions of Europe, Asia, and America. The rocks of this type consist of red sandstones, shales, and clays, often several hundred feet in thickness. Thin bands, a foot or two thick, of creamy white or black limestone, invariably fine grained, occur at intervals. With the exception of a few plants in the shales and sandstones and of small organisms (*Entomostraca*) in the limestones, these rocks are alike destitute of coal and organic remains. It is impossible to escape the conviction that these strata were laid down under very different conditions to those under which the coal-bearing rocks beneath were deposited. It is interesting also to note that the closing phases of the coal-bearing strata of later formations are generally of a red colour.

The probable solution of the difference is to be found in the closing up of the outlet through which the waters of the lagoon bordering on the swamps of the coal-bearing period escaped and the formation of a closed basin. Under these conditions, each grain of sand and each pellicle of clay would become coated with a thin layer of iron oxide (Fe_2O_3), precipitated from the stagnant waters. The water containing the iron salts also held lime in solution, which was precipitated to the bottom as evaporation took place, and gave rise to the limestone bands, which are, therefore, to a great extent of inorganic and not of organic origin, like those of the Carboniferous Limestone.

The sediments of coal-bearing formations were not only distributed very irregularly, but were deposited at very different rates. Most of the Carboniferous strata, it is generally accepted, were laid down very rapidly, and, according to a recent estimate by Mr. Sorby, some of the sandstones were precipitated at a rate of one inch per minute. The same bed may have been very rapidly formed at one spot, and very much more slowly over a closely contiguous area, a few inches of strata in the latter case having been deposited, it may be, during the time represented by several feet of strata in the former case. This affords one solution for the very great variability met with in the thicknesses of individual beds separating two or more seams of coal in areas a few miles and sometimes only a few yards apart, a variation with which the coal-miner is only too familiar.

Associated Igneous Rocks.—The sedimentary rocks associated with coal-bearing strata are arranged in layers one bed above the other. The igneous rocks, on the other hand, are for the most part thrust intrusively among these stratified sediments. The igneous material may occur as a bed interstratified with the sediments, or as a sheet cutting across them at different angles, and not infrequently may be found as a dyke or wall of igneous rock running more or less vertically across the stratified rocks and coal-seams.

When a layer of igneous material is found lying parallel with the bedding of the sedimentary rocks, it may either have been thrust along the bedding planes or poured out over the layer of sandstone, shale, or coal at the time this was in process of formation. In the former case the igneous rock will be found to have baked and hardened the beds into which it is thrust, the layers immediately above and below it being more or less equally affected. In the latter case only the rocks directly below the igneous material will have been affected, and not those lying above it.

The importance of being able to distinguish between an igneous rock poured out during the formation of any coal-bearing strata and one of later origin is dealt with in a succeeding chapter. When heated igneous material, as before stated, comes in contact with a seam of coal, it often entirely changes the nature of the coal. The heat of the molten material drives off the volatile constituents, and in some cases, if the heat is very intense, it may convert a coal into soot, and so render it worthless; at other times it may cause a seam to be enriched in carbon, and so enhance its value.

In the Coal-measures of Carboniferous age igneous rocks are comparatively rare. Among the coal-bearing strata of Mesozoic age in Australia, India, and South Africa, however, later intrusions often completely destroy seams of coal, which in areas free from such disturbances are of great value. Coals of Cretaceous and Tertiary ages are also much affected by igneous intrusions.

CHAPTER IV

FORMATION AND ORIGIN

It is now universally admitted that the several varieties of coal have resulted from the alteration of vegetable matter, but very divergent opinions are still held as to the method of its accumulation and conversion into coal.

Accumulation.—Extensive and often thick deposits of vegetable material are to be found in peat-bogs and swamps, or they result from the accumulation of drifted wood carried from the land and laid down under water at the mouths of large rivers.

In this country and in America, due mainly to the teaching of Logan, de la Beche, and Principal Dawson, a coal-seam is considered to represent an original peat-bog; on the Continent the opinion is almost universally held that the majority of coal-seams have resulted from drifted material.

Two opposing views, known as the 'growth-*in-situ*' and 'drift' origin, are in consequence held, though there is at present a tendency for some geologists in this country to regard many of the British seams as having been formed out of drifted material.

The supporters of either view do not suppose that the vegetation accumulated in deep water on the one hand, or on elevated ground on the other. Both theories start with a low-lying maritime morass or a peat-bog, but, according to one view, the coal-bed and its seat-earth represent the actual site of the swamp, while, according to the other view, the vegetable débris was floated out from the swamp into the neighbouring still lagoons.

Thick seams of coal containing numerous partings of shale, like those of India, Africa, and Australia, have always been considered to have originated from vegetable material drifted out into inland lakes.

The essential factors which either theory must satisfactorily account for are: (1) The great areas often occupied by individual seams; (2) the absence of foreign material, such as sand, mud, etc., from the coals; (3) the maintenance of a uniform thickness, often by a thin seam, over considerable areas; (4) the behaviour of a coal-seam as a sedimentary rock amidst rocks whose sedimentary origin is unquestionable.

By those upholding the 'growth-*in-situ*' theory stress is chiefly laid on the purity of many seams, and the frequent, but by no means universal, occurrence of an underclay (fire-clay), considered to be an old soil beneath the seam, and on the occurrence of vertical stems of fossil trees in the rock forming the roof of a coal with their roots penetrating the underclays. 'Seat-earths' are, however, often absent, and the seam lies directly on sandstone, conglomerate, or shale, without a trace of rootlets, while it is not certain that the seat-earths represent ancient soils.

A strict analysis of the position of the trunks of trees in the so-called 'fossil forests' shows a greater percentage of prostrate or inclined trunks than those having a vertical position.

In the case of numerous and closely contiguous seams, separated by marine sediments, the 'growth-*in-situ*' theory demands rapid and frequent oscillatory earth-movements. First, a land surface with the formation of peat; then its depression and burial, and the formation of a fresh land surface, these operations being many times repeated. This theory satisfactorily accounts for the purity of many seams.

The supporters of the 'drift' origin of the woody material base their chief claim on the behaviour of a coal-seam as a sedimentary work. Many seams, made up of layers of coal with partings of dirt, shale, clay or sandstone, varying from a mere film to several feet in thickness, pass laterally into beds of almost pure coal. According to this view, therefore, a seam of nearly pure coal indicates a spot to which only the lightest and finest material has access. Coal-seams would be formed during intermittent, but downward, earth-movements, during the formation of a depression which became consecutively filled with coarse material (sandstone), followed by finer sediments (shales and clays), and finally by drifted wood and plant débris—the lightest of all.

The thickness of individual seams does not receive a satisfactory solution from the 'growth-*in-situ*' theory. It is calculated that it takes 10 feet of peat to form one foot of coal. The 30-Feet Coal of Dudley, therefore, would represent an original thickness of 300 feet of peat, which is far in excess of any peat at the present day.

Again, for the 'drift' theory it is difficult to imagine an area to which only the lightest material had access for a period represented by 30 or more feet of coal, though there is reason to suppose that the transported decayed vegetation would reach its resting-place in a more or less condensed and incompressible state, so that 30 feet of pure coal, according to this view, need not represent many times its bulk of transported material.

In regard to the vast areas, exceeding 12,000 square miles, over which one particular seam, such as the Pittsburg Coal of America, extended, it is useless to speculate in face of our ignorance of the past conditions of climate, land configuration, and the growth and distribution of plant life; neither can we estimate over how great an area a deposit of one kind, and of fairly uniform thickness, could be laid down. The Rhætic bone bed and shales, among sediments, show that even a thin layer can, under favourable conditions, be almost uniformly laid down over an area of many thousands of square miles.

Both these theories apply to the accumulation of vegetable matter as a whole. The most ardent advocate for the 'growth-*in-situ*' origin of coal admits that some seams, such as cannel coals, must be formed from drifted vegetation, while supporters of the 'drift' origin do not deny that some seams of coal are probably derived from the conversion of vegetation *in situ*.

For practical purposes, however, the miner has no occasion to trouble himself with either view. A seam of coal behaves as any other stratified rock, and is mined accordingly.

Conversion.—The varieties of coal given in Chapter II. will be seen to differ from each other in the relative proportion of carbon to hydrogen and carbon to oxygen. In lignite the hydrogen and oxygen ratios are relatively high; in some bogheads we find a total elimination of hydrogen; and in graphite, the final stage in the conversion, a total elimination of both hydrogen and oxygen.

The relative proportions of hydrogen and oxygen present in the different varieties of coal are more clearly brought out if the amount of carbon is taken as constant, and the proportion of the other constituents increased in the same ratio. This will be understood from the following table:

	Carbon.	Hydrogen.	Oxygen and Nitrogen.
Wood	100	12·3	86·8
Peat	100	9·7	54·7
Lignite	100	8·3	40·0
Brown coal	100	7·4	29·7
Coal	100	6·4	13·4
Anthracite	100	2·6	2·3

The increase in weight due to the conversion of wood into coal is shown by one cubic foot of wood weighing 30 pounds, and one cubic foot of anthracite weighing 90 pounds.

It is usual to consider that all coal, from the lignitic to graphitic varieties, once existed in a state of peat, and that the subsequent alteration of the only partly decayed vegetable matter proceeded by successive stages long subsequent to burial. Recent researches, however, more especially by M. Renault, indicate that very different degrees of alteration can be effected by biological action prior to entombment, while the subsequent mechanical and physical changes may be relatively trifling.

The conversion of once living vegetable matter into the mineral coal can therefore be considered under two headings: (1) Changes prior to burial beneath sediments; and (2) changes subsequent to entombment.

The chief constituent of plants consists of some multiple of cellulose ($C_6H_{10}O_5$) with some nitrogen. Protoplasm, the living gelatinous substance, forms only a small portion, and perishes at death. In addition, there is a small percentage of inorganic salts of iron, potash, silica, and sulphur, seldom exceeding 3·5 per cent. The three main elements of vegetable tissue occur in the proportion of C, 50 to 58 per cent.; O and N, 28 to 45 per cent.; and H, 5 to 7 per cent. This is true of the lowest plants, seaweeds, mosses, ferns, etc., and of the highest, the flowering plants.

At the death of the plant, the cellulose, under favourable conditions, undergoes a partial deoxygenation and dehydrogenation with the evolution of carbonic acid and marsh gas. The unused portions of the carbon and hydrogen of the cellulose enter into new combinations to form humic acid and hydrocarbons. The first is soluble in water; the latter consist of gaseous, liquid, or insoluble solid products.

In stagnant peat-bogs the humic products prevent further decay, and decomposition is arrested after a certain stage has been reached. In a free circulation of water, however, decomposition continues, due in great part to bacteriological fermentation, certain parts of plants being found to present different resistances to the action of bacteria. In the Blatter Kohle and Papier

Kohle of Toula in Russia—of lower Carboniferous age —for instance, the cuticles of *Bothrodendron* are found to have greatly resisted destruction. Epidermal cells, cuticles, grains of pollen and spores, are the most indestructible, but these ultimately become destroyed.

Prolonged maceration and bacteriological action result, therefore, in an almost total obliteration of organic structure, and a loss in bulk amounting to from 10 to 30 per cent. of the original mass of vegetable débris. The successive stages are marked by the gradual elimination of hydrogen and oxygen, and a consequent increase in the carbon percentage. It is thus obvious that the chemical composition of the resulting organic pulp depends upon the stage at which decomposition was arrested. It is, therefore, possible that an organic pulp, having the chemical composition of a lignitic, a bituminous, or even an anthracitic coal, may result, according to the stage at which the decomposition of the vegetable débris was arrested.

The carbonaceous slime resulting from the decomposition of the bodies of aquatic animals and plants living in stagnant water is termed *sapropil.* When in a sub-fossil state it forms a gelatinous substance, and is then called *saprokohl.* Sapropil, when dried or in a fossil state, is hard. Cannel coal may be regarded as fossil sapropil.

In a previous chapter the original nature of the vegetable débris, whether pollen grains, macrospores, leaves, cuticles, tissue, or bark, was shown to have played an important part in forming the composition of the resulting coal in its earlier stages. To this we may now add the resistance offered to bacteriological fermentation by the different parts of a plant. It will now be understood why one coal is almost structureless, another contains leaf-stalks and cuticles, and another spores; and also why vegetable tissues, the most readily attacked of all parts of a plant by micro-organisms and fermentations, are so rarely preserved in coal. The easy decomposition of tissues forming the chief bulk of plants will also in some degree account for the fragmentary nature of the vegetable remains met with in coal. These do not necessarily imply that they are fragments torn away from the plants by wind and dropped into the morass, or floated out into the neighbouring lagoons, but are the remnants left of the more indestructible elements.

It is, however, more usually considered that the change from woody tissue into coal has for the most part taken place subsequently to the burial beneath sediments, and no doubt many important changes have resulted from the pressure and heat to which the original material has been subjected.

Heat, resulting from the thick covering of the strata, from pressure and folding, or due to the intrusion of igneous material, is undoubtedly an important, though it may not be one of the chief factors in the conversion.

Bituminous coals of all ages in various parts of the world become anthracitic when in contact with contemporaneous or intrusive igneous material. The change, however, is usually local and sporadic. Anthracitized coals, however, in contact with igneous rocks, possess, as might be expected, a higher percentage of ash than those in which the cause of carbonification is obscure, but, except locally, are certainly not due to the heat derived from igneous intrusions, and presumably, also, not to that engendered during folding.

The alteration in the character of the sediments effected by heat evolved during the folding and compression of the strata partakes, on the other hand, of a regional type. The Pennsylvanian and South Wales anthracite fields are both situated in regions of intense folding, while in the adjacent less disturbed areas the coal assumes a more bituminous character.

In South Wales the seams in the eastern and less disturbed areas contain a much lower percentage of carbon than in the western highly disturbed district. In following the lines of anthracitization from east to west it is found as a whole, though there are some exceptions, that the lower seams are the first to change, while the coals along the southern outcrop retain their bituminous character even when greatly folded.

In the intensely folded Alpine regions, the whole of the original volatile matter of some coals has in places been eliminated, and a bed of graphite formed. In Russia the seams richest in carbon lie in the disturbed zone bordering the Ural Mountains. Again, the American anthracite coals of Carboniferous age are confined to the folded Pennsylvanian basin, the bituminous varieties occurring in the less disturbed Appalachian Coalfield. The same continent shows the phenomenon of the Cretaceous and Tertiary coals, losing their volatile matter on approaching the folded strata of the Rocky Mountains, and becoming converted into anthracites in the most disturbed belts.

It thus appears that earth pressure results in a certain amount of anthracitization, but the exceptions show that other considerations, such as original composition, must be taken into account.

Where coal-seams lie at great depths, or have once been covered by an immense thickness of strata, it is evident that the lower layers must have been subjected to a higher temperature than the upper seams.

The amount of volatile matter, it is observed, decreases with the depth of the seam, the rate of change being more rapid in the bituminous than in the non-bituminous coals. This is known as Hilt's law, and is found to be applicable to many coalfields. There are, however, some notable exceptions. In the Saarbrucken coalfields the more bituminous seams are the deeper seated; and, again, in South Wales, the bituminous coals along the southern outcrop have lain under as thick, or possibly a thicker, cover than the anthracite fields to the north. Neither can it be demonstrated that depth and pressure combined have resulted in an equal loss of volatile constituents, for in the northern coalfields of France lean, dry coals have been thrust over gas coals, both lying at considerable depths. Again, Hilt's law will not account for the cannel coals of Russia of Lower Carboniferous or later Devonian age, while pressure and depth both fail to give a satisfactory solution to the undisturbed anthracites of Carboniferous age in China. Many coals, it is observed, tend to become anthracitic on exposure to air at ordinary temperatures, and also lose some of their volatile constituents in the proximity of open faults or below a sandstone roof.

CHAPTER V

DISTRIBUTION

Distribution in Time.—The formations older than the Cambrian, and known as the Pre-Cambrian or Archæan, consist to a great extent of crystalline metamorphic rocks and those of volcanic and igneous origin. Coal, as might be expected, does not occur among strata of this character.

The veins of graphite, however, met with in the crystalline metamorphic rocks of Pre-Cambrian age may possibly represent original vegetable matter, though the absence of any signs of terrestrial plant remains in the Pre-Cambrian shales and sandstones—such as the Torridonian Sandstone of Scotland—may indicate either the absence of land vegetation at this early period, or, at any rate, not sufficiently abundant to form a seam of coal. The graphitic veins may be, in part at least, of inorganic origin. Combustible material of undoubted vegetable origin is certainly absent in the Pre-Cambrian rocks of any part of the world.

Coal also does not occur in the older Palæozoic formations—Cambrian, Ordovician, Silurian—though black shales sometimes carbonaceous are abundantly developed. In many cases the sediments of the older

Palæozoic rocks preserved to us must have been laid down in deep water, but coal-seams are not known even in the inshore and terrestrial deposits older than the Devonian epoch. Very little of the terrestrial flora of the older Palæozoic rocks has been preserved, so that it is impossible to say whether the absence of coal-seams is to be attributed to unfavourable conditions of preservation or to insufficient vegetation.

In the Old Red Sandstone (the lacustrine equivalent of the marine Devonian formation), the oldest of the later Palæozoic strata, ferns and other cryptogamic plants occur. It is not, however, until towards the close of the period that coal-seams appear; and so far they are only known in Russia, where several seams of inferior quality, but mainly of the nature of boghead, are interstratified between the Carboniferous Limestone and the Devonian.

From the Carboniferous period upwards to the Quaternary, each of the stratified formations, in one part of the world or another, contains fossil fuel, either as true coal or in the form of Brown coal or lignite.

The most valuable seams of coal are met with in the Carboniferous formation, and for this reason it is found that, in countries where coals of various ages occur, chief attention is given to the exploitation of those of Carboniferous age, even when they are less easily accessible than the inferior seams in the newer formations.

The Carboniferous strata exceed 10,000 feet in thickness, and are generally separable into two divisions—a Lower Marine and an Upper Estuarine, or Freshwater division, though in some countries the strata of both are mainly marine.

The more important coals are met with in the strata of the upper division, which, as a rule, occupy more restricted areas than the Lower Carboniferous rocks, and some countries only possess this earlier marine phase.

Succeeding the Carboniferous, the Permo-Carboniferous, Permian, and Triassic formations yield the chief coals of the Southern Hemisphere. These coals are usually of inferior quality to those of the Carboniferous, and are chiefly worked in countries where seams of Carboniferous age are either absent or but feebly developed.

Coals of Jurassic, Cretaceous, and Tertiary ages are generally of a lower grade than those of the earlier Mesozoic and later Palæozoic ages. They are also less evenly distributed, though sometimes occurring in beds exceeding 100 feet in thickness, and are occasionally of superior quality to the Carboniferous coals in adjacent areas.

Distribution of Space.—The superficial extent of the coal areas of the world has been estimated at 605,500 square miles, of which about one-third belongs to formations newer than the Carboniferous. Coal is met with in all latitudes, from well within the Arctic Circle to the Straits of Magellan, and from Franz Josef Land to the Auckland Islands.

In the Northern Hemisphere, with the exception of India, the coals of Carboniferous age are most widely distributed. In the Southern Hemisphere and in India the chief seams belong either to the Mesozoic or Tertiary period.

The Carboniferous rocks cover immense areas in North America. The coals occur in the upper division, and, except those of Alaska, the coalfields lie between the 30th and 100th parallels of latitude.

In the Old World, the chief coalfields of Carboniferous age are situated between the 40th and 60th degrees of latitude, and, with the possible exception of the almost unknown coalfields of China, Northern Europe possesses the largest areas and the highest quality seams. Russia comes first as regards the area of her coalfields, but Great Britain contains the best quality seams, and in South Wales possesses the finest seams of steam-coal and anthracite in the whole world.

The Permo-Carboniferous and older Mesozoic coals attain their chief development in Australia, Tasmania, India, South Africa, and South America.

In South Africa the Karroo formation contains the chief coals, and is extensively developed in Cape Colony, Natal, and the Transvaal. It is now generally agreed that the more important coals belong to the lower beds of the Karroo system, though these are unproductive, if not completely barren, in Cape Colony, where they attain a great thickness and cover large areas; but in the Orange River Colony, Natal, and the Transvaal they become productive.

Rocks undoubtedly belonging to the Karroo system are also met with north of the Zambesi, in the region of the great lakes, and possibly underlie vast areas in the Congo Free State; but whether these strata belong to the upper or lower division of the Karroo is as yet uncertain.

Up to the present time Central and Northern Africa have shown few signs of containing coal in any great quantity.

In Peninsula-India the Gondwana system represents

TABLE OF COAL-BEARING FORMATIONS.

Era (Group).	Period (System).	Localities of Coals and Lignites.
Cainozoic or Tertiary.	Pleistocene.	Peat only.
	Pliocene.	,,
	Miocene.	Lignites and lignitic coals in Germany, etc.
	Oligocene.	Hungary, Austrian Alps, Moravia, Russia.
	Eocene.	Japan, United States (Pacific Coast, Gulf States), Sumatra, New Zealand.
Mesozoic or Secondary.	Cretaceous.	Northern Germany, Hungary, Rocky Mountains, Alaska, British Columbia, Manitoba, Japan, Borneo.
	Jurassic.	Yorkshire, Brora, Caucasus, Siberia, Japan, Alaska.
	Triassic.	Southern Germany (Lettenkohle), United States, Tonkin, Yunnan, Japan.
Palæozoic or Primary.	Permian and Permo-Carboniferous.	Central France, South Africa, India, Australia, South America.
	Carboniferous.	True coals and anthracites in Northern Europe, North America, China.
	Devonian.	Russia.
	Silurian.	No coals.
	Ordovician.	,,
	Cambrian.	,,
Eozoic.	Archæan.	,,

the Karroo formation of South Africa. It is extensively developed, and contains many seams of coal, equal in quality to those of the Karroo, but much inferior to the European coals of Carboniferous age. In surface area and in the quality of some of the seams, however, the Gondwana system ranks as an important coal-bearing formation.

The older Mesozoic rocks are met with in Queensland, New South Wales, and Tasmania. The lowest formation agrees with the Karroo system in being coal-bearing and containing a similar flora and fauna, but differs in intercalation of the marine sediments. The coalfields are extensive, but no reliable approximate estimate of the available quantity of good coal has yet been ascertained.

New Zealand, Japan, and the Malayasian Islands are devoid of Carboniferous and Permo-Carboniferous coals. Japan contains good coals of Cretaceous and Tertiary ages. The Sumatra coal is of Eocene age, and the seams of New Zealand are either of Tertiary or later Cretaceous age.

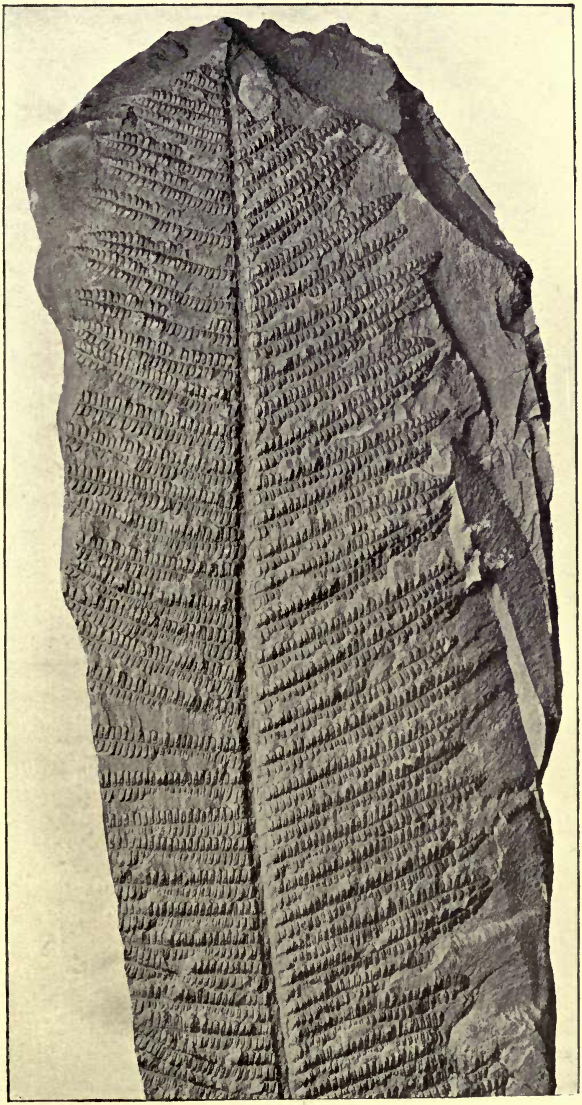
CHAPTER VI

FOSSILS AS ZONAL INDICES

General.—The various sedimentary strata comprising the greater portion of the rock sequence, from the oldest up to the most recently deposited, do not materially differ either in appearance or lithological characters one from another. Thus a limestone, sandstone, or shale of Cambrian, Ordovician, or Silurian age may bear a close resemblance to one of Carboniferous or later age. In the Warwickshire Coalfield, for example, black shales, now proved to belong to the Cambrian formation, are underlain by a hard quartzitic sandstone, and so close is the general resemblance of these Cambrian shales and quartzites to the overlying quartzitic sandstones and shales of Coal-measure age as to have led to their being included in the Carboniferous system.

Again, in Pembrokeshire and North Wales the black shales of Ordovician and Silurian ages are in appearance indistinguishable from the neighbouring Carboniferous shales, and shafts in search of coal have, even in recent years, been sunk in these black shales with the expectation of finding seams of coal.

In the attempts now being made to prove coal in the



Photo] [*R. Kidston.*

PECOPTERIS ARBORESCENS, SCHL. SP. *Reduced.*

south-eastern counties of England, and to a greater extent in northern France, black shales are often encountered in borings, the age of which, judged by their lithological characters alone, cannot be determined.

Red strata very often underlie and overlie the Carboniferous rocks of Europe—the one of Devonian, the other of Triassic age. Lithologically, it is often impossible to distinguish one from the other; yet the importance of being able to do so is evident, for if the red strata are of Triassic age, then the coal-bearing Carboniferous rocks may be found below them; while if they are Devonian, the quest for coal beneath them is useless, since, as before stated, coal makes its first appearance in the Carboniferous formation.

The geologist has, fortunately, an infallible means of distinguishing an older from a newer set of strata, even though similar both in colour and mineral composition.

The means of determination lies in the distinct character of the fossils met with in the different geological formations.

Among the pre-Carboniferous rocks *Graptolites* do not occur above the Silurian, and therefore the presence of even a fragment of a Graptolite indicates at once a horizon far older than any of the coal-bearing formations of the world.

The *Trilobites* met with in the older rocks are of species quite distinct from those which occur in rocks of Carboniferous age. The pre-Carboniferous strata also contain numerous other invertebrate fossils, of which, though the genera may be similar, the species are readily distinguishable from any met with in rocks of later ages. The fish remains, too, in the formations older than the Carboniferous belong, as a whole, to different types to those met with in the Carboniferous and later periods.

The occurrence of fossils, then, or even one fossil, such as a Graptolite, will at once determine whether the strata in which they occur are of Carboniferous or older age, even though lithologically the strata may be indistinguishable.

The fauna and flora of the Secondary and Tertiary formations, as is well known, differ essentially from those found in the Palæozoic rocks.

We have next to consider the characteristic fossils of the Carboniferous system, and how far they serve to distinguish one part of the system from another.

The Carboniferous period was essentially the age of cryptogamic plants—that is, plants of simple organization, such as horsetails, ferns, mosses, etc. The vegetation did not reach a higher stage than that of rudimentary palms—*Pteridophytes*. The palæobotany of the Carboniferous rocks is, however, undergoing revision, and plants formerly grouped with the Filices are now proved to belong to higher orders. Much is also being learned about the habitat of the Coal-measure plants, especially about the submerged and partially submerged species.

While the flora of the period belonged to a humble stage in plant evolution, the fauna shows a great advancement on the preceding forms. Bony fishes reach a high state of development, and air-breathing vertebrates make their first appearance. The presence of these in association with abundance of cryptogamic plants, and the absence of the higher orders of Phanerogamous plants, therefore, serves to distinguish the Carboniferous from any preceding formation.

Plate II.

Photo] [*R. Kidston.*

SIGILLARIA RUGOSA, BRONGT. *Natural Size.*

We have now to see how far fossil evidence is of use in distinguishing one part of the Carboniferous formation from the other. Since this formation may, and often does, exceed 10,000 feet in thickness, and the coal-seams are practically restricted to one portion, it is evidently of importance to be able to recognize the coal-bearing from the non-coal-bearing Carboniferous strata.

The Carboniferous system of Western Europe and of the United States can be separated into a Lower and an Upper Division. The Lower Division rarely contains workable coals, and the thickest and most valuable seams are met with in the Upper Division.

Fossils of the Lower Carboniferous Rocks.—The Lower Division (Dinantian) consists usually of highly fossiliferous limestones, fine-grained sandstones and shales, the latter often bearing a close lithological resemblance to the sandstones and shales of the Upper Division.

Marine conditions prevailed generally in Europe throughout the Lower Carboniferous, and freshwater phases, as in the Calciferous Sandstone Series of Scotland, may be regarded as the exception.

A very different fauna inhabited the Dinantian seas from those of the Upper Carboniferous period. Corals (*Syringopora reticulata, Zaphrentis, Lithostrotion basaltiforme, Dibunophyllum*) were abundant, and are not found irregularly distributed, but arranged in sequence; *Dibunophyllum*, for instance, indicating a higher horizon than that in which species of *Zaphrentis* occur. Some of the Brachiopods, Lamellibranchs, and Cephalopods are common to the Dinantian and Upper Carboniferous strata; but others, such as *Productus giganteus, Posido-*

nomya becheri, *Prolecanites compressus*, are not found above the Lower Division.

In cases where the Lower Carboniferous strata consist of black shales and mudstones most of the fossils met with in the limestone do not occur, but are replaced by animals suited to the changed conditions from clear and open seas to muddy water. The shells of these animals, however, are very distinct from those which lived on the muddy flats and in the estuaries and shallow Upper Carboniferous seas (*cf.* Figs. 1 and 2, pp. 59 and 63).

Plant remains are somewhat rare in the Lower Carboniferous rocks. Many of the genera and most of the species are distinct from those found in the Upper Carboniferous strata. Thus, *Lepidodendron veltheimianum* (Plate VII., p. 67) is a species confined to the Lower Division.

Fossils of the Upper Carboniferous Rocks.—The Upper Division of the Carboniferous system contains, as we have said, the chief coal-seams in Europe and North America. The fauna indicates that the strata were laid down partly under freshwater, estuarine and marine conditions. Taken collectively, the strata consist of alternating sandstones and shales, and an occasional thin band of limestone.

The seams of coal are very unevenly distributed, often occurring in groups, and zones rich in coals are often separated from one another by barren strata. Many of the better-class seams are found to occupy definite positions in the Coal-measure sequence. It is obviously of great use, therefore, to be able to distinguish the horizons of the productive from the unproductive strata,

Photo] [*R. Kidston.*

NEUROPTERIS GIGANTEA, STERNB. *Natural Size.*

and to recognize the positions of the more important coals.

To what extent, then, does the distribution of the fossils among the Upper Carboniferous rocks enable this to be accomplished?

It may at once be said that the fossils of the Upper Carboniferous strata, whether plant or animal, do not strictly lend themselves to what is known as the zonal method. There are hardly any proved restrictions of genera or species to zones of limited thickness over wide areas, as is the case with the *Graptolites* of Ordovician and Silurian ages; nor can it be said that any such zones and sub-zones have been established as those afforded by the *Ammonites* of the Jurassic period and the *Echinodermata* of the Cretaceous period.

Viewed broadly, the fossils of the Upper Carboniferous strata have a wide vertical range. A plant or shell makes its appearance, attains a maximum development, and then dies out. As one genus or species becomes rare, another form makes its first appearance in limited numbers, then becomes predominant, and finally passes away.

The distribution of the plants is considered to be governed by the law of evolution, but that of the mud-loving mollusca seems to be dependent on local conditions of sedimentation, for the majority of the species occur at different horizons in different places according to environment, and changes due to evolution cannot be demonstrated.

Over limited areas a species or genus may be restricted to a particular horizon, but may mark a quite different horizon in another region. It is therefore necessary to distinguish between those fossils which everywhere indicate a high or low position in the sequence from those forms which, locally restricted to a particular bed or group, can only be taken to possess a local value, since in other areas they are found at other horizons.

The Upper Carboniferous strata of Britain are divided into two series—a Lower or Millstone Grit Series, and an Upper or Coal-measure Series. For the latter several classifications have been suggested, the terms Upper, Middle, and Lower Coal-measures being the best known; and so far as these terms are merely taken to imply a relative position in any given sequence they can be retained, though they may be valueless in comparing one coalfield with another.

Plant remains are rare in the Millstone Grit Series, and afford little help in the identification of horizons. The fauna is almost exclusively marine, and in this respect differs from the overlying Coal-measures. The series may be in part recognized by the absence of the plants and estuarine and freshwater shells, common to the sub-divisions of the Upper, Middle, and Lower Coal-measures.

The distribution of the various plants and mollusca throughout the Coal-measures serves to identify the position of certain groups of strata.

The zones formed by the vertical distribution of the plants are of great thickness. Instances are rare where a plant, or an assemblage of plants, defines one stratum, and when this does happen the occurrence can only be regarded as quite local. On the other hand, plants form a reliable index in determining whether a group of Coal-measure strata occupies a high or low position in the sequence.

The Upper Coal-measure age of a series of strata is assured by the presence of *Pecopteris arborescens* (Plate I., p. 48), *Pecopteris unita*, and *Alethopteris serli*, which are unknown in the Lower and Middle Coal-measures. The occurrence of *Sigillaria rugosa* (Plate II., p. 51), *Sphenopteris obtusiloba* (Plate VI., p. 61), and *Neuropteris gigantea* (Plate III., p. 52) will determine the age to be Lower or Middle Coal-measures, since these forms are restricted to these sub-divisions. *Alethopteris lonchitica* (Plate IV., opposite) is a common form in the Middle Coal-measures, but occurs much less profusely in the Lower Coal-measures, and is rarely found in the Upper Coal-measures. *Stigmaria ficoides* (Plate V., p. 58) is a plant common to all the sub-divisions of the Upper Carboniferous Series, and is therefore valueless as an index of horizon.

Palæobotanists place reliance on the presence of many other plants of rarer occurrence—the abundance of some forms and the exclusion of others—or on a special assemblage of certain plants. Such intimate knowledge, however, is seldom attainable either by the miner or field geologist.

Plants, then, as an index of horizon, are of service to the miner only in a broad, general sense. It is otherwise with the mollusca. These not only indicate a relatively high or low position in the sequence, but in many coalfields fix the horizon of a particular bed, and can be used to identify the position of a seam of coal from place to place.

The mollusca can be referred to two faunas, which keep quite apart from each other, and are never found associated together in the same zone, though the two zones may be separated by only an inch, or even less, of shale or other material. One of the faunas is certainly marine, and since the two faunas never commingle it is thought that the other includes the mollusca of an estuarine or freshwater habitat.

The estuarine and freshwater faunas occur throughout the Coal-measures, and are evenly distributed, but may be aggregated in a bed a few feet in thickness. The marine fauna is met with in bands, seldom exceeding 10 feet in thickness, and is restricted to the Middle and Lower divisions.

The freshwater and estuarine mollusca belong to the order Lamellibranchiata, the chief forms being *Carbonicola* (*Anthracosia*), *Anthracomya*, and *Naiadites*. These have a wide distribution, and are the commonest shells met with in the Coal-measures throughout the world. Fluviatile and lacustrine Gasteropoda are much rarer, and are confined to a few coalfields, and not generally distributed like the Lamellibranchiata.

In the coalfields of Central England the various species of *Carbonicola*, *Anthracomya*, and *Naiadites* occur in a definite sequence. Most of the species have a wide vertical range, but a few are considered to be confined to particular bands. To what extent the vertical range of a species in the coalfields of Central England coincides with that in other British and foreign coalfields has not been as yet ascertained, but the available evidence seems to show that the succession of the freshwater and estuarine Lamellibranchiata of Central England does not apply to foreign coalfields.

It has been before stated that the occurrence of a certain species at any one place was largely governed by local conditions, and that the different species of Lamellibranchiata do not demonstrate any marked evolutionary change. The mollusca followed the sediments brought down, and the food these contained. Under varying conditions, the animals would consequently migrate backwards and forwards from one district to another, and accommodate themselves to the food-supply. This does not necessarily invalidate their use in the determination of a local sequence, or over a broad area like the coal-basin of Central England, which, though subject to fluctuations, certainly existed as an area of continuous deposition throughout the Coal-measure period.

The succession of the Lamellibranchiate fauna established for the Midland coal-basin may not, therefore, hold good for other districts. It is, indeed, more likely that each separated area will present its own individual order of life forms, as deposition, and consequent food-supply, may have been arrested at one stage in one area and at another stage in a separate area.

In the Midland coal-basin of Central England the species of *Carbonicola*, *Anthracomya*, and *Naiadites* appear in the following order from the base of the Coal-measures upwards:

Carbonicola robusta (Fig. 1).—This fossil is found in great numbers in the strata containing the chief seams of coal, and occurs in many of the so-called mussel bands. Isolated specimens are met with low down in the Coal-measure sequence, but the species dies out in the Middle Coal-measures. It may be safely regarded as indicative of the lower seams of the Middle Coal-measures.

Carbonicola turgida (Fig. 1).—Like the last-mentioned fossil, this species is associated with the chief seams of coal, and does not ascend into the Upper Coal-measures.

It is found singly or in association with *Carbonicola subrotunda* and *Carbonicola gibbosa*.

Carbonicola subconstricta (Fig. 1).—This form is also confined to the Middle or productive series (p. 178).

Carbonicola acuta and *Carbonicola aquilina* (Fig. 1).—Both these species have a wide range throughout the Lower and Middle Coal-measures. Though they are among the commonest fossils found in the Coal-measures, they cannot be assigned to any distinct zones. *Carbonicola acuta* is common in the so-called mussel-beds, where it occurs in association with the species above mentioned.

This genus, it will be seen, does not occur in the Upper Coal-measures.

Naiadites quadrata (Fig. 1).—This is also a common fossil in the Middle Coal-measures, either occurring alone or in association with *Naiadites carinata* and *Naiadites modiolaris* (Fig. 1). It is unknown in the Upper and very rare or absent in the Lower Coal-measures.

Anthracomya williamsoni (Fig. 1) and *Anthracomya modiolaris*.—Both these species are confined to the Middle Coal-measures, and are of much less common occurrence than the species of *Carbonicola* and *Naiadites*.

Anthracomya adamsi (Fig. 1).—This has a very restricted range in the Middle Coal-measures (p. 178).

All these fossils are confined to the Coal-measure strata situated between the top of the Millstone Grit and the base of the Upper Coal-measures, and may certainly be regarded as representing the estuarine development of the Lamellibranchiata at this period.

We shall now consider the fossils of the Upper Coal-measures, taking this term to include the barren

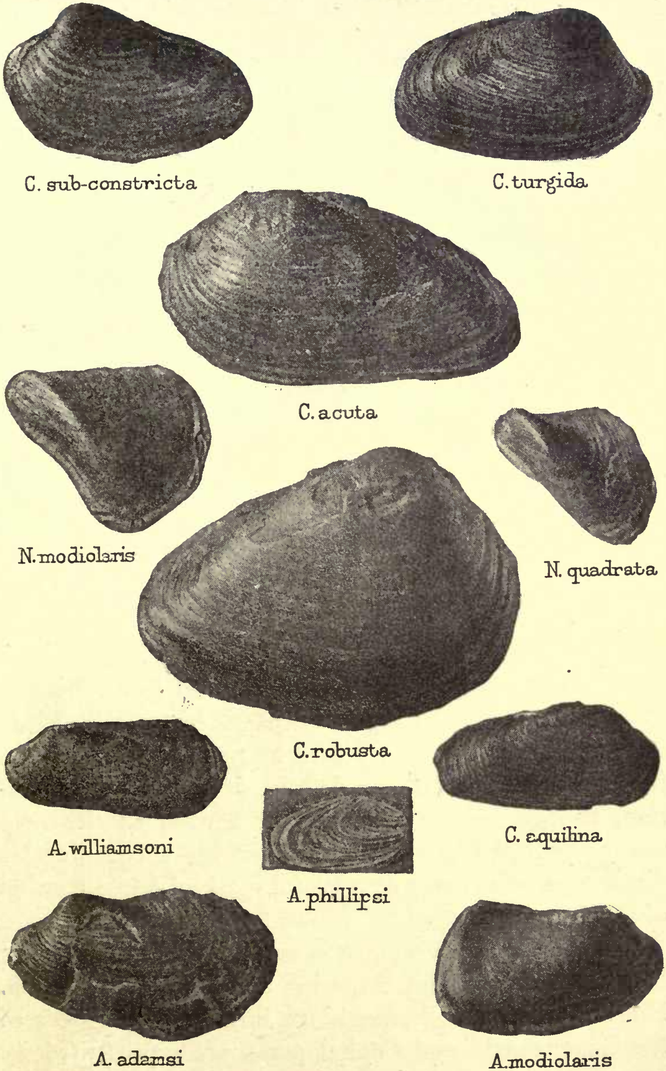


FIG. 1.—CARBONICOLA (C.); ANTHRACOMYA (A.); NAIADITES (N.) FROM THE ENGLISH COAL-MFASURES.

strata overlying the Middle Coal-measures of the Midland Province and the measures above the Pennant rock in the Southern Province (p. 144).

The commonest fossil met with is *Anthracomya phillipsi* (Fig. 1), and throughout the Midland coal-basin it indicates a high position in the Coal-measures, for it first appears towards the top of the Middle Coal-measures, and becomes abundant only in the lower part of the Upper Coal-measures.

The last survivor of the freshwater Lamellibranchiata is *Anthracomya calcifera*, a small shell met with high up in the Upper Coal-measures, but having a limited vertical distribution.

We have now traced the vertical distribution of the Coal-measure Lamellibranchiata in the order in which they occur in the Midland coal-basin. To what extent this order holds good for other British coalfields has not been determined.

In the north of England and in South Wales *Carbonicola robusta* appears to be restricted to low horizons, while *Anthracomya phillipsi* indicates a high position. It does not, however, appear safe at present to rely upon these or other species as a definite means of determination, though locally a species or several species may always be found in a particular bed for a considerable distance, and so serve as a useful mark of identification of much local value.

The marine mollusca are more varied both in genera and species than the estuarine and freshwater forms. Not only the Lamellibranchiata, but also the orders of the Gasteropoda and Cephalopoda, are represented by many genera and species. Few of the forms, however, are peculiar to the Coal-measures, and the majority are identical with, or have a close affinity to, the marine mollusca of the Lower Carboniferous rocks and the Millstone Grits.

The chief mollusca common to both divisions are:—

Brachiopoda.

Lingula mytiloides (Sow.).
Orbiculoidea (Discina) nitida (Phill.).
Productus (scabriculocostate form).
Productus scabriculus (Mart.).
Spirifer bisulcatus (Sow.).

Lamellibranchiata.

Ctenodonta lævirostris (Portl.).
Leiopteria longirostris (Hind).
Nucula gibbosa (Flem.).
Nucula æqualis (Sow.).
Nuculana sharmani (R. Eth. fil.).
Posidoniella lævis (Brown).
Posidoniella minor (Brown).
Pseudamusium fibrillosum (Salter).
Pterinopecten carbonarius (Hind).
Pterinopecten papyraceus (Sow.).
Syncyclonema carboniferum (Hind).

Gasteropoda.

Euphemus urei.
Raphistoma radians (de Kon.).

Cephalopoda.

Cœlonautilus, *cf.* subsulcatus (Phill.).
Conularia quadrisulcata (Sow.).
Dimorphoceras gilbertsoni (Phill.).
Dimorphoceras loonyi (Phill.).
Gastrioceras coronatum (Foord and Crick).
Glyphioceras micronotum (Phill.).
Glyphioceras phillipsi (Foord and Crick).
Glyphioceras reticulatum (Phill.).
Nomismoceras ornatum (Foord and Crick).
Pleuronautilus armatus (Sow.).
Pleuronautilus falcatus (Sow.).
Pleuronautilus rotifer (Salter).

The occurrence of these fossils alone would therefore only determine the sandstones and shales in which they occur to be of Carboniferous age. The presence of the following fossils would, however, clearly demonstrate the Upper Carboniferous age of the beds, since, so far as is known, they are only met with in this division of the Coal-measures, both in British and continental coalfields.

Some of these marine fossils, now thought to be confined to the Lower Carboniferous, may ultimately be found in the marine bands of the Upper Carboniferous rocks; others, again, given in the following list, and at present known only to occur in later Carboniferous times, may have made their appearance during the deposition of the Lower Carboniferous strata.

Brachiopoda.

- Ambocœlia carbonaria.
- Chonetes aff. laguessiana (de Kon.).
- Productus anthrax.

Lamellibranchiata.

- Ctenodonta undulata (Phill.).
- Nucula oblonga (M'Coy.).
- Nuculana acuta (Sow.).
- Posidoniella sulcata (Hind).

Gasteropoda.

- Loxonema acutum (de Kon.).
- Naticopsis brevispira (de Ryck.).
- Turbonellina formosa (de Kon.).

Cephalopoda.

- Ephippioceras costatum (Foord).
- Gastrioceras carbonarium (L. von Buch.).
- Gastrioceras listeri (Martin).
- Glyphioceras paucilobum (Phill.).
- Pleuronautilus costatus.
- Temnocheilus carbonarius (Foord).
- Temnocheilus concavus (Sow.).

The material in which the fossils are contained is invariably a shale, either dark blue in colour and of greasy appearance or jet black but non-carbonaceous. Sandy light grey shales or black highly carbonaceous shales seldom, if ever, contain marine organisms. The

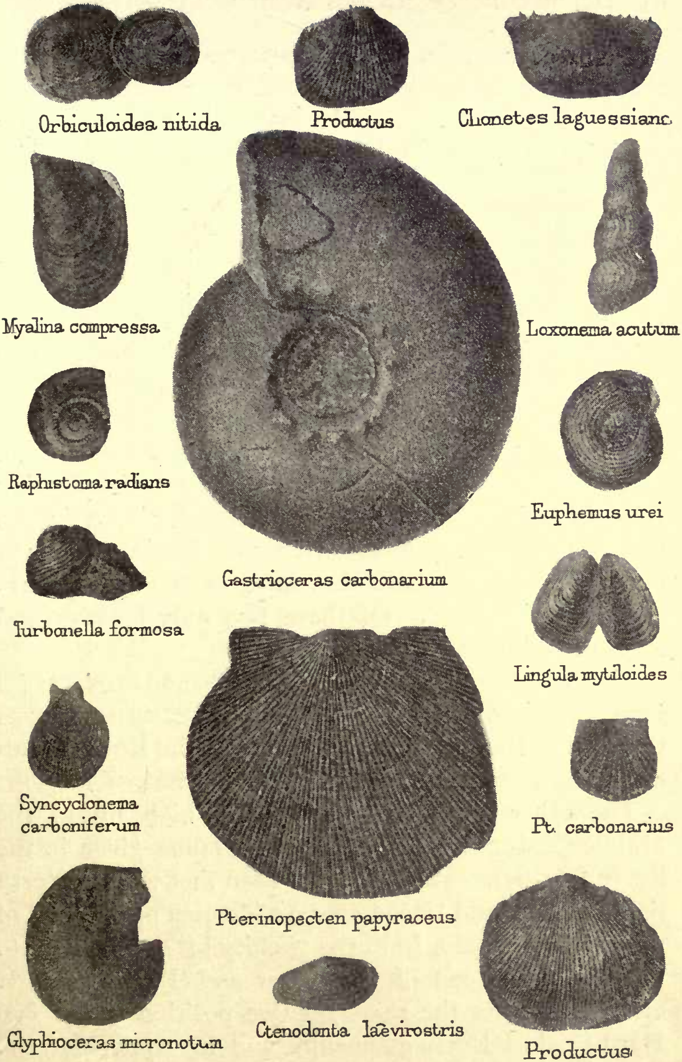


FIG. 2.—MARINE FOSSILS FROM THE COAL-MEASURES OF CENTRAL ENGLAND.

fossils are more frequently preserved in iron pyrites than is the case with the freshwater and estuarine Lamellibranchiata. Argillaceo-calcareous ironstones in nodules or in thin bands are common, and usually contain the best-preserved specimens. The greasy blue shales (soapy binds of the English miner) contain the richest and most varied fauna, while that of the black shales is usually restricted to species of *Goniatites*, *Pterinopecten papyraceus*, *Lingula*, and *Discina*.

The marine bands vary from a few inches to over 30 feet in thickness, the thickest beds being those formed of the greasy blue shales with ironstone nodules.

Excluding such bands as have so far been recognized, only over very limited areas and the beds yielding *Lingula* and *Discina* only, the marine horizons in the Coal-measures do not exceed four or five in number in Central England, where they have been most systematically investigated. Of these, two only have proved to be of wide distribution.

The lowest band, containing *Goniatites* and *Pterinopecten papyraceus*, is only a few feet in thickness, and forms the roof of the lowest seam of coal in the Lower Coal-measures throughout the Midland Province.

The other marine horizon, lying high up in the Middle Coal-measures, contains the fauna given in the list (pp. 61-62). This band has been met with in North Staffordshire, and traced over a wide area on the east of the Pennine Chain, from the vicinity of Nottingham to the neighbourhood of Doncaster and Pontefract. It always occupies the same relative position to the Top Hard Coal of Nottinghamshire and its equivalent, the Barnsley Coal of the Yorkshire Coalfield.

Between these two generally recognized bands, and again higher up in the sequence, other marine beds are recorded from several coalfields, but it remains to be proved whether these occupy definite positions, or if they merely represent local marine incursions in a sequence mainly estuarine or freshwater, as determined by the character of its fossil contents.

Thin bands of shale, containing *Lingula* and *Discina* or only the former, are of more common occurrence in the Midland Coal-measures than is usually thought to be the case. The zones are seldom more than a few inches thick, and seem to be only of local character, unless their existence has escaped notice owing to the thinness of the bands and the smallness of the fossils, though they may be easily recognized by the glistening scale-like character of the horny shells. Some fish scales and the smaller forms of *Anthracomya* might be mistaken for a *Lingula*, but the usually ornamented character of the fish scales and the calcareous shell of *Anthracomya* will distinguish these fossils from the plain chitinous shell of the small Brachiopods.

In tracing a band containing *Lingula* it is frequently found to pass laterally into a band containing Goniatites and *Pterinopecten*. The Brachiopod then becomes rare or absent, as if the presence of this animal marked a change from a purely marine phase to one less favourable to the existence of marine organisms.

In Great Britain the highest Coal-measures do not contain workable seams. In the United States the Dunkard formation, placed by some geologists in the Carboniferous and by others in the Permian, is likewise practically barren of coals. In Central France and Germany, however, a group of strata (Stephanian) of lacustrine origin contains many valuable seams. The flora is distinctive of the highest Coal-measures in England, but is associated with many other plants not found in the Upper Coal-measures of this country.

Fossils of the Later Formations.—In the Southern Hemisphere—Australia, India, South Africa, and South America—the chief coal-bearing formations are of Permo-Carboniferous, Permian, and Triassic ages. The flora of the Permo-Carboniferous is peculiar, and is easily recognizable from that of the later formations by the presence of the fossil plants *Glossopteris browniana* (Plate VII., p. 67) and *Sigillaria brardi* (Plate VIII., p. 290).

Position among the Permo-Carboniferous rocks can also be roughly determined by the vertical distribution of the Reptilia.

The question of determining the age of the coal formations of the Mesozoic and Tertiary periods by means of the fossils does not at present particularly attract the attention of the miner, since in most countries, especially in Europe, coal-mining enterprise is chiefly directed to the exploitation of the more important Carboniferous coals, while the Mesozoic and Tertiary coals, besides being of inferior value, lie at shallow depths, and are readily exploited.

In Alaska good coals of Carboniferous age exist side by side with important seams of Mesozoic or Tertiary ages; but the great distinction between the lowly organized flora of the Carboniferous and the higher Cycadaceous and Dicotyledonous flora of the Mesozoic and Tertiary formations will readily determine the age of any coal-bearing strata in which these fossils occur.

Concluding Remarks.—The most valuable coals belong, as before stated, to the Carboniferous system, and in the past coal-mining has been chiefly carried on in those regions where the Coal-measures lie at the surface. Now, however, explorations are being extended into areas where the character, or even the existence, of coal-bearing strata is often a matter of considerable speculation.

As we have shown, the fossils afford a reliable guide in determining positions in the sequence. Since, however, the Coal-measure strata are so similar in appearance, it is useful in the case of a boring or shaft passing through several hundred feet of such strata to know in what kind of rocks the fossils distinctive of definite horizons may be expected to occur.

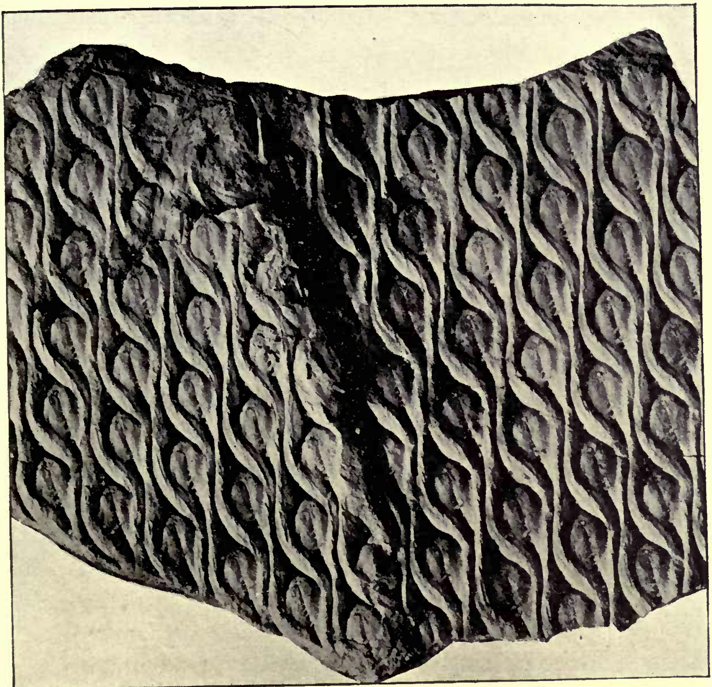
Beds containing marine fossils should be looked for among the blue-grey shales, and in the calcareous clay-ironstones commonly associated with them, and not in the more arenaceous rocks or in the black carbonaceous shales. Plants, on the other hand, should be searched for in these sandy shales, while the estuarine Lamellibranchiate fauna may be expected in the jet-black shales, and in the ironstones that almost invariably accompany them.

The use of fossils to fix horizons among the strata of the Coal-measures may be as much abused, and lead to as many mistakes as the old, and for a long time only, practice of taking the bed next-in-order, which makes use of a sandstone, clay band, seam of coal, or a series of sandstones and coals, as an indication of position in a local sequence.

The determination of an horizon on the occurrence of a single fossil, whether plant or animal, is a fatal error, and has frequently led to very false interpretations. In the Upper Coal-measures, for instance, a profusion of *Alethopteris serli*, in association with *Pecopteris arborescens* and *P. unita*, and the absence of many common Middle Coal-measure plants, may be relied upon in assigning the strata in which they occur to the Upper Coal-measures. In the same way the occurrence of *Alethopteris lonchitica* in association with Middle and Lower Coal-measure plants indicates an horizon below the Upper Measures. But the plants of the Upper series make their appearance towards the summit of the Middle series, and further research may discover them in the Lower series.

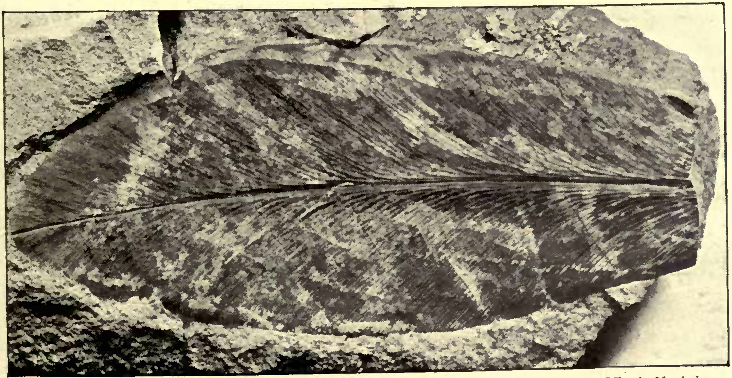
As our knowledge of the vertical distribution of the plants increases, a form for a long time considered to be confined to a low horizon is found to occur, though not in profusion, at a higher horizon, just as a high zonal plant may be found, though not abundantly, at a much lower level. Conclusions, therefore, based solely on the occurrence of a single fossil would in these cases be quite misleading; the field of observation must be sufficiently large, the fossil plants sufficiently abundant, and the knowledge of a particular district sufficiently extensive. It must be ascertained whether the absence of certain plants is due to the small amount of material examined, or whether the local conditions were not favourable to their preservation, before it is safe to conclude that certain forms did not exist side by side with those found in a fossil state.

The same precaution is necessary in using the mollusca, whether marine, estuarine, or freshwater, as zonal indices. In the absence of low zonal forms of *Carbonicola* and *Anthracomya*, the presence of *Anthracomya phillipsi* can be relied on in this country as a safe index of a high position in the Coal-measure



Photo] [R. Kidston.

LEPIDODENDRON VELTHEIMIANUM, STERNB. *Natural Size.*



Photo] [E. A. N. Arber.

GLOSSOPTERIS BROWNIANA, BRONGT. *Slightly Reduced.*

sequence, since in those coalfields in which extensive collecting has been done, the general absence of this fossil has been proved in the measures in which forms like *Carbonicola turgida* and *C. robusta* are present. But it would not be safe to assume that this rule holds good in other countries; and, indeed, on the Continent *Anthracomya phillipsi* occurs below the zone of *Carbonicola robusta* and *C. turgida*, but even here we are not aware that it is found in association with these fossils.

Fresh information on the distribution of fossils tends as a rule to lessen the number of forms originally considered to be restricted to definite horizons, and to show that each district has its own peculiar floral and faunal distribution, dependent upon local conditions or the accident of preservation, though each geological province may possess distinctive palæontological characters useful as a whole in extended correlation, but of little service to the miner.

The determination of horizons in the Coal-measures by means of fossils, whether plant or animal, may perhaps still be regarded as on trial, since the amount of material to be dealt with is so great and active research in many districts is not common. In numerous sinkings and underground explorations, indeed, the material has not even been examined, or, at any rate, only partially examined, for fossils. This being the case, it were as unwise at present to consider the value of fossils as zonal indices in the Carboniferous rocks to be firmly established as to cast entire discredit on the whole method.

Fossiliferous bands are certainly of great importance where one valuable coal lies among a thick mass of strata in which there are often no well-developed coal-seams or rock bands. This is the case in the East Yorkshire Coalfield, where the Barnsley Coal lies at the base of about 1,100 feet of strata containing many thin seams, but none of them of sufficient importance or sufficiently distinctive in character to have received special notice in the records of old pit sinkings. Towards the middle of the strata above the Barnsley Coal a bed occurs containing fossils peculiar to this band, and not met with in any other beds above the Barnsley Coal. While, therefore, the strata above this coal possess no very distinctive lithological characters, this band can be recognized by the peculiar assemblage of fossils. It therefore serves as an index of position among a great thickness of strata of which one portion is very similar to another.

The Bullion Coal of Lancashire, the Crabtree Coal of North Staffordshire, and the Pecten Bed and Alton Coal of Yorkshire and Derbyshire, afford another example of a coal lying amidst a considerable thickness of barren strata, but readily identifiable by the fossils met with in the roof shales.

These fossiliferous bands, used merely as indices of position, cannot be regarded as of more value than a known seam of coal possessing marked characters, a bed of sandstone or a local development of one particular kind of rock; but they certainly do afford confirmatory evidence, and sometimes constitute the only reliable index, of position in a local sequence. The practical miner can seldom be expected to recognize the species of a fossil, but he can scarcely fail to discriminate between the fossils of a marine band (Fig. 2, p. 63) and those of an estuarine bed; nor can the fossil assemblage of a rich zone like that above the Gin Mine be mistaken for the one above the Crabtree Coal of North Staffordshire or for that above the Deep Hard Coal of Derbyshire (p. 198). These three separate horizons contain several fossils in common, but in the higher (Gin Mine) several species and genera of peculiar and easily recognizable characters, and unknown in the lower zones, are always met with.

CHAPTER VII

PROSPECTING AND BORING

FOSSIL evidence will in most cases correctly determine whether a formation is or is not likely to contain coal. In Europe and North America strata containing Upper Carboniferous plants may be reasonably expected to be coal-bearing, while in the Southern Hemisphere, strata yielding the fossil plants *Glossopteris* and *Sigillaria* may be searched for coal. The probability of coal existing in formations newer than the Carboniferous or newer than those containing *Glossopteris* will depend upon the character of the sediments. Since coal has been formed out of vegetable material growing on the spot now occupied by a seam of coal or from vegetable débris floated out and deposited in water in near proximity to land, coals will not be expected to occur in sediments whose deep-sea origin is evident from the nature of the fossils. Thus, among the later Mesozoic and Tertiary formations coal does not usually occur in the essentially marine sediments of these formations, but in the strata of estuarine and freshwater origin.

Coal rapidly perishes at the surface. It is, therefore, seldom seen in natural sections, except in sea-cliffs, as along the Durham, Fifeshire, Pembrokeshire, and Nova

Scotia coasts; in New South Wales, near Sydney, and in New Zealand, near Dunedin, where it attracted the attention of the early settlers. Even where deep valleys have intersected seams of coal the outcrops are seldom visible, as rain-wash and vegetation commonly conceal them. Coal-seams are sometimes visible in the rocky sides and beds of rapid streams and along the faces of recent landslips.

As before stated, a coal-seam is commonly overlain by a water-bearing sandstone, and underlain by an impervious layer of shale or clay. The outcrop, or 'basset edge,' of a coal-seam is in consequence often indicated by a line of wet ground, on which rushes and other marsh plants grow.

Coal-seams and the closely associated shales and clays usually contain iron pyrites, which is readily decomposed, and gives rise to protoxide of iron, which is soluble in water. The water containing these soluble iron salts, when exposed to the atmosphere, deposits the insoluble sesquioxide of iron. If, then, in an area known to be coal-bearing a line of chalybeate springs be followed along a valley-side, it not infrequently happens that a spot is reached affording a section of a seam.

Sea-cliffs, the beds of streams having a rapid fall, cascades and waterfalls, the scarred faces of recent landslips, etc., afford, as a rule, the only, and certainly the best, sections of coal at the surface. Fragments of the harder varieties, such as anthracite and cannel, may occur in the alluvial deposits of streams and main waterways, and by following the stream towards its source the outcrop of the coal, from which the fragments have come, may be detected.

Such natural exposures of coal are, however, rare, and a stream or river bed may not afford any reliable indication whether the rocks which crop out along their course are coal-bearing or otherwise. In South Africa prospecting along the spruits and valleys would not in many cases afford any indication that the strata composing the district were coal-bearing, owing to the wasting away of the coal for considerable distances along the outcrop (Fig. 32, p. 291).

In the Northern Hemisphere, within the zone of glaciation belonging to the Quaternary period, the surface clays and sands not infrequently contain fragments of coal or coal-shale. Such fragments may not indicate the near proximity of coal-bearing strata; but if the direction from which the ice travelled be known, the trail formed of the glacial detritus may be followed to its source. The gravels, sands, and boulder clays of the Vale of York, along the path of the Stainmoor glacier and those of the Midland Triassic plain, on which the Welsh glacier debouched, contain numerous coal fragments derived from seams cropping out in those regions over which these glaciers passed; but the rocks at the surface on which the glacial deposits rest are many miles distant from the outcrop of coal strata. Sometimes a considerable mass of coal and coal-bearing strata have been carried far from their source by glaciers, and this occurrence has been erroneously taken as evidence for the existence of a coalfield.

The presence of coal-bearing strata being suspected, the means employed to prove the number and thicknesses of the seams of coal will naturally vary according to circumstances. Where the strata lie almost horizontal and the country is but little dissected by valleys, a trial-shaft or boring will give the most satisfactory results. Where, as in South Africa, the coal perishes along the valleys and in the hollows or pans (Fig. 32, p. 291), the trial-shaft or boring—preferably a shaft where the thickness of strata to be penetrated is not great, and the general character of the rocks to be sunk through is known—should be placed on the higher ground. Where intrusive igneous material is developed on a large scale, and is known to have a deleterious effect on the quality of the coals, a site for the experimental trial is chosen removed as far as possible from the neighbourhood of the igneous rock. If the strata thought to be coal-bearing are very steeply inclined, then a trench cut at right angles to the strike of the beds will afford a good chance of proving any seams of coal.

In areas close to existing workings, or where the certainty of finding coal at workable depths admits of little doubt, it is usual to commence sinking a shaft of the required diameter without any preliminary trials. In more remote districts, however, where the depth to the coal, its quality, or even its existence, are more or less speculative, attempts are generally made to prove the value of the unknown ground by sinking a trial-shaft or by boring.

A trial-shaft undoubtedly gives the more satisfactory results, but, owing to the expense necessarily involved, this method is only adopted in areas where the probability of finding coal is practically assured, though the quality, thickness, and number of the seams are more or less unknown factors. Where the risk is greater, boring is usually resorted to.

Boring for coal is not so simple an operation as it appears to be, and requires much more care and supervision than is generally thought to be the case. The system of drilling adopted must be one capable of producing cores of reasonable diameter—say, not less than 4 inches—of the strata passed through, and, what is a more difficult task, the drill is required to draw a core of coal from which its quality, thickness, and component parts can be satisfactorily determined. A considerable measure of success has been achieved in obtaining cores of rock between 4 and 6 inches in diameter at depths exceeding 2,000 feet, but, with the exception of the harder varieties of coal, a system of drilling capable of producing good cores has as yet to be invented, though better results may be expected when the difficulties of the operation are more clearly understood.

Many borings have been successful in proving the position of numerous seams and their thicknesses to within a few inches, but have failed to produce a core of coal, and have practically resulted in commercial failure. A case is also known where a seam, subsequently proved to be 4 feet in thickness, passed notice altogether in the drill-men's record, but was met with in the shaft that followed the experimental boring. Obviously, the detection of the occurrence of a coal and the determination of its thickness depend to a great extent on the acuteness of the man in charge at the time the drill is passing through a coal which is not of sufficient hardness to yield a sound core.

As regards the depth obtainable by the diamond drill, the maximum of 6,572 feet bored in Upper Silesia far exceeds the limits at which coal-mining is at present considered practicable on the Continent, where the limit is generally placed at 4,900 feet depth. In Fifeshire a boring has already reached 4,000 feet, the limit of depth considered practicable for working coal in this country.

While, then, drills can far exceed the depth at present fixed upon as the limit of profitable working, the production of a complete core of coal which would justify the necessary expenditure in sinking shafts to any great depths has not as yet been successfully accomplished, so that comparatively few borings have been followed by shaft-sinkings.

The object of any boring for coal is to obtain cores of the different strata passed through. The rotatory type of drill is, therefore, alone admissible.

A description of the mechanism of the different types of this kind of drill will not be attempted here, but the general principles will be explained.

The actual cutting is performed by a crown set with diamonds, or by means of chisels placed at an angle round the crown, or by the rasping action of chilled shot washed down to the bottom of the hole, where they find their way beneath the crown. Usually a combination of both methods is resorted to, chisel cutters being used for the softer strata, and diamonds or chilled shot for the harder rocks. The core is retained in a hollow inflexible cylinder, from 8 to 20 feet in length, termed the core-barrel.

In the Calyx drill the hydraulic cylinder forms an important feature. By means of a gauge connected by a high-pressure hose to the water in the cylinder, the foreman in charge can usually obtain a good idea of the kind of rock being bored through. In boring through a hard rock like sandstone, the pressure indicated by the gauge is much lower than in going through a soft substance like coal. It is obvious, however, that the gauge will not differentiate between a coal-seam and any rock offering a similar resistance to the passage of the drill.

The existence of a hard or soft bed is thus indicated by the gauge, but without stopping the drill and drawing the core, the composition of the particular strata being bored through can only be ascertained by the fragments or washings brought to the surface and issuing with the stream of water at the top of the hole. A great deal is, therefore, left to the foreman.

In the case of a soft coal which is readily ground into powder by the action of the drill, much of the fine material, it is thought, escapes capture, and, ascending through the borehole, reaches the surface in the water continually flushing the hole. This escape water, with any sediment it may contain, flows through a series of troughs conveniently arranged at the surface and supposed to catch the sediments brought up. The coal-dust or pieces of coal escaping capture in the core-barrel and chip-cup should theoretically be retained here, and it is supposed that the fragments of coal which the core-barrel or chip-cup fail to retain will be found in the slimes of the settling troughs. Since, however, the stream of water entering the troughs ultimately escapes into a sluice or neighbouring stream, it seems quite possible for very finely divided coal to pass out of the troughs, and thus escape notice altogether. It is, however, denied that any loss of core occurs in this way.

The choice of a site for a boring depends largely on the royalty it is intended to prove, of which the extent is determined beforehand on both commercial and geological considerations. A good supply of water is essential both for the engines and to keep the borehole continually flushed, and this must be taken into account in choosing the site.

The most suitable spot for the borehole having been chosen, it is then necessary to decide upon the initial diameter of the hole. This depends, neglecting the cost, chiefly upon the nature of the strata to be penetrated.

The rocks forming the cover of most coal-bearing formations are generally favourable for drilling. Most of the coal-bearing strata, and especially the Coal-measure strata of Carboniferous age, consist of marls and clays, and strata of this character swell up and have a tendency to close in on the hole. To obviate this, it is necessary to case off these rocks by iron piping, and this repeated casing and lining of the hole naturally necessitates a diminution in its diameter. Under ordinary conditions, if it is desired to draw a core of from 4 to 6 inches in diameter at a depth exceeding 2,000 feet, the initial size of the hole should not be less than 18 inches across. Borings have been put down in which, the diameter at the commencement being much too small, the diameter in the final stages was under one inch, and therefore practically useless. On nearing the horizon at which a seam of coal is expected, it is preferable, whenever possible, to discontinue drilling at night-time, though in the case of deep holes this method adds considerably to the cost, and may sometimes be impracticable.

It is assumed that a hole starting straight proceeds vertically downwards to the bottom; but few borings achieve this desideratum, unexpected turnings from the perpendicular being of frequent occurrence. Absolute proofs of the amount of deviation have not, in many cases, been ascertained, and in some borings no allowance has been made for possible deviations from the vertical. In South Africa a deviation of 2,185 feet in a depth of 4,802 feet has been recorded, and in Germany as much as 47 degrees departure from the vertical at a depth of 750 feet has been notified.

Various methods for determining the amount and direction of the deviation have been tried, but most of them are open to criticism, though in some cases satisfactory results have been obtained. One of the commonest, but certainly one of the least reliable, is to lower down the hole a tube containing liquid gelatine or cement, and to note the angle at which it sets. In shallow holes this method may give a satisfactory result, but in deep holes the liquid may set owing to the cooling effect of the water used to flush the hole long before it reaches the stage where the deviation is to be ascertained. The plan of using the effect of a solution of hydrofluoric acid in etching a glass tube lowered down the hole is also resorted to, and may give a reliable result, since a solution of sufficient weakness can be used which does not act until the glass tube lowered down has reached the spot where the deviation is supposed to have taken place. Another method is to employ electricity in fusing solid paraffin, or other liquefiable substances, after the tube has been placed in the required position in the hole.

The effect of a boring ceasing to be plumb is to give an exaggerated dip and thickness to the strata, the actual depth attained by the boring being improved, unless the amount of deviation can be correctly ascertained. Whenever feasible, therefore, it is essential that careful tests should be made to find out whether the boring has turned from the vertical.

The preservation of the cores and the correct description of the strata passed through ranks of considerable importance. The notification of any fossils met with is also most desirable, as these may in many cases afford the only true index of position.

The most satisfactory method of keeping the cores so that they can be readily examined at intervals is to place them in a galvanized iron shed. In the case of deep borings, this shed should be from 50 to 100 feet in length, and of sufficient width to allow the cores to be arranged on the ground in a single tier, each length, say, of 100 feet being separated from the next by match-boarding.

The frequent practice of arranging the cores in layers one above the other is greatly to be deprecated.

The depths from which the cores are obtained should be inserted on them at frequent intervals by means of labels, affixed by some adhesive not affected by damp.

A careful record of the boring as it proceeds is essential. This is usually left to the foreman, who states the depth bored, the amount of core drawn, and the amount lost. He is not, however, as a rule, sufficiently acquainted with the rock sequence of the district to be able to put in writing a correct description of the strata passed through. Instances occur where a bed, important from the evidence it affords of the position attained in a coal-bearing sequence, is described in terms quite misleading as to its character. It is advisable, therefore, to have the cores so arranged that they are readily accessible. The foreman's record can then be checked from time to time, and any necessary alteration and additions can be made with little trouble.

On the completion of a boring a thorough survey of the borehole should be made, and lengths of core of important horizons—not merely chips, as is frequently the case—should be placed in boxes for future reference. If the entire length of cores can be preserved so much the better, and where a boring is put down in an area where the rock sequence is comparatively unknown, it is certainly advisable that the whole of the cores should be kept, since an horizon thought to be of little importance at the time may ultimately prove of value.

We have before stated that the production of a core of coal sufficient to identify the seam is seldom achieved, while to obtain rock-cores is a comparatively simple matter. Though borings may therefore be unsuccessful in respect to the chief object—that of securing a core of coal—they seldom fail to produce cores of other rocks, from which important conclusions may be drawn as to the structure of the area, the depths to the seams, and the nature of the strata, whether water-bearing or not. In the case of mining royalties of considerable area, boring may be discontinued at a stage when sufficient information has been attained as to the thickness and nature of the cover, whether likely to be water-bearing or not, and when the productive Coal-measures have been proved to be present over the entire royalty, or when the same bed has been found in three or more of the borings from which the general dip of the strata may be approximately obtained, and, in consequence, the position can be determined where the winning shafts can be most advantageously placed. The quality of the coal, its thickness and character, can, as a general rule, only be determined by experience obtained in mining.

CHAPTER VIII

STUDY OF AN EXPOSED COALFIELD

THE term 'coalfield' is applied to any area over or under which coal has been proved to exist, or is expected to occur at workable depths. When the coal-bearing strata are exposed at the surface, as is the case in all the more important coalfields of the world, the tract is called a 'visible coalfield'; if the coal strata are hidden beneath a formation differing in age from the one in which the coal occurs the area is termed a 'concealed coalfield,' such as that of Dover. In many instances a coalfield is partly exposed and partly concealed.

Those coalfields in which the coal-bearing strata appear at the surface have naturally been the first to be explored for coal, and it is from the examination of these coalfields that conclusions are drawn as to the probable character of the concealed areas.

In every visible coalfield it is essential to determine —(1) the boundaries of the field; (2) the sequence exhibited by the coal-bearing strata; (3) the geological structure; (4) the total available quantity of coal.

Shape.—The boundaries of a coalfield may be formed by rocks newer or older than the strata in which the coal occurs.

When a coalfield is surrounded by newer formations, the relation of these to the coal-bearing strata, whether conformable or unconformable, must be ascertained. If conformable, then the coal-bearing sequence may be continued beneath them; but if unconformable, a part, or even the whole, of the productive measures may be absent.

The coalfield of South Staffordshire, for instance, is surrounded by two thick deposits of red strata, both barren of seams of coal. The one, so-called Permian, is conformable to the Coal-measures; the other, Trias, is unconformable. Beneath the so-called Permian the Coal-measure sequence is intact, while the Triassic rocks rest at one place on a productive zone, and at another on an unproductive zone. In a strict sense, the visible coalfield may be said to terminate at the outcrop of the Permian; but the so-called Permian may, as is now frequently done, be grouped with the coal-bearing strata, and thus considered as a part of the visible coalfield.

Similar instances can be given from many other coalfields where a coal-bearing formation is overlaid by two groups of rocks very similar in character, the one resting conformably, the other unconformably, on the productive measures. The determination of the relationship is evidently of vital importance to the coal-miner, and will be further exemplified in dealing with a concealed coalfield in a succeeding chapter.

Many coalfields are bordered by rocks which can at once be recognized as older than the coal-bearing formation. In Central France and South Africa the strata containing the coal are surrounded by crystalline rocks or by strata of such different types from those in which the coal occurs that they cannot possibly be mistaken for them. The boundaries of the coalfield in such cases are clearly defined by the outcrop of these very different rocks.

In other coalfields the older strata possess many characters in common with the coal-bearing formation, and a closer examination is necessary to distinguish between them. For example, in the Warwickshire Coalfield black shales and sandstones of Carboniferous age rest on black shales and sandstones of Cambrian age, the lithological characters of the two being very similar—indeed, so similar are they that geologists were misled as to the difference in age, and it was only on fossil evidence that the disparity in age between the two formations was recognized.

A study of the fossils and the stratigraphical relationship of the individual strata will, however, generally determine the age. Thus, the presence of fossils only found in rocks older than the Carboniferous will at once show that the measures in which they occur antedate any coal-bearing strata (p. 49). The difference in age may also be determined if one set of beds contains pebbles of the underlying rocks, or if one group rests on the eroded and upturned edges of another group.

The shape of the coalfields, surrounded by rocks older than the Carboniferous, has been largely determined by that of the eroded hollow in which the coal strata were laid down.

We now come to those coalfields whose configuration has been caused by pressure exerted subsequent to the deposition of the measures.

The shape and size of the Carboniferous coalfields in the Northern Hemisphere have been to a large extent determined by the great earth-movement which supervened at the end of the Carboniferous period. During this period of disturbance the strata were folded in two directions at right angles to each other, with the result that the Carboniferous rocks occur mainly in basins. Since, as before stated, the productive portion of the Carboniferous formation is for the most part confined to the Middle, or Coal-measure, stage, it happens that the chief coal strata of the Northern Hemisphere occupy the centre of these basins, the lower Carboniferous strata—generally unproductive—forming the margins.

The shape of the individual basins has been determined by the direction of the major folding. Most coalfields have either a longitudinal or latitudinal extension, according as the maximum pressure was exerted from the east and west or from the north and south, the direction of folding being naturally at right angles to the direction from which the pressure came. The coalfields of South Wales, Southern England, Northern France, and Belgium, for instance, extend latitudinally, since the chief pressure came from the south. The coalfields of Central and Northern England and of the United States have their longest diameters arranged longitudinally, or at right angles to the pressure which was exerted from the east. Within these major folds minor crumplings occur, and though a coalfield as a whole may possess a longitudinal direction, parts of it may extend at right angles to the general direction of folding.

In some cases the tangential pressure affected the narrow depression in which the coal-bearing strata had been deposited, with the result that the original shape of the hollows has been wholly or in part obliterated or their outlines have been accentuated, thus giving a general orientation to several small basins, like the coalfields along the line of disturbance traversing the central plateau of France, those following the line of the Alpine disturbance, and the Tertiary and Cretaceous coalfields of the Rocky Mountain region.

The result of pressure acting on any extensive deposits of coal-bearing rocks is to buckle them up into a number of anticlinal and synclinal folds. Subsequent denuding agencies, by removing large masses of strata from off the anticlines, have led to the formation of separated synclines or basins of Coal-measures, rimmed round by older formations, which have been laid bare by denudation. In this manner a once continuous sheet of coal-bearing strata has been broken up into distinct coalfields. The present disunited, but at one time connected, Yorkshire and Lancashire coalfields afford an excellent example of this arrangement.

Some coalfields, then, are bounded by newer rocks, others lie in the eroded hollows of older strata, and some owe their separate existence to earth-movements. Not infrequently, however, the delineation of a coalfield has resulted from the combination of all three factors. Thus, the Coal-measures of Coalbrookdale, Forest of Wyre, were deposited in hollows of the older rocks; the newer Triassic strata cover them on the east; while their north and south orientation was, for the most part, outlined by post-Carboniferous earth-movements.

Again, in Central England we find at least five distinct coalfields. There is little doubt that the Carboniferous rocks composing them were once more or less continuous, and were deposited in a very irregular hollow, carved by denudation in strata older than the Carboniferous. By post-Carboniferous earth-movements this once-continuous but irregular sheet of strata was bent up into a number of folds, trending generally north and south. Subsequent to or during the process of folding, large masses of strata were removed, and one portion of the area was separated from another. The Triassic deposits were afterwards laid down on these folded and denuded strata, and further tend to disguise the original connexion of the coalfields. These factors in the delineation of the coalfields of Central England also apply to many other coal-bearing regions. In describing the general outlines of several coalfields, distinctions must be made between those of which the boundaries represent the original margins of deposition and those of which the boundaries are the result of earth-movements, supervening at a later date to the deposition of the coal strata, and those in which the margins are composed of newer strata.

Sequence.—From dealing with the general form and outline of a coalfield, we now pass to a study of the individual members which build it up—that is, to the character and arrangement of the strata associated with the seams of coal.

The strata of one coal-bearing formation may be similar to or differ from those of another. The same formation also frequently presents different phases of development from place to place, but generally a definite sequence can be established which may be taken as a type for a considerable area containing several coalfields, or the sequence may be quite local.

Thus, the development of the Carboniferous rocks of the coalfields of South Wales and Somersetshire differs from the succession met with in the coalfields of Central England, and this again departs in many respects from the Carboniferous sequence in Northumberland and Scotland.

These three coal-bearing regions, however, possess a common individuality—they are all of Carboniferous age, and may be regarded as representing one genus, each region being a separate species, including several varieties.

The framework of the genus is in each case the same, being made up of limestones, conglomerates, sandstones, shales, clays, and seams of coal; but these are differently arranged, and possess individual characters for each of the three regions.

The methods employed to determine the individuality of a coal region can be illustrated by the succession and character of the Coal-measure strata of the North Staffordshire Coalfield, a type species of the coalfields of Central England. This coalfield belongs to the Coal-measure division of the Carboniferous formation. The Coal-measures rest conformably on a coarse pebbly sandstone in the north-east, but are unconformably overlain by or faulted against the newer Triassic formation. While, therefore, the base of the Coal-measures is clearly defined by the coarse pebbly sandstone, the summit lies concealed beneath the cover of red Triassic rocks.

The thickness of the Coal-measure strata capable of investigation amounts to over 7,000 feet, clearly divisible, by the difference in character of the strata, into two divisions—a lower series, 5,000 feet thick, consisting of repeated alternations of grey sandstones and grey and black shales with numerous coal-seams and fireclays; and an upper series, consisting mainly of red sandstones and marls without coal-seams. The lower series can be further sub-divided into an inferior sub-group with few coals, and a superior sub-group with numerous seams of coal.

Neglecting the coal-seams, the strata belong to two very different types—the arenaceous group, including the sandstones and grits, and the argillaceous group of shales and clays. Owing to their superior hardness, the arenaceous strata generally occupy the elevated ground and give rise to conspicuous ridges, while the soft shales and clays form the gentle slopes or lie in the bottom of the valleys. The distinct surface contour of the sandstone ridges enables them to be picked out at the surface and followed for considerable distances. These features, indeed, are the chief landmarks of the geological surveyor mapping a coalfield. By laying down the position of these on his maps he is generally able to arrive at a fairly accurate knowledge of the main structure of any coalfield.

Variability both in thickness and lithological and physical characters is the salient feature of the Coal-measure sandstones of the North Staffordshire Coal-field, as, indeed, it is of the sandstones of all ages associated with seams of coal. Some of the sand-stones, however, maintain a nearly uniform thickness for considerable distances; others increase or diminish in certain definite directions (p. 25). In North Stafford-shire the tendency of the arenaceous rocks in the lower group is to increase in thickness northwards, and to dwindle away, or even die out entirely, to the south.

Their character changes both laterally and vertically. The lateral change often takes place abruptly, a homogeneous sandstone at one spot passing in a short distance into a group of sandstones, shaly sandstones, and shales, and then reverting back again to an undivided sandstone. Generally speaking, the beds of sandstone become coarser in texture in the direction in which they increase in thickness—that is, to the north. In a vertical direction it is observed that the sandstones towards the base of the lower group are coarser in texture than those higher up in the sequence. An increased coarseness in texture among sandstones is commonly taken to indicate that they were laid down in the proximity of land, but many marked exceptions are known.

The shales and clays are less liable to change in character and thickness than the sandstones. Three varieties of shales are met with. The commonest is a pale-bluish grey, laminated shale, more persistently developed in the upper part of the lower group. A jet black, closely-laminated variety also occurs in the lower portion, with or without an associated seam of coal. These shales are rare in the upper part, except in close association with seams of coal. Occasionally, and generally at definite horizons, though of no great lateral extension, bands of purple or reddish shales are developed in the lower series.

Like the shales, the clays vary in colour from black to grey, the latter being the most prevalent colour towards the summit of the lower group, where, however, certain bands assume a purple or reddish tinge.

From generalities we now pass to details, describing the character of any individual beds, from below upwards, which are of service to the miner or the geological surveyor.

The lower sub-group includes the strata between the coarse pebbly sandstone (First Grit or Farewell Rock of the miner) at the base of the Coal-measures and a coal known as the Winpenny. The general sequence in descending order is given in the following table:

	Thickness. Feet.	Thickness. Inches.
WINPENNY COAL - - -	—	—
Sandy beds - - -	170	0
BRICKKILN ROW COAL - - -	—	—
Sandy beds, pottery marl at base -	20	0
SILVER MINE COAL - - -	3	0
Sandy beds and shale - -	90	0
CANNEL ROW COAL - - -	3	0
Sandy beds and shale - -	90	0
THIN COALS - - - -	—	—
Sandstones, gannister and dark shales - - - -	520	0
Thin coal - - - -	1	8
Shales (marine fossils at base) -	130	0
CRABTREE OR FOUR-FEET COAL -	4	0
Pebbly grit and shale - -	61	0
Small coal - - - -	1	0
Dark shales - - -	59	0
LITTLE ROW OR TWO-FEET COAL -	2	3
Purple sandy shales - -	47	0
Dark shales - - -	100	0
COAL - - - - -	1	0
Purple shales - - -	5	0
Coarse pebbly sandstone (First Grit).		

The diagnostic characters of this sequence are the purple shales below the Little Row Coal, the pebbly grit below the Crabtree Coal, and the shales with marine fossils above it, the barren measures between this coal and the Cannel Row and the sandy beds forming the floor of the Winpenny Coal. This sequence holds good for some of the other Midland coalfields where the group is developed and a sufficient examination is made, while throughout the Midlands the roof shale of a coal similar in position and character to the Crabtree Coal invariably contains a marine fauna (p. 64).

The upper sub-group includes the strata between the Winpenny Coal and the red marls at the base of the upper division. A sub-division, based on the character of the coals, and to some extent on the nature of the strata and fossils, has been made at the horizon of the Ash Coal. Owing to a gradual increase in the collective thickness of the measures northwards, and a rapid diminution to the east, the thicknesses given in the following table represent only an approximate average thickness throughout the coalfield.

	Thickness. Feet.	Inches.
Shales, sandstones, and thin coals	150	0
GIN MINE, OR TWIST COAL	3	0
Shales, sandstones, thin coals, and ironstones	540	0
MOSS, OR MOSSFIELD COAL	5	0
Shales and sandstone (Yard Coal Rock)	220	0
YARD COAL	6	0
Shales and sandstones (Ten-Feet Rock).		
TEN-FEET COAL	7	0
Shales and sandstones	300	0
BOWLING ALLEY COAL	4	0
Shales, and some sandstone	80	0
HOLLY LANE COAL	4	0
Shales	75	0
HARD MINE COAL	4	0
Shale, sandstone (Bambury Rock)	350	0

	Thickness. Feet.	Inches.
Seven-Feet Bambury Coal - -	4	6
Shale and sandstone (Cockshead Rock) - - - -	150	0
Eight-Feet Bambury or Cockshead Coal - - - - -	8	0
Sandstone, shales, and thin coals -	260	0
Bullhurst Coal - - -	5	0

The chief components of this sub-group are the coals, but their character and development at any one horizon must, for the present, be regarded as varietal and not specific—that is to say, the coals belong to the North Staffordshire variety, though it may be found that some of them are correlative with coals occupying approximately the same position in the Midland sequence, for the best and most persistent coals throughout the Midlands are found to occur at about this horizon in the Upper Division of the Carboniferous rocks.

In the same manner the sandstone members are variable, though they are more persistently developed than in the upper sub-groups, as in other Midland coal-fields. The Ten-Feet Rock can be traced regularly throughout the district, but is apt to become split up by shale bands in some places. The two Bambury Rocks and the Yard Rock, though less conspicuous at the surface, are recognizable by the miner in most shaft sections. Each of these sandstones may rest directly on the coal from which it takes its name, or may be separated from it by several feet of shale and clay.

The beds of shale unquestionably form the truest index of horizons, but this arises, not from any distinctive lithological characters or the development of one kind of shale at any definite horizon, but from the fossils found in them (pp. 57-64).

The sequence of the strata in the upper sub-group—that is, between the Ash Coal and Bassey Mine Coal—is given in the following table :

	Thickness. Feet.	Inches.
Shales, thin limestones, and Black Band ironstones - - -	360	0
BASSEY MINE COAL - - -	2 to 6	0
Shales and clays - - -	45	0
PEACOCK COAL - - - -	2	10
Grey shales, sandstones, and thin coals - - - -	105	0
GREAT ROW COAL - - -	8	0
Clay, shales, ironstones, and thin coals - - - -	66	0
CANNEL ROW COAL - - -	5	0
Sandstones, shales, clays, and ironstones - - - -	390	0
BAY COAL - - - -	2	1
Rock - - - -	21	0
Shales and ironstones - -	30	0
KNOWLES OR WINGHAY COAL - -	6	0
Shale, clay, and sandstone - -	300	0
ASH OR ROWHURST COAL - -	6 to 10	0

Varietal rather than specific characters predominate in this sub-group. Thus, the number and value of the Black Band ironstones above the Bassey Mine distinguishes the North Staffordshire Coalfield from any other in the Midland Province, where they are either altogether absent or but feebly developed. The thin beds of limestone, again, though prevalent in the other coalfields towards the summit of the sub-group, are not always present. Below the Bassey Mine Coal the absence of thick-bedded and persistent sandstones may be noted.

Reviewing the lithological characters of the upper group as a whole, it will be seen that they are ill-defined and form uncertain, though locally useful, guides to the miner or geologist. The variability in the lithological character, thickness, and development of the sandstones and shales of the Pottery Coalfield is also characteristic of other coalfields, and has always to be taken into account. The correct identification of the local variety presented by the sequence is of much greater practical value than broad generalizations, based on what for the present must be regarded as imperfect knowledge.

Upper Division.—Three very distinct groups of strata, known in descending order as the Keele, Newcastle, and Etruria Marl groups, succeed the Lower Division. These three groups are typically developed in the North Staffordshire Coalfield, and, where not denuded, are met with in the other Midland coalfields, but are absent in the Southern and Northern coalfields. We have therefore to deal with specific and not generic characters.

The Etruria Marl Group consists of a great thickness of purple and red unstratified marls. Especially characteristic are some bands of green grit occurring at several horizons. These green grits are found to be largely made up of fragments of igneous material set in a matrix of the same nature, and containing pieces of other rocks. The Newcastle Group consists of grey sandstones and grey shales, with three or four thin seams of coal, while the Keele Group is composed of red sandstones and red marls, without any bands of green grit. Thin limestones with *Spirorbis* are common to the three groups.

Geological Structure.—The strata associated with the seams of coal were laid down approximately horizontal, but there are few coalfields in which the original position of the strata has been maintained. On the contrary, they are found lying at all angles, often nearly vertical, and in some cases the beds have been completely overturned, and the order in which they were originally deposited is reversed, the oldest being at the top and the newest at the bottom.

Earth pressure, and more rarely igneous intrusions, have been the chief cause in effecting the change from the original position.

In accommodating themselves to the pressure the beds were folded on each other, were fractured (faulted), and one portion depressed or elevated relatively to another.

Many coalfields, as we have stated, owe their shape to pressure exerted in one or more directions. The same pressure has a powerful effect on the internal structure of a coalfield by throwing the strata into folds, or causing them to break across and become faulted. Folding and faulting are sometimes beneficial, but more often adverse to coal-mining. They may, for instance, bring a seam of coal nearer to the surface than it would otherwise have been, or in other cases may have depressed a whole number of seams beyond reach. It is thus evident that a knowledge of the amount of folding and faulting to which a coalfield has been subjected is of great importance to the coal-miner.

Folds.—As an example of the general principles

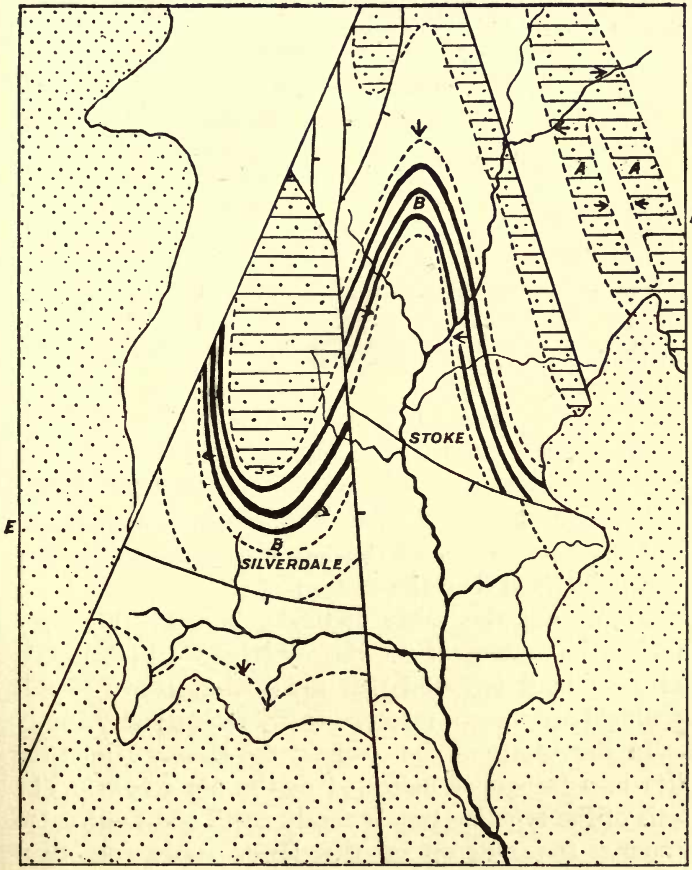


FIG. 3.—MAP TO ILLUSTRATE THE STRUCTURE OF AN EXPOSED COALFIELD.

In N.E., lower measures are line-stippled; chief coal-bearing strata shown by curved thick lines; newer formations by open stipple. Arrows indicate the direction of dip.

included in the study of the folding and faulting of a coalfield, the North Staffordshire Coalfield—represented, to some extent, diagrammatically in Fig. 3—will be taken, since a knowledge of the strata involved is essential.

If the bed of coarse, hard, pebbly sandstone (*A*, Fig. 3) be followed from the south-east to the north-west, it is found to be highly inclined to the west. Crossing the outcrop and going eastwards, the same sandstone crops out again, but now dips at a high angle to the east, reappearing again at the surface a little further east, with again a westerly dip. We have here an example of a narrow trough, or syncline, formed by the band of pebbly sandstone and enclosing the strata of the Lower Division of the Coal-measures in the centre of the trough. By tracing the sandstone round the trough the axis is found to trend west of north, and the western side of the basin is found to be more highly inclined than the eastern side.

Employing the same methods, but, in this case, taking the outcrop of the Bassey Mine Coal (*B*, Fig. 3) as a guide, it is found that the Coal-measures of this coalfield are thrown into two easily recognized folds.

In the centre of the coalfield the Bassey Mine Coal lies in a trough, as indicated by the dip arrows. The axis of the syncline trends nearly north and south. On tracing the outcrop of the lower coals and their associated sandstones round the trough, it will be found that the fold widens out in the south and comes together in the north, the seams rising one after another to the surface until the pebbly sandstone (*A*) lies at the surface. In the south, on the contrary, the seams get deeper and deeper.

North-east of Silverdale the Bassey Mine Coal, as shown by the arrows on the map, dips to the south-east; but inclines south-west, a little to the north-west of the same locality. This is an example of a ridge fold or anticline, as opposed to the trough fold or syncline, assumed by the Coal-measures in the central parts of the coalfield. The axis of the anticline trends a little north of east and rises to the north, so that lower and lower measures come to the surface in this direction, as they did in the syncline. Mining on the anticline shows that the seams are highly inclined near the surface, but flatten out after a certain depth on the

FIG. 4.—SECTION BETWEEN *E—F* ON FIG. 3, P. 99.

east and west flanks. The fold has thus the shape of an inverted vase.

The direction in which coal workings are carried on is greatly influenced by the foldings to which the strata have been subjected. Mining has naturally proceeded along or near the outcrop of the seams round the central syncline and western anticline, the deeper seams still remaining untouched towards the centre of the syncline, where the Keele Group is at the surface. In the anticlinal region, on the other hand, mining necessarily proceeds outwards to the east, south, and west, since the core of the fold is only occupied by the lowest measures, the Seven Feet Bambury Rock occupying the crest. The determination of the position of a bed, whether occupying the crest of an anticline or the centre of a syncline, is therefore of great importance.

The open folding in the coalfield described is common in the coalfields of Great Britain generally.

In Pembrokeshire, Pennsylvania, and Northern France earth-movement has resulted in far more complex crumpling of the strata, and surface observations may be altogether misleading as to the underground structure. A number of higher seams, for instance, may be greatly contorted at the centre of a compressed syncline of the vase-shaped structure, and be almost horizontal at great depths; on the other hand, in an inverted vase-shaped anticline, in a region of intense folding, the upper strata will be less crumpled and compressed than the lower, the amount of compression depending upon the restricted space to which the rocks had to accommodate themselves.

After the nature and amount of folding have been determined, the next point to be settled is the period or periods at which it took place.

In North Staffordshire there are some grounds for supposing that earth-movement was taking place during the deposition of the Coal-measures, since, to whatever extent the great variability in the thickness of the individual strata may be attributed to excess of material and the power of the transporting agency, there must have been depression to allow the sediments to accumulate. As there is no reason to suppose that the strata immediately below had been eroded into irregular hollows—in fact, the evidence rather points the other way—the irregular deposition of the sediments can reasonably be attributed, at least in part, to contemporaneous and local earth-movement.

To what extent such contemporaneous depression and elevation took place is unknown, but it is certain that the chief folding occurred after the deposition of the highest strata of the Keele Group, and that the crests of the folds were extensively denuded before the deposition of the succeeding rocks (Trias).

These newer strata lie almost horizontal, but in the south-east and south-west there is evidence that they were folded along the same lines as the Carboniferous rocks.

A later fold superimposed on an earlier one is known as a posthumous fold.

Faults.—Relief from pressure may be attained by folding alone, but is usually accompanied or followed by faulting.

Faults ('heaves,' 'troubles') may be normal or reverse—normal when newer beds have been depressed relatively to the older strata, and reverse when older beds have been thrust over newer. In a normal fault newer strata, in a reverse fault older strata, are found on the side to which the fault is inclined. Normal faulting occurs when strata have to accommodate themselves to increased space, reverse faulting when strata are compressed into a space less than their original horizontal extension.

North Staffordshire affords an excellent field for the study of normal faulting. The direction of the main or 'master' faults can be easily determined at the surface, and their throw approximately made out; but there are many small faults, the existence of which has only been made known by mining.

The type region, however, affords few examples of reverse faults, but they are of frequent occurrence in the Pembrokeshire Coalfield, in the coalfields of Northern France (p. 241), and in the anthracite fields of Pennsylvania (p. 270), and, in fact, in all regions where earth-movement has been excessive. They are common in many coalfields of Carboniferous age, and also in the Tertiary coalfields of America, Japan, and in other countries along the lines of maximum disturbance.

A fault may be often detected at the surface by its bringing together beds of different horizons in the sequence. Sometimes, though not frequently, the actual fracture is visible. The existence of a fault may also often be suspected from an abrupt discontinuity in the surface features.

The chief points to determine about a fault are the direction, the inclination, the amount of throw, and the age.

The fault shown to the east of Silverdale (Fig. 3, p. 99) brings a high horizon of the Keele Group on the east within a short distance of a much lower horizon of the same group on the west. Again, a little farther to the north, Keele beds are in contact with the Newcastle Group, and to the west of Stoke the Keele Group almost comes in contact with the Bassey Mine Coal. By connecting the various points at which these abnormal junctions of strata are seen, we obtain the north to south direction of the fault. This method of determining the direction of a fault requires that the points of observation shall not be far apart, as the same juxtaposition of beds may be brought about by another fault having a different direction.

The inclination of a fault plane from the vertical is termed the 'hade' or 'underlie.' Hade is, therefore, the complement of dip which is measured from the horizontal. Strictly speaking, a low hade fault is one highly inclined from the horizontal, while a vertical fault possesses no hade. Not infrequently, however, the term 'low-hading fault' is incorrectly applied to one which makes a high angle with the vertical, and should be called a high-hading fault. In coal-mining the general practice is to speak of a fault plane as being highly inclined or as having a high dip when the hade is low, and as being gently inclined or as having a low dip when the hade is great. The term 'hade' is seldom used by coal-miners, and it would be better to restrict it to

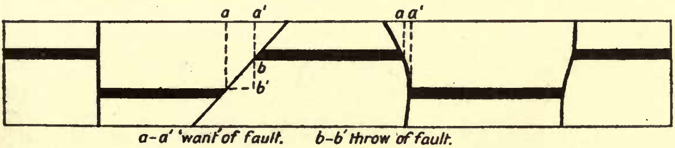


FIG. 5.—TO ILLUSTRATE VARIOUS HADES IN FAULTS.

metalliferous mining, and in coal-mining to state the amount of inclination in degrees measured from the horizontal, since this is the idea generally meant to be conveyed. The hade in the upper workings of a mine may differ from that in the lower workings (Fig. 5).

Fault planes are frequently curved, and if a distinct inclination of the fault in the direction of the working face were observable, the fault encountered may still be a downthrow with respect to the seam being worked, and the seam sought for lie at a lower level on the other side of the fault.

The amount of 'throw,' either downthrow or upthrow, is the vertical distance that a bed has been displaced. It may vary from a few inches to several hundred feet. Underground the amount of throw can be accurately measured, but at the surface an approximate estimate is usually all that can be attained.

The apparent horizontal displacement of beds by a fault as seen on the surface of the ground is termed the 'lateral shift' or 'shift,' the intervening space (a—a^1, Fig. 5) being known as the barren ground, or 'want' of the fault. The width of the barren ground varies with the hade and amount of throw. Many geological plans give the width of the 'want' by showing in separate colour the surface position, its position on the upthrow side, and on the downthrow side, as in the illustration on p. 105.

To the west of Stoke the fault previously mentioned as bringing Keele beds against the Bassey Mine Coal can be estimated at over 400 yards, while the fault shown to the west of Silverdale possesses a throw of over 700 yards in one locality.

In mine workings the amount of throw is usually proved by driving or boring across a fault until the seam is met with on the other side. The limited space for observation underground frequently renders it difficult to decide whether a fault is an upthrow or a downthrow, and an intimate knowledge of the local sequence is often needed to decide. For instance, a colliery working the Great Row Coal (p. 96), and following it under ground to the west of Stoke, encounters a fault bringing red marls against the coal. Boring up and down in these red marls proves them to be the red marls associated with the Red Mine Ironstone some distance above the Bassey Mine Coal. The fault is therefore a downthrow to the west.

In another case a fault met with in the workings in the Ash Coal (p. 96) brings this seam against shales containing the peculiar marine organisms only met with in the shales a few feet below the Gin Mine Coal. The approximate throw and its direction can therefore thus be determined.

After driving a short distance across a fault, a bed may be met with containing fossils, occurring in a band known in the proved coalfield to lie 300 feet above the seam being worked. Further, this fossiliferous band lies a few feet below a bed of sandstone. If, therefore, on continuing the cross-cut in the direction of dip this sandstone is met with, there is the strongest evidence for regarding the fault as being a downthrow in respect to the coal being worked, and that the throw approaches 300 feet. The seam sought for will in this case be found 300 feet below the level of the same seam at the working face where the fault was encountered.

A fossiliferous bed containing very distinctive fossils must be regarded as of rare occurrence. There may, however, be two beds, one above and one below a seam of coal, or they may both be above or both below the coal, the fossils of both being identical. These two fossiliferous bands will, however, afford good evidence of position in the sequence. If, for example, on crossing a fault a coal-seam is met with, and then by boring up and down, the coal is found to occupy a position between these two fossiliferous beds, or if both lie above or both below the coal, then the identity of the seam receives strong confirmation.

A distinctive fossiliferous bed in an area of normal or reverse faulting will satisfactorily prove both the character and amount of throw of a fault. Where two or more fossiliferous bands containing similar fossils are present, caution must be exercised in the determination of the amount of throw of a fault where both normal and reverse faults occur. In this case other beds will have to be taken into account, and their relative order of occurrence noted.

Joints.—The divisional planes called 'joints,' traversing a seam of coal and the associated strata at right angles to the bedding, are the result of mechanical strain due to pressure exerted subsequently to the deposition. They may be well developed in districts where folding and faulting are slight, and are invariably present in disturbed regions.

Joints in coal can be recognized by the bright glistening planes traversing the dull layers ('mineral charcoal') at right angles. A coal may be broken by two or more sets of joint planes, as in the Dicey Coal, but usually two sets of joints are more perfectly developed than the others. One set of joint planes, known as the 'face' or 'cleat,' is generally more prominently developed than the other plane, known as the 'end,' and extends for greater distances, as well as maintaining a general direction in any particular coalfield. In the North of England, for instance, the cleat runs approximately north and south.

The working of a coal is largely determined by the direction of the jointing. Main roads run parallel to the cleat, while 'bords' are driven at right angles to the cleat. In working coal on the 'long-wall' system, the face, when paralled to the cleat, is said to be 'on the end'; when perpendicular to the cleat, 'on the face'; and, when in another direction, the face is termed 'half-on.'

Fault Systems.—From dealing with individual faults we now pass to the study of faults as members of one or more systems.

In the type region two systems are displayed: in one system the faults have a meridional trend, in the other a latitudinal trend. In this region the two systems have been formed simultaneously, and since their throw is greatest in the strata of the Carboniferous formation, they must be mainly regarded as pre-Triassic in age, though displacement along both lines has taken place subsequently to the deposition of the unconformable covering strata.

In other coalfields it is possible to definitely prove that one system of faulting is older than the other, as in the Cumberland Coalfield.

Taking the Carboniferous coalfields of Europe as a whole, it may be said that the chief faults crossing them were formed, and had attained their maximum development, before the deposition of the Secondary formations, though subsequent movement has in some cases taken place along the same lines. Thus, in the type region the fault of 700 yards downthrow to the west, bounding the coalfield on the west, has nothing like the same amount of throw in the Trias. If it did possess this amount of throw, the upper and not the lower members of the system would be in contact with the Coal-measures. The east-and-west fault south of Stoke, with a downthrow south of nearly 90 yards, does not much exceed 50 yards throw in the Trias. Many more striking examples of the difference in the amount of throw of faults in the older rocks and in the overlying newer strata may be cited from other coal-fields. Generally speaking, the throw in the newer formations is less than in the older, but it may be equal in amount, and is sometimes greater.

Faulting, like folding, has in many cases been completed before the deposition of the newer strata, and because the younger formations are but little fractured, it does not hold that the older rocks upon which they rest will be found equally undisturbed. As a general rule, however, if the newer strata forming the surface formations are very much faulted, the older strata below will, in most cases, be found disturbed to a much greater extent.

Unconformity.—The geological structure of a coalfield may have been formed during the deposition of the coal-bearing strata, or it may have resulted from subsequent disturbance which has modified the original structure. It is often of importance to determine whether a period of movement and contemporaneous erosion on an extensive scale took place while the coal-bearing strata were being laid down, or whether the disturbance is of later date.

In North Staffordshire the Keele Group has been considered to be unconformable to the grey productive strata and to be of Permian age. Along the western boundary of the coalfield it was thought that in one locality the whole of the Newcastle Group, Etruria Marl Group, and the grey productive measures down to the Great Row Coal, had been denuded away before the Keele Group of sandstones and marls was deposited. In other words, considerably over 1,500 feet of Carboniferous strata were denuded before the deposition of the Keele Group commenced (p. 176).

A detailed survey of the coalfield shows, however, that the Keele Group invariably succeeds the Newcastle sandstones and marls, and whenever the Keele beds are in juxtaposition with any lower strata, they are found to have been brought into this position by faulting. The apparent unconformity along the western boundary would therefore be anomalous, and it appears still more striking when it is found that a short distance away the normal succession is present. Either the red strata along the western margin do not belong to the Keele Group, or if they do, then their present position is due to faulting, a conclusion strengthened by the knowledge that throughout the Midlands the Keele Group is invariably conformable to the Newcastle sandstones or their equivalent. Local knowledge and detailed mapping could alone have settled the conformable relationship of the Keele Group to the Coal-measures in North Staffordshire.

On dealing with concealed coalfields in a subsequent chapter, the determination of the relationship of the different divisions and groups of the Coal-measures will be seen to be of great practical importance. In several coalfields geologists are still debating as to what extent intercarboniferous movement and denudation have taken place.

Supply.—Estimates of the amount of available coal contained in a visible coalfield, only partially worked, must be regarded as merely approximations at the best. Allowances have to be made for the waste in working, the coal left to maintain shafts, for the support of buildings, railways, canals, and rivers, and for the barriers between royalties and properties. Again, in many coalfields the best seams lie towards the bottom of a great thickness of strata, and, except near their outcrops, lie beyond the depth at which it is at present considered practical to work them. In this country the maximum depth at which coal is considered workable is fixed at 4,000 feet, and on the Continent at about 4,900 feet.

The minimum thickness of a coal-seam that it will pay to work depends upon local circumstances, such as demand, price, and cost in working. In this country one foot is the minimum thickness adopted by the Royal Commissioners in their calculations in the Report on Coal Supply for 1905, and this is adopted in the description of the different British coalfields in succeeding chapters.

Many of the problems connected with the determination of the total available supply of any coalfield belong essentially to the province of the mining engineer, but the geologist may be called upon to estimate the depths of seams, and the direction and amount of throw of faults in unproved ground, together with other essentially geological problems.

In North Staffordshire, for example, the centre of the major syncline is occupied by the upper barren division of the Coal-measures. If the thickness of the groups making up this division can be ascertained and their outcrops laid down on a map, it will be possible to estimate the approximate depths to the workable seams under the area occupied by each of these groups. Mining has not proved the thickness of the groups, but this can be ascertained by an examination of the surface outcrops. Thus, a shaft commencing towards the summit of the Etruria Marl Group would reach the Bassey Mine Coal at a depth between 1,100 and 1,500 feet, and the Ash Coal between 1,800 and 2,400 feet. The same seams would be reached from 300 to 400 feet lower by a shaft starting near the summit of the Newcastle Group, while at least 700 feet must be added for the depths to these seams where the Keele Group passes under the Trias, as it does along the southern boundary of the coalfield. Many of the lower and best seams below the Ash Coal would therefore here exceed the limit of workable depth of 4,000 feet. In their estimation for 1905 the Royal Commissioners regarded the North Staffordshire coals to exist at workable depths half-way across the outcrop of the Keele Group.

Cover.—Where the Coal-measures of North Staffordshire sink below or are faulted against the Triassic strata, the visible coalfield passes into the category of a concealed coalfield. It is, however, convenient to discuss here the relation of the Triassic cover to the underlying Coal-measures.

As previously stated, this relationship is one of complete unconformity. At one place on the east of the coalfield the practically horizontal Triassic rocks rest on the folded, highly inclined, and greatly denuded Lower Carboniferous strata, at another place on the lower division of the Coal-measures, and at another on the Keele Group.

The red rocks were evidently deposited in hollows worn in the Carboniferous strata, thus levelling up the older inequalities, and in other cases were banked against the steep slopes of the highly inclined Carboniferous strata. In such cases as this the junction of the two sets of strata has the appearance of a fault. This is especially deceptive where the red marls of the

Upper Trias overlap and successively hide up the subdivisions of the Lower Trias until they abut against the Carboniferous strata. When in contact with the harder members of the Carboniferous rocks, the red marls, partly owing to slip, appear crumpled, and it may be erroneously considered that the junction of the newer and older strata is a fault having a throw equal in amount to the thickness of the Lower Trias.

When newer unconformable strata are faulted against older rocks, it is often impossible to calculate the amount of throw, since it is not always practicable to determine to what extent the juxtaposition is due to unconformity or to faulting. Thus, along the western margin of the North Staffordshire Coalfield the Trias at one spot is faulted against Middle Coal-measures and at another against the Keele Group, but this does not necessarily imply that the fault possesses a greater throw in the first case than in the latter. By neglecting to make allowances for unconformity faults bringing newer strata against the Carboniferous rocks have often been assigned a great magnitude of throw.

Calculations have often to be made as to the thickness of the Triassic rocks based on their inclination observable at the surface. This can be more or less satisfactorily done in the case of the Keuper Marls, in which bedding planes are on the whole clearly developed. In ascertaining the amount and direction of dip in the red sandstones and conglomerates which form the greater part of the Lower Trias, and which are usually met with around the margins of the English coalfields, care is necessary to distinguish between 'true' and 'false' bedding.

Irregular bedding, where the individual laminæ are not parallel to the surfaces of the greater bed in which they occur, but where the laminæ in one bed slope at very different angles, or in different directions, to those in the bed above or below, is a common characteristic of Triassic sandstones. False bedding on a larger scale occurs where one bed has been deposited on the sloping and worn surface of another.

Rough approximations as to the thickness of the Trias sandstones are all that can be usually made, and these are frequently very wide of the mark.

Geological Maps.—The outcrops of the more important strata, seams of coal, faults, and other geological information of use to the miner, are generally shown on the geological maps issued by most Governments. In this country these maps are drawn to a scale of one inch and six inches to the mile, but in foreign countries maps on the larger scale are rarely available. In many of the Colonies the scale adopted is usually less than one inch to the mile.

In the case of the one-inch maps of the Geological Survey of the United Kingdom, two editions are published for many of the coalfields. One of these shows the superficial deposits, and the other the solid rocks only. On a drift map the lines of visible outcrop of the solid formations are continued under the superficial deposits. The accuracy of these lines depends upon the amount of evidence available for determining the approximate position of the hidden strata.

CHAPTER IX

STUDY OF A CONCEALED COALFIELD

In Europe the visible coalfields have been to some extent worked out, and it is necessary for collieries of long standing to seek fresh areas outside the visible coalfields in which most of the coal has been leased. Explorations in search of coal are in consequence being extended into regions where coal-bearing strata are thought to exist beneath the newer formations.

Such explorations are to a great extent confined to the margins of the visible coalfields, but several attempts have been made, or are now in progress, to prove the existence of buried coalfields remote from any known workings. Especially is this the case in Central England, and also in the south-eastern counties. In Northern France, Belgium, and along the Franco-German border in Alsace-Lorraine, these experimental trials are also being conducted on a considerable scale.

In an exposed coalfield many of the geological problems to be solved are of a comparatively simple nature. From observations made at the surface with the help of the knowledge obtained in mining, the general structure of an exposed coalfield and many of its details can be satisfactorily determined.

In the choice of a site for a new sinking or boring in a concealed coalfield, and in the interpretation to be placed on the result obtained, the miner needs a wider knowledge of geology than in the case of an exposed coalfield.

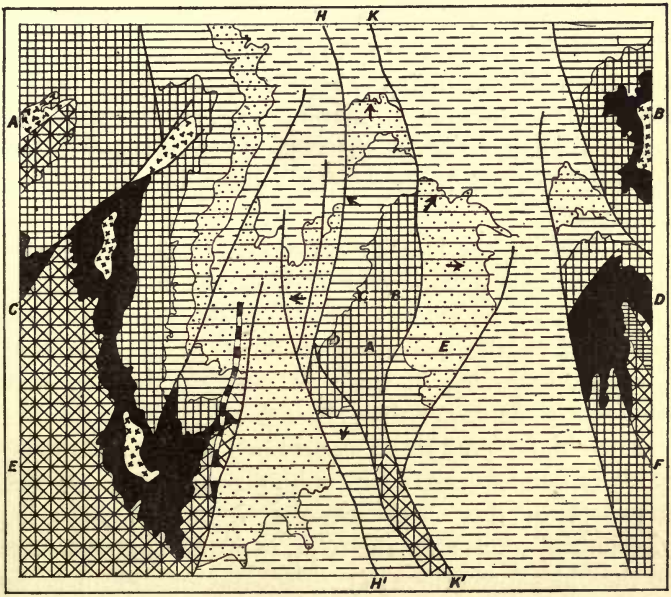


FIG. 6.—MAP TO ILLUSTRATE A CONCEALED COALFIELD.

An anticline of newer rocks overlying Coal-measures traverses the central area from north to south, coal-bearing strata crop out to the east and west.

As an example of a buried coalfield we take the area figured in Fig. 6. This represents, in diagrammatic and simplified form, the south-eastern half of the Midland coal-basin of Central England at a time when the

Coal-measures on the east and west were exposed at the surface much as they are now, but when denudation had not stripped the Triassic cover from off the South Staffordshire Coalfield.

Observations made at the surface and underground over the visible coalfields on the east and west indicate that the coal strata, consisting of the Middle and Upper Coal-measures (p. 172), slope inwards towards the centre of the region occupied by the newer formations. The inference is, therefore, drawn that the coal-seams cropping out in the east are prolonged underground, and rise again to the surface in the western coalfield.

In choosing the locality where it is best to commence an experimental boring or sinking, the miner will be guided by his experience gained in the marginal coal-fields and on the geological structure of the district as a whole, including in this case an acquaintance with the formations newer than those bearing the coal.

The chief points to be ascertained before exploration work is commenced in an unknown area are: (1) The sequence of the Coal-measures in the neighbouring visible coal-tracts; (2) the relation of the Coal-measures to the older formations; (3) the character and thickness of the covering strata and their relation to the productive measures.

Sequence.—The Coal-measure sequence in the exposed coalfields consists essentially of a lower division of grey strata (Middle Coal-measures) containing several workable seams of coal, and of an upper division of red strata with no workable seams. In this sequence definite positions can be fixed by the presence of thin bands or groups of strata possessing distinctive lithological or palæontological characters, which are found to be similar to those appertaining to the type region of North Staffordshire (p. 176), though the individual groups may differ to some extent from the type region. The relation of the red upper division of the Coal-measures to the lower grey division is found to be one of strict conformity. The grey measures are succeeded by the Etruria Marls, these by the representative of the Newcastle Group, and this in turn by the Keele Group. In no instance do the Keele or Newcastle beds rest directly on the grey measures, and when apparently found to do so the juxtaposition can be demonstrated to be a fault.

In tracing the Coal-measure strata from north to south, however, it is found that first the lower division ends off against rocks older than the Coal-measures; and again, farther south, that one group after another of the upper division terminates against a bank or ridge of older rocks, until, along the southern margins of the exposed coalfields, the Keele Group rests directly on strata of Cambrian age. This relation to the older strata must not be confounded with an unconformity within the Coal-measures sequence, but as an example of overlap, though, as is well known, there is a very great unconformity between the Coal-measures and the older rocks.

The covering up of a lower member of the Coal-measures by a higher may, in the same way, be regarded as an illustration of progressive overlap in the direction of an old shore line, and as indicating the gradual sinking of the basin and its successive infilling with the various Coal-measure sediments. In this case the uselessness of exploring for coal along the southern margins is obvious, since the latest strata deposited do not contain workable coals and the lower members will be absent.

The general sequence of the Coal-measures, as before stated, conforms to the North Staffordshire type; but while, except in thickness, there is the closest similarity between the three groups of the upper red division, the lower grey division presents several local variations, and that of the eastern coalfields is somewhat different to that of the western fields.

The Coal-measures in the three coalfields figured show a considerable diminution in thickness in comparison with the type region, and it is doubtful to what extent the lowest measures are developed, if they occur at all. In the north-eastern field the thickness of the Coal-measures amounts to about 1,500 feet, which has decreased to under 1,000 feet in the south-eastern field. In the western field the total thickness of productive measures does not amount to more than 500 feet.

The change in the thickness of the strata is accompanied by a change in the thickness and number of the seams. Thus in the north-eastern field the seams rarely exceed 7 feet in thickness, and about a dozen are workable. In the south two or more of these seams unite to form one bed of coal between 15 and 16 feet in thickness, but both this thick seam and the others rapidly deteriorate and become valueless towards the southern extremity of the coalfield. No thick seams occur in the western field.

One portion of the productive measures is scarcely recognizable from another by the lithological characters.

A group of red marls is commonly present above a persistent seam about 100 feet above the thick seam. A band of shale and ironstone with marine fossils occurs a short distance above a thin seam of coal in the west. We shall, however, consider that the information collected about these marine beds is too indefinite to enable them to be absolutely reliable guides, other than indicating the presence of the productive measures.

Associated with the grey measures in the north-eastern and western coalfields, a crystalline rock recognized as a basalt lies parallel with the bedding planes in the east and cuts across them in the west Fig. 7, p. 125). In the latter case there can be no doubt that the igneous rock is of later date than the Coal-measures, but the age of the igneous rock in the north-eastern coalfield must be determined by observation of its effect on the beds immediately above and below it. If it alters or bakes the beds above and those below, the intrusion is obviously of newer date; but if it only alters the underlying bed, it might be regarded as contemporaneous with the deposition of the strata. In many cases, however, it is difficult to detect any signs of alteration either by contemporaneous or intrusive igneous rocks. When the igneous rock is found in contact with a coal-seam, it may cause the coal to become anthracitized, coked, and in many cases render the seam worthless. It is of importance to the miner in this area to be able to distinguish between an igneous rock contemporaneous with or intrusive into the Coal-measures from one of much older date than the Carboniferous formations. Examples occur in the south-eastern coalfield where igneous rocks penetrate the pre-Carboniferous rocks, but had obviously consolidated and been denuded before the Coal-measures were deposited.

Carboniferous and post-Carboniferous igneous rocks generally present, except near their selvedge margins, crystals of felspar, augite, and olivine, in a more or less fresh state. In the pre-Carboniferous igneous rocks the olivine will be found to be much serpentinized, and several minerals—chlorite, calcite, and epidote—resulting from decomposition, are developed.

The central portions of an igneous rock will be, as a rule, less decomposed than the margins, and in the determination of the age by mineral composition comparisons should be made between the undecomposed portions.

In the eastern coalfield an igneous rock, termed diorite, perceptibly alters the Cambrian shales and quartzites when in contact with them; but while the Coal-measures rest on its eroded edges, they contain rounded pebbles of the igneous rock, and are not in the slightest degree disturbed or altered, even when in actual contact. This is clearly, then, an igneous rock of later date than the Cambrian, but older than the Coal-measures, or than the igneous material occasionally met with in the Coal-measures, and to which these vastly older igneous rocks bear some resemblance.

Igneous dykes may be nearly vertical, or they may cut across the strata at an oblique angle. In the former case it is obvious that a boring may give a very exaggerated thickness to a dyke, and also make a seam of coal beneath it appear to lie at a much greater depth from the surface than it really does.

Igneous material, when not a contemporaneous flow, may have come up along fissures as dykes or as necks.

The latter are vertical pipes filled with volcanic material, often descending to great depths, but are absent in the area under description, and in many other coalfields have been found to be far less common than is generally supposed. Indeed, they are rarely met with in the majority of European and American coalfields of Carboniferous age.

Relation to Older Formations.—In the type region of North Staffordshire the productive measures rest conformably on the sedimentary rocks belonging to the Lower Carboniferous formation. Wherever the base of the Coal-measures can be seen the bed immediately below is found to be a coarse pebbly sandstone, which can be proved by fossil evidence to belong to the Carboniferous formation—that is, to the same formation as that in which the coal occurs—but to have been deposited at an earlier stage of the Carboniferous period than that in which the coal-beds were formed.

The Coal-measures shown on the map (Fig. 6, p. 117) rest on very different rocks: those of the south-eastern coalfield lie on strata consisting of quartzitic grits, black shales, or igneous rocks, and those of the western coalfield on red sandstone. In the former case the fossils prove that the black shales and quartzites, though in some respects resembling the overlying Coal-measures, are of Cambrian age; in the western coalfield the fossils of the red sandstones show them to be of Devonian (or Old Red Sandstone) age (see table, p. 46). At another place the Coal-measures rest on limestones and shales containing Silurian fossils.

The older rocks appear either as promontories or as bays round which the sediments were unevenly deposited during the Coal-measure period. The surface of the older rocks when in contact with the Coal-measures is very irregular, but on the whole may be regarded as forming two uneven platforms—an eastern and a western one—on which the Coal-measure strata were accumulated. These platforms descend somewhat abruptly, to the east and west respectively, into the hollows now occupied by strata newer than the Coal-measures.

On examining the relation of these older to the newer strata, it will be found that, though in some cases the inclination of the older rocks may be the same as that of the Coal-measures, the older rocks have been greatly denuded and worn into hollows before the coal-bearing strata were deposited.

The exact underground configuration is indeterminable, but it will be observed that the strike of these older ridges trends roughly a little west of north. Along their margins underground explorations show that the coals deteriorate both in thickness and quality, and often become a worthless mixture of shale and coal. This deterioration is not, however, due to the character of the older rocks, but to their forming the margins of the basin in which the Coal-measures were deposited.

An examination of the older rock masses in the visible coalfields shows them to occur as irregular bosses, greatly denuded and worn into hollows before the deposition of the coal-bearing strata, but with a general trend a little west of north.

Cover.—From a consideration of the floor on which the coal-bearing strata were deposited we now pass to

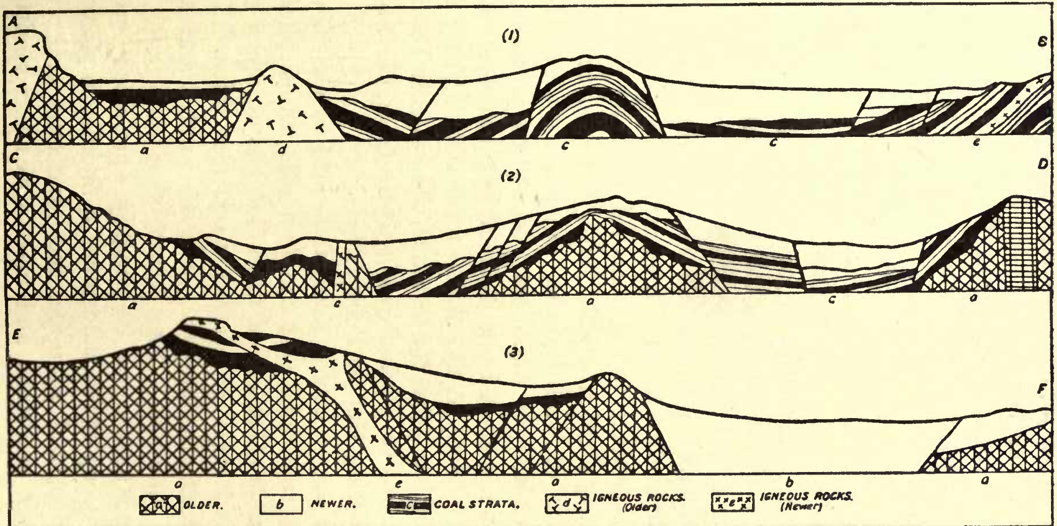


FIG. 7.—SECTION ACROSS MAP (FIG. 6). HORIZONTAL SCALE ABOUT $1\frac{1}{2}$ TIMES.

a study of the formations which cover them and conceal them from view.

The red rocks forming the first cover of the Coal-measures bear some resemblance to the Keele beds, the highest strata of the Coal-measures, with which, in fact, they were formerly grouped, but in North Staffordshire they are seen to be strongly unconformable to the Keele Series and to the Carboniferous generally (p. 113).

This unconformity is still more marked in the southern coalfields of the Midland Province, where the Triassic rocks are found resting on the folded and eroded edges of the Cambrian strata and Silurian formation, or on members of the Carboniferous series. Not infrequently they rest directly on a seam of coal, an occurrence demanding some attention, for if it is intended to work this seam of coal beneath the red rock covering, a great quantity of water may be expected, unless shut off from the seam by a layer of impermeable marl or shale belonging to the newer formation. In a colliery in Nottinghamshire, for instance, the valuable Top Hard Coal cannot be worked owing to its being close to the water-bearing Bunter Pebble Beds.

The cover of newer strata falls into two divisions—a lower sandstone and conglomerate series attaining a maximum thickness of 1,200 feet, and an upper sandstone and marl series over 1,000 feet thick. These thicknesses are, however, liable to sudden and unexpected variation. The lower sandstone and conglomerate series can be roughly subdivided into an inferior group of red sandstones, a middle conglomerate subdivision, and an upper red sandstone series. In the upper sandstone and marl series the sandstones occur below the marls.

The upper division as a whole overlaps the conglomerates and sandstones of the lower division, and in many places along the southern margin of the basin the marls of the upper division bury up by overlap the sandstones at the base. We have here an instance of the infilling of a basin during gradual depression, as in the case of the Upper Coal-measures, but with a totally different class of rocks. The juxtaposition of the upper marls with the sandstones and conglomerates of the lower division does not, therefore, necessarily imply the existence of a fault; neither does the junction of the marls with the Coal-measures or the older rocks, since the newer rocks may, as before mentioned (p. 113), have been banked against cliffs or deposited in hollows of the older rocks.

The red covering strata, it will be observed, are crossed by a number of curving faults trending nearly north, or a little east or west of north—that is, roughly, parallel to the trend of the older ridges.

The basin between the eastern and western coalfields is crossed by a gentle anticline, faintly but still discernible in the red rocks, and having a general north and south direction.

In the type region it was seen that the red rocks, newer than the Carboniferous, were similarly thrown into gentle folds, superimposed upon folds of greater intensity in the Coal-measures beneath, but having the same general direction.

A trough fold (syncline) or a ridge fold (anticline) in newer rocks may be based vertically on an older fold affecting the older strata beneath, no matter what amount of denudation the older strata may have been subjected to prior to the deposition of the younger strata. Posthumous folding, as this is called, may show itself by a corresponding arch or trough in the newer rocks, or by a thinning of the newer strata as they approach the axis of the fold. Sometimes, though rarely, a crest fold may be superimposed on a trough fold, or *vice versa*, or the axes of the newer folds may not exactly coincide in position or direction with the older folding, but may nevertheless indicate the general direction of the folding in the older ridges. In taking the direction of folding in the newer strata as

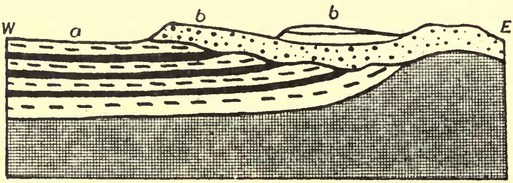


FIG. 8.—POSTHUMOUS FOLDING. FOLDS IN NEWER ROCKS (*b*); SUPERIMPOSED ON THE DENUDED FOLDS OF OLDER ROCKS (*a*).

an indication of that probably to be found in the older rocks, these differences must be kept in mind.

Folds, too, of small intensity and of open character often overlie folds of great complexity, of which the newer strata show no signs, especially in those cases where a long period of great earth-movement and denudation has supervened between the older and the superimposed but gentler crust movement.

In a greatly folded region, for instance, the structure may consist, on the whole, of a number of broad anticlines and synclines, but each broad anticline may be composed of smaller anticlines and synclines, the composite anticline forming what is called an anticlinorium;

similarly a broad syncline is frequently built up of lesser synclines and anticlines, the name synclinorium being applied to the composite synclinal fold. A simple anticline in the newer strata often overlies an anticlinorium, or a simple syncline overlies a synclinorium. A syncline in newer rocks may also overlie an anticlinorium in older strata, and *vice versa*. In all these cases folding in the newer strata, while it may outline that in the subjacent older rocks, may convey no signs of the complexity in the latter. For instance, the almost

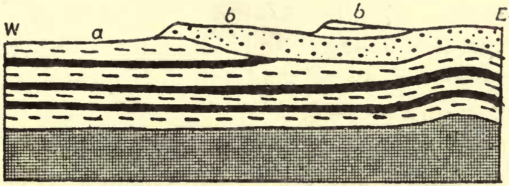


FIG. 9.—FOLDING IN NEWER ROCKS (*b*) CONTEMPORANEOUS WITH OLDER ROCKS (*a*).

horizontal Secondary rocks of the Somersetshire Coalfield rest on the much disturbed Coal-measures and older formations. Again, in northern France the Secondary rocks, but little disturbed, overlie intensely folded and over-thrusted Carboniferous strata.

On the other hand, folding seen at the surface in newer rocks may correspond with the folding of the rocks beneath, but the folding of both may be the result of one earth-movement.

Applying the doctrine, that folds in the newer strata roughly indicate the folds in the underlying older rocks to the area under discussion, we may regard the ridge-fold traversing the centre of the basin either as a posthumous fold of a simple character moulded on another and more ancient one of greater intensity, or as a recent fold in which the supposed Coal-measures below and the newer rocks have equally anticipated. In the first case, the older rocks may have been greatly denuded before the newer strata were laid down on them, and may exhibit much complexity of structure; in the latter case, the structure of the newer rocks will approximate that of the older strata.

Experience gained in the type region and in the visible coalfields on the east and west of the basin leads us to expect that the folding faintly discernible in the newer strata is of the posthumous type, and that the Coal-measures, if they exist at all beneath the red rocks, will be greatly denuded, and will display a considerable complexity in structure.

A consideration of general principles, therefore, fixes the most suitable site for an experimental trial somewhere in the area, between the two lines of structural faults H-H′ and K-K′ (Fig. 6, p. 117). A site directly on a line with the strike of the older rocks forming the ridge north of K′ will be avoided; nor will one be chosen towards the southern extremity of the fold, as experience in the exposed coalfields shows a marked deterioration in the quality of the seams to the south. We may expect the coal-bearing strata to have been in places greatly denuded, or even completely removed before the deposition of the newer rocks.

Exploration Work.—Suppose a site is chosen at A, towards the middle of the central ridge, where boring operations may be conveniently and advantageously commenced, and that the initial size of the hole is fixed according to the character of the strata it is expected will be found, and the depth to which it is intended to bore.

The boring starts in the lower red sandstones of the covering strata, which are found to be 300 feet in thickness. Grey measures are then entered, very similar in character to those of the productive series, but containing the fossil plant *Pecopteris arborescens*, unknown in the grey measures of the lower productive division, but characteristic of the Newcastle beds in the type region, and in the neighbouring exposed coalfields. The district, however, being little known, too much reliance will not be placed on this scanty palæontological evidence.

Beneath these grey measures red marls are met with containing the characteristic bands of green grits (Espley Rocks). There can now therefore be little hesitation in considering that the boring enters the Upper Coal-measures beneath the red rocks at the horizon of the Newcastle Group, and that the red marls and Espley Rocks represent the Etruria Marl Group of the type region. These are known to be conformable to the grey productive measures which are apparently entered at 800 feet from the surface.

A crystalline rock, evidently of igneous origin, is encountered after a few feet of grey measures have been penetrated. This rock agrees in the freshness of its minerals with the intrusive or contemporaneous rocks met with in the exposed coalfields. Moreover, slight, though perceptible, alteration of the beds with which it is in contact may be detected by the naked eye, and becomes still more obvious when the contact rocks are sliced and examined under the microscope.

The conclusion, therefore, is drawn that the boring tool has struck an igneous sheet or dyke contemporaneous with the Coal-measures or intrusive into them, and not one of the igneous rocks associated with the strata of pre-Carboniferous age. The boring is then continued through the igneous rocks, and again meets with Coal-measures and indications of coal-seams, and a coal 27 feet thick is found at a depth of 900 feet below the base of the red cover, and 300 feet below sea-level, the surface of the ground being 600 feet above OD. The Coal-measure strata passed through consist, in descending order, of Newcastle beds (100 feet), Etruria Marls (400 feet), productive measures down to the top of the thick coal (100 feet). Besides the thick coal, a seam from 4 to 6 feet in thickness is met with a few feet below the red Etruria Marls, or at 200 feet below sea-level.

The direction of inclination of the strata was not satisfactorily determined.

At another boring at B, to the north of A, the Triassic cover is proved to be 400 feet thick, the Newcastle Group is absent, and the Etruria Marls only 300 feet thick. The pre-Triassic denudation is therefore more excessive here than at the borehole A. The thin coal noticed in the boring at A as lying 100 feet above the thick coal was recognized at 700 feet from the surface or 100 feet below sea-level, again taking the surface elevation at 600 feet above OD. The strata evidently rise between A and B, or a fault with a downthrow between the two intervenes. Instead of the thick coal, four or five coals from 4 to 7 feet are met with, so that the region of the thick coal has been passed, and the boring thus shows the same splitting up northwards of the thick coal as takes place in the exposed coalfield.

In a boring at C, to the west of B, the surface of the ground is 800 feet above OD. The red Triassic sandstones prove to be 500 feet thick, and the Etruria Marls down to the first seam prove to be the same thickness as at B, and lying almost horizontally. The first coal, then, lies at sea-level, and unless there is faulting a fall of 100 feet must take place between C and B.

We will now suppose an attempt to be made to prove whether the thick coal extends as far west of A as the point D.

Beneath the Trias a few feet of Etruria Marls are met with, and below these the first thin seam of coal in the grey productive measures; then almost immediately pale grey shales, not unlike Coal-measures, are entered, but found to contain fragments of trilobites and other Silurian fossils. A few thin bands of limestone also, with Silurian fossils, are interstratified with the shales.

The site D, therefore, indicates the position of the underground continuation of the ridge of older rocks. Supposing boring explorations had commenced at D instead of at A, a check to future explorations in the district would doubtless have ensued, unless the knowledge obtainable in the visible coalfield on the east, where valuable seams are seen to lie within a few hundred yards of the older ridges, had been taken into account.

Several explorations in the Midlands have met with the fate of borehole D, and adverse conclusions have in many cases been drawn as to the value of considerable areas from the results obtained in a single unsuccessful boring.

The geologist cannot always be sure of choosing a successful site, but he can, in many instances, determine beforehand the difficulties to be faced, and indicate the areas in which exploration would be fruitless.

Suppose, for instance, it is resolved to prove the ground to the east of the fault K K′. A site will be selected some distance to the east of the fault, for not only may the coals be expected to be broken up near the fault, but these boundary faults are observed to correspond, both at the surface and in the boring at D, with the position of the older ridges. A site is therefore selected at E, at which it is expected the thick coal lies concealed.

The amount of throw of the fault K K′ is unknown, but the measures are known to dip eastwards, and at E a considerable thickness of the Upper Coal-measures may be expected to occur above the productive strata.

The Triassic cover is known to be about 600 feet thick, and, as the boring is situated towards the centre of the syncline between the anticlinal region and the exposed eastern coalfield, the amount of pre-Triassic denudation will not be so great as over the anticline. A considerable thickness of the upper barren measures may therefore be expected. In addition to the Trias covering, it would be advisable to allow for at least 600 feet of Keele strata, 300 feet of Newcastle beds, 400 feet of Etruria Marls, and about 100 feet more for the grey measures above the thick coal. Estimates must therefore be formed for a borehole of over 2,000 feet in depth, and, in choosing the initial size of the hole, due allowance made for the frequent casing that will be found necessary in passing through the great thickness of bad drilling ground to be expected in the Keele and Etruria Marl groups. The first 600 to 800 feet, being chiefly sandstones, will afford good drilling ground and need little casing, and this may be taken into account when fixing the original size of the hole. In a modern boring the size of the hole to begin with would not be less than 18 inches in diameter.

Red marls and sandstones with indeterminable plant remains and beds of conglomerate are met with beneath the Trias, and below these come more red marls containing a thin band of black limestone with Spirorbis. The sequence evidently agrees with the upper part of the Keele Group (Fig. 14, p. 181), and, unless there is faulting, some 700 feet of these rocks may be expected. Another band of limestone with Spirorbis is entered lower down, and the marls here contain several specimens of *Pecopteris arborescens.* At 670 feet below the base of the Trias, grey measures are entered, with a band of blue limestone containing Spirorbis in abundance, and evidently the band at the summit of the Newcastle Group.

It may now be calculated, assuming the complete absence of faults cutting out some of the measures, that a position about 700 feet above the grey productive strata has been reached, and that about 300 feet of good drilling ground, formed by the sandstones of the Newcastle Group, lie immediately ahead.

Below the Newcastle Group drilling can be confidently carried on until a considerable thickness of the Etruria Marls has been penetrated. On passing from the red ground of the Etruria Marls into grey strata, extra care will be taken to look for indications of the first thin seam of coal of the productive measures, and after that for the thick coal. If practicable, drilling operations will be conducted only during daylight.

A few borings put down along the margins of the known Midland coalfields will afford concrete examples of explorations in search of coal in unproved ground.

In South Staffordshire and Warwickshire the pre-Carboniferous floor consists of deep, broad hollows and narrow ridges. Post-Carboniferous denudation has removed a great thickness of the coal-bearing strata off the ridges, but has left them in various stages of denudation in the intervening hollows.

The pre-Carboniferous floor of the Leicestershire Coalfield presents a broad platform of Archæan rocks, with here and there rocky prominences and shallow depressions, with some deeper hollows. Denudation at the close of the Carboniferous period has unequally affected the Coal-measures and Lower Carboniferous strata deposited on this platform. In some cases denudation has removed all the Carboniferous rocks that were laid down; in others it has stripped off the Upper Carboniferous rocks, while in other places it has left them more or less intact.

Since the red rock cover in Leicestershire is generally at its thinnest and never at its maximum, the thickness of barren strata is seldom great enough to make the Coal-measures lie at an unprofitable depth beneath them. Many explorations have been made to prove the extent of the productive strata under the Trias, and are likely to be still further carried on. It is evident that no very clear forecast can be made as to whether Upper or Lower Carboniferous strata will be encountered, or if both divisions will be absent; but the two divisions of the Carboniferous system in the Midlands are as a whole so distinct (p. 51) that there should be no doubt as to whether a boring reaches an horizon high up or low down in the Carboniferous sequence.

One instance may be cited of a boring put down between Leicester and the exposed coalfield.

A colliery not far removed from the site of the proposed boring finds the Leicestershire coals of good quality and at shallow depths. It is therefore thought feasible that they may exist to the west under an area not far distant from the workings.

The boring is started in the red rocks of the Trias, and beneath these enters some red shales and sandstones containing marine fossils, but otherwise similar to the Etruria Marl Group. The marine fossils show that the Carboniferous strata do not belong to the Upper barren series, but whether they are part of the Lower Carboniferous, or are marine beds stained red but belonging to the productive measures, cannot be decided until the boring has been carried down a few feet lower. When this is done, strata containing Carboniferous Limestone fossils in abundance are encountered, and it is evident that the productive strata were either never deposited or have been completely denuded away.

Attempts to reach coal-seams in the neighbourhood of the Leicestershire Coalfield have been made along the valley of the Soar, where the proximity of a direct railway route to London naturally encourages exploration. In some of these borings igneous and sedimentary rocks older than the Carboniferous, in others Lower Carboniferous strata, have been met with.

Examples have now been given as to how the measures of a concealed coalfield in an anticlinal and synclinal region can be recognized. The Coal-measure sequence in its upper portion is of a clearly defined type, and the productive strata of no great thickness. The chief risk lies in the uncertainty of the position of the buried ridges of older rocks and the extent to which the productive measures have been denuded.

Instances will now be taken from the concealed coalfield lying to the east of the Pennine Chain, and where new pits in unknown ground have been or are being sunk.

Here the risk of meeting older rocks does not exist, but travelling eastwards from the exposed coalfield an ever-increasing thickness of cover has to be contemplated. Moreover, the grey productive measures here exceed 5,000 feet in thickness, and the Barnsley Coal, one of the most valuable seams, and therefore chiefly sought for, lies over 1,600 feet from the summit. Since the cover (at Haxey, Scarle, Selby, etc., p. 202) may exceed 1,600 feet, it is obviously of importance to be able to determine what horizon in the productive strata is met with immediately below the unconformable cover of newer rocks.

At Scarle boring, for instance, the red measures beneath 2,019 feet of Permian, Trias, Lias, and Superficial rocks have been considered to belong to the Upper barren measures, which are known to be conformable to the productive strata as in the type region. Supposing, therefore, that these red strata lie at the base of the Etruria Marls, then the Barnsley Coal can be calculated to be well over 3,000 feet below the surface.

Over large areas in the concealed coalfield the Etruria Marls have been denuded away, and a shaft or boring enters the productive measures immediately beneath the Permian strata. Again the question arises as to the horizon encountered, whether close to the

Barnsley Coal or a considerable distance above it. Estimates based on the inclination or depth to a particular seam in the nearest workings are apt to be misleading. In a recent case, for instance, a coal was calculated to be 2,700 feet below the surface, but was met with under 1,800 feet.

The productive strata above the Barnsley Coal contain few distinctive bands, though certain groups of strata can be recognized, and thick sandstones are better developed at one horizon than another, though lithologically similar to each other. These rocks serve as indicators of position when viewed on a general scale, but it is necessary for a considerable thickness of strata to be proved before a position can be safely decided upon.

In the Mansfield district a thick band of blue shale lying 650 feet above the Barnsley Coal (here recognized under the name of Top Hard) contains a rich and peculiar marine fauna (p. 63). Many of the fossils do not occur in any of the other marine beds above or below the Barnsley Coal. Here, then, we have a reliable index of position in a thick series of grey measures of peculiar lithological sameness throughout.

Attempts are now being made to prove the existence of a concealed coalfield beneath the Secondary rocks at Louth, in Lincolnshire, partly on the assumption that the generally easterly dip of the measures along the western margins of the proved Yorkshire Coalfield changes into an easterly rise in the neighbourhood of the Louth anticline visible in the Secondary formations, in which case the great thickness of cover may be counterbalanced by the chief seams of the productive measures being brought within workable depth by the easterly rise.

Here, again, it is of importance to be able to identify the horizon reached beneath the unconformable cover. The upper barren strata may be expected to retain their individuality, since they do so over the whole Midland province. A few feet of red strata without any fossil evidence would not, however, be a sufficient guide, since the grey productive measures at many horizons are stained red for a few feet by percolating water charged with iron salts derived from the overlying Permian and Triassic strata.

The Mansfield marine band would distinguish the strata above the Barnsley Coal, and may be expected to occur here, unless the measures have been denuded below this level, since there is good evidence to show that the marine incursion at this horizon has a wide distribution over the Midland Province. The bed, however, must not be confounded with one about 600 feet below the Barnsley Coal, and which bears a close resemblance to it, as well as containing some fossils in common, though not the peculiar forms. Fossils in the strata associated with the two bands are also not the same, and there is some difference in the lithological character of the strata above the Barnsley Coal from that below it. Possibly the lower part of the Coal-measure sequence, the Millstone Grits, or even the Lower Carboniferous rocks, may lie directly beneath the Secondary formations at Louth. The identification of these horizons will rest in part on fossil evidence and in part on lithological characters.

Explorations in search of Carboniferous coals now in progress in the south-eastern counties of England afford more complex problems. The probable structure of the buried coalfields is here based on the assumption that the east and west Mendip folding (p. 158) is continued beneath the Secondary rocks towards Dover, and thence undersea, to reappear at the surface in northern France. On the eastern or French side of the south-eastern coalfields the structure of the Carboniferous coal areas is one of great complexity. On the western or Somersetshire side, the proved coalfields also possess a somewhat intricate structure, and the several distinct coalfields are separated from each other by strata older than the coal-bearing rocks, and for the most part concealed under newer formations.

CHAPTER X

COALFIELDS OF GREAT BRITAIN

Introduction.—The coalfields of Great Britain range themselves in three separated areas, which may be termed the Southern, Midland, and Northern provinces. Each possesses distinctive structural and lithological features.

The Southern Province includes the coal-basins of South Wales, Forest of Dean, Somersetshire, and that of the concealed Dover Coalfield. East-and-west folds predominate; the chief lithological characteristic is the development of a thick massive sandstone (Pennant Sandstone) in the midst of the Coal-measures. Besides house and gas coals, one part of the province yields the highest class of steam coal, that of South Wales meeting with no rival in any part of the world.

The Midland Province contains the coalfields of Central England, in which a north-and-south fold—the Pennine Anticlinal—becomes the dominant structural feature, while the development of red Coal-measures overlying the chief coal-bearing strata forms the main lithological characteristic. The Midland Province furnishes best house coal, and also gas and steam coal.

In the Northern Province, which includes the coalfields of Cumberland, Durham, Northumberland, and Scotland, sheets and dykes of igneous material are of general occurrence, and numerous workable seams of coal, not found in the Midland and Southern provinces, make their appearance in the Carboniferous Limestone Series. The Northern Province is an area of gas coals, but also furnishes best house and steam coal.

Southern Province.

The east-and-west folds visible in the exposed coalfields of South Wales and Somerset, and partly proved to exist in the concealed coalfield in the south-east of England, belong to a system prevailing in the coalfields of Belgium and northern France, and known as the Hercynian. The folds of this system are the result of a powerful thrust, acting from the south, which buckled the Carboniferous strata into a number of crest and basin folds with their longer axes directed latitudinally.

Formations older than the Carboniferous were involved in the folding, and occur in the centres of the crest ridges; but the areas occupied by these older rocks, and the number and continuity of the folds formed, have not been determined owing to their lying concealed beneath the Secondary formations to the east of Somersetshire. The Hercynian folding was mainly completed before the deposition of the Trias, but movement in the same direction took place in early Mesozoic times, and there is reason to believe that some of the disturbances in South Wales were in operation at a late geological period.

The general succession of the Carboniferous formation for the Southern Province is as follows:

THE CARBONIFEROUS SEQUENCE IN THE SOUTH-WEST.

		Somerset and Bristol.	South Wales.
Coal-measures.	Upper	Radstock Series. Farrington Series.	Supra-Pennant Series (Swansea Measures).
	Middle	Pennant Sandstone Series.	Pennant Series.
	Lower	New Rock Series. Vobster Series.	Lower or Steam Coal Series.
		Millstone Grit Series.	
		Carboniferous Limestone Series.	

One of the characteristic features of the Coal-measure sequence in each district is the thick mass, seldom less than 1,000 feet, of the practically barren sandstones of the Pennant Series which separates a lower productive from an upper productive series.

South Wales Coalfield.—The Carboniferous strata of South Wales certainly lie in one of the elongated trough folds of the Hercynian earth-movement. Formations older than the Carboniferous form a nearly complete girdle round the coalfield, being only interrupted on the south by the sea of Carmarthen and Swansea Bays, and by rocks belonging to the Secondary system in South Glamorganshire.

The Carboniferous and older strata rise up to the south at very high angles, and frequently reach a vertical position ; but they rapidly flatten towards the centre of the trough, and then rise again to the north at a gentle angle.

The basin is interrupted towards the south by a sharp anticlinal fold running east and west, accompanied, along a portion of its course, by a fault (Moelgilau Fault), considered to possess a downthrow to the north of over 1,000 yards. At the Vale of Neath a fault trending north-east and south-west, and having a considerable downthrow to the north, towards the head of the valley, separates the north part of the coalfield into an eastern half, without anthracites, from a western half containing chiefly anthracite coals. West of the Neath Valley the main dislocations have a north-east and south-west trend, and thrust faults, increasing in number and intensity westwards, make their appearance and disguise the sequence of the strata. East of the Neath Valley the faults are normal, with a general north-west and south-east direction, excepting the east-and-west Moelgilau Fault.

Denudation, besides removing a vast amount of strata, has carved the Coal-measures into a series of deep valleys, along the sides of which the coal-seams crop out, and were formerly won by 'day levels.' These valleys either trend north-east and south-west, or else longitudinally.

The Carboniferous sequence has been divided as follows:

1. Coal-measures.
2. Millstone Grits.
3. Carboniferous Limestone.

The Coal-measures fall naturally into an Upper Coal Series, a Middle or Pennant Sandstone Series, and a Lower or Steam-coal Series. The Upper Series extends down to the Mynyddislwyn Seam in Monmouthshire, and to the Wernffraith and Swansea Four Feet Coal in Glamorganshire. The Middle Series, mainly massive sandstones, has the Brithdir Seam at its base in Monmouthshire, and the Rhondda No. 2, Ynysarwed or

Garn Swilt Seam in Glamorgan and Carmarthen. The Millstone Grit forms the base of the Lower Series.

This threefold subdivision is most marked in Monmouthshire, where the massive Pennant Sandstone separates a lower shale series from an upper shale and sandstone series. On proceeding to the west Pennant-like sandstones make their appearance towards the summit of the lower series, and attain a great thickness in western Glamorganshire and Carmarthenshire. At the same time the upper part of the Pennant Series includes several bands of shale and workable seams of coal west of the Vale of Neath. It therefore happens that a considerable diversity of opinion has arisen as to the precise correlation of the seams occurring east of the Neath trough with those on the west.

Much confusion has been caused by the different application of the terms Upper and Lower Pennant. In the Swansea and Neath districts the Upper Pennant Series is sometimes taken to include the measures above a seam known as the Wenallt, Esgryn, or Hughes Vein, lying towards the middle of the thick sandstones and shales between the Ynysarwed (Rhondda No. 2) Coal and the Wernffraith (Mynyddislwyn) Coal; while the term Lower Pennant is given to the sandstones and shales lying between the Wenallt and the Ynysarwed coals. Others restrict the use of the name Lower Pennant to the thick sandstones (Llynfi or Tormynydd rock) at the summit of the Lower or Steam Coal Series, while others, again, place these lower sandstones, together with the main mass of the Pennant Series up to the Wernffraith, in the Lower Pennant Group, including only the measures above the Wernffraith in the Upper Pennant Series.

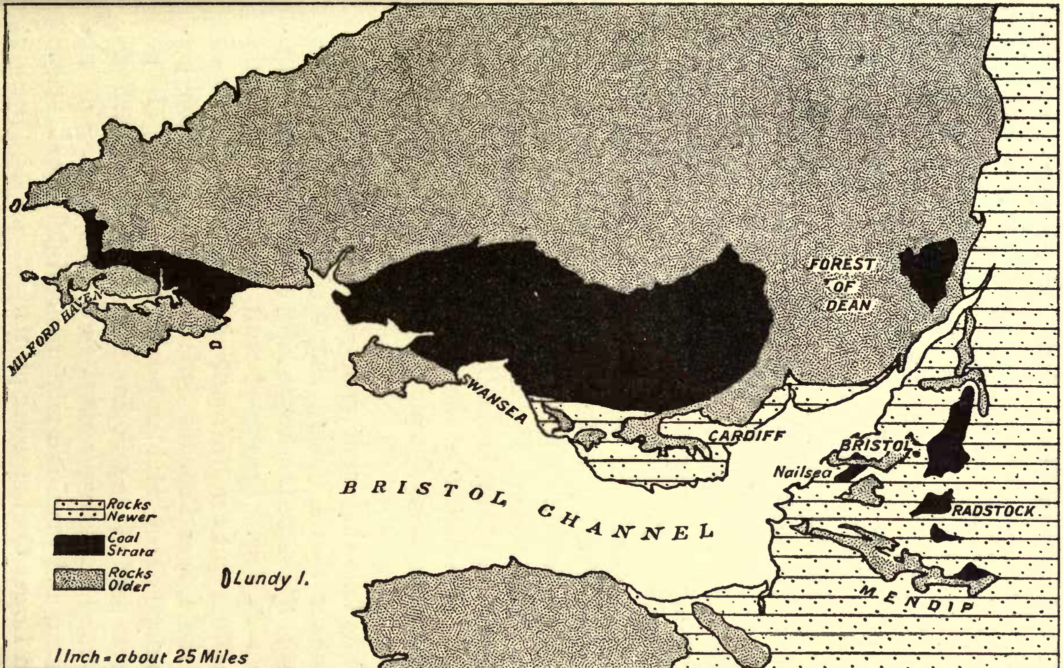


FIG. 10.—GEOLOGICAL MAP OF THE SOUTH WALES, FOREST OF DEAN, AND SOMERSETSHIRE COALFIELDS.

The Lower or Steam Coal Series is sometimes subdivided into a Lower or White Ash Series, and an Upper or Red Ash Series. In Monmouthshire the line of demarcation occurs about the horizon of the Elled Coal; in Glamorganshire, the base of the Red Ash Series is taken at the horizon of the Gorlwllyn Coal.

While the Coal-measure strata have received a threefold grouping, it is not generally admitted that these divisions correspond to the Upper, Middle, and Lower Coal-measures of other British coalfields. By Mr. Kidston, the Upper Series, on the plant evidence, is grouped with the lower portion of the highest measures of the Bristol and the Midland coalfields; the Lower Pennant Sandstone he regards as a transitional series between the Upper and Middle Coal-measures, the latter term being equivalent to the White Ash Series as defined above. The Lower Coal-measures he considers to be absent in South Wales.

The correlation of the South Welsh Coal-measures with those of other coalfields possesses little practical value.

The following fossil plants are abundant in the Upper Pennant Series (taking the Wernffraith Coal as the base): *Sphenopteris neuropteroides*, *Alethopteris serli*, *Sigillaria tesselata*. Associated with these are *Alethopteris lonchitica* and *Pecopteris miltoni*. The same plants occur in the Lower Pennant Series, but with a greater preponderance of Middle Coal-measure forms. In the lower part of the Steam Coal or White Ash Series *Sphenopteris neuropteroides* and *Alethopteris serli* are absent, and there is a mixture of Middle Coal-measure and Lower Coal-measure plants.

The Upper Series is chiefly distinguished by the presence of *Alethopteris serli* and *Sphenopteris neuropteroides*, but also by the occurrence of *Anthracomya phillipsi*, which, though rarely found low down in the Middle Series, is never met with in the Lower Coal Series between the Millstone Grit and Rhondda No. 2 Seam.

A band containing marine fossils occurs above the Bydyllog Coal in Monmouthshire, but no attempt has been made to trace this marine band over the coalfield. A marine band associated with the Rosser Veins of East Monmouthshire belongs in reality to the Millstone Grit Series.

Carbonicola robusta has been found only in connexion with the lowest seam (Gnapiog or Garw Coal). The roof of the Ras Las Coal contains *Naiadites carinata*, *N. modiolaris*, *N. quadrata*, *Anthracomya modiolaris*, and *A. williamsoni*.

Anthracomya adamsi has been recorded from the measures above the Big Coal of Rhymney, and above the Black Pins and Soap veins of Ebbw Vale. The zonal value of these fossils in South Wales remains to be proved, and the palæontology of the coalfield requires much further investigation before it can be said to possess much practical value.

The coals rarely exceed 10 feet in thickness, except when over-thrusting or folding locally brings two or more seams together.

In Pembrokeshire ten seams give a thickness of 28 feet of coal; in Carmarthen eighteen to thirty-four seams give from 47 to 83 feet of coal; in Glamorgan twenty-six to forty-eight seams give from 70 to 124 feet of coal; while in Monmouth eleven to twenty-one seams give 38 to 47 feet of coal.

The coals range in quality from bituminous to steam and anthracitic. The first-class Steam Coals—that is, coals used in the Royal Navy and obtained from collieries included in the Admiralty list—are, as is well known, of unrivalled quality. The net available quantity of steam coal is estimated at 8,013,082,381 tons, and of anthracite 6,310,292,214 tons, contained in seams exceeding one foot in thickness, and lying at a depth not exceeding 4,000 feet. The bituminous coals constitute 31 per cent., anthracites 22 per cent., and steam coals of all classes 47 per cent. of the total coal-supply of this field.

In following the seams across the coalfield, the carbon percentage shows a general progressive increase from east to west, and on crossing the Neath disturbance this anthracitization, or the reduction in volatile matter, proceeds westwards at a somewhat rapid pace, except along the southern outcrop, where the coals remain of a bituminous character, and the anthracitization takes place from south to north.

West of the Neath River the bituminous coals cover an area of 94 square miles in the south; to the north a belt of 61 square miles in extent contains steam coals; north of this, again, in an area of 77 square miles the upper seams are steam coals, and the lower seams anthracites, while yet farther north is an area of about 133 square miles, in which all the seams are anthracites.

As in other coalfields, the seams change their names from place to place, and in the more disturbed regions in Carmarthen and Pembroke the same coals are often known under one set of names on one side of a fault and under different names on the other side. In Monmouthshire the chief seams in the Lower Series, commencing at the lowest, are: Old (Lower Four Feet), Yard, Nine

Feet (Ras Las), Six Feet, Upper Four Feet, and Elled coals. In Glamorganshire, east of the Neath disturbance, the same seams are represented, but locally receive different names.

Crossing the Neath disturbance, the chief seams in the Lower Series on the north crop are known at Ystradgynlais and in the Aman Valley in descending order as: Pinchin, Red Vein, Stwrain, White Vein, Pancraig, Big or Stanllyd, and Brass. In the Gwendraeth Valley the seams receive different names, but the Gwendraeth Stanllyd is probably the same seam as the Aman Stanllyd or Big, and the Carway of Gwendraeth appears to represent the Red Vein of Ammanford.

On the south crop in Gower the seams receive names so different from those on the north crop and in East Glamorganshire that a comparison is at present impossible.

In Pembrokeshire the Timber Vein—an anthracite of the Lower Series—ranges from 2 to 10 feet in thickness.

In Monmouthshire the seam at the base of the Pennant Series is known as the Tillery Vein, and, excepting this coal, the Pennant contains no workable seams. In eastern Glamorganshire this seam is known as Rhondda No. 2, and continues under this name up to the Vale of Neath. West of this it is known as the Ynysarwed or Garn Swilt Vein. Seams of little importance in the Pennant to the east of the Vale of Neath increase in thickness to the west of this valley, and in ascending order are known as: Hughes, Graigola, Victoria, and Three Feet coals, and the other Swansea seams.

In the Upper Series of Monmouthshire the Mynyddislwyn Vein, a highly bituminous coal, has alone been worked. In eastern Glamorganshire seams known as the Llantwit coals make their appearance, while west of the Neath disturbance the Upper Series, with the Wernffraith (Four Feet or Church) Vein at the base, contains a workable seam known as Drews or Bryncôch Vein.

In Monmouthshire and eastern Glamorganshire the Pennant Sandstone, though a massive and water-bearing formation, does not assume the proportions it does on approaching the Vale of Neath and to the west, where some 4,500 feet of measures separate the Wernffraith from the more valuable seams of the Steam Coal Series. The following table shows the approximate thickness in feet of the strata separating the seams above the Hughes Vein :

Gnoll and Eaglesbush (east of Neath).	*Dyffryn and Skewen (west of Neath).*	*Llansamlet and Swansea.*
	Bryncöch,	Drews,
	450.	400.
	Wernffraith,	Four Feet or Church,
	430.	400.
Court Herbert,	Greenway of Dyffryn,	Five Feet or Penfilia,
370.	340.	360.
Greenway of Gnoll,	Graigola,	Six Feet or Great,
830.	810.	900.
Esgryn or Wenallt.	Hughes.	Hughes.

The thickness of the Pennant below the Hughes Vein down to the Ynysarwed amounts to about 1,330 feet. As a consequence of this great thickness of strata above the Steam Coal Series, the workings are at present divided between those of the Pennant and supra-Pennant seams of the Neath, Swansea, and Llanelly basins and those of the Steam Coal Series on the north and south of these basins. Attempts to reach the lower seams beneath the Pennant are now under contemplation, and it is on the winning of these deeper-seated coals in Glamorganshire and Carmarthenshire that the future extension of the coalfield greatly depends.

It will be seen from the map (Fig. 10, p. 147) that the newer rocks which border the coalfield to the west of Cardiff surround ridges of rocks older than Coal-measures, and it is therefore fruitless to search for coal-seams under these newer formations.

In St. Bride's Bay the quantity of undersea coal is estimated at 53,360,000 tons, and that in Carmarthen Bay at 329,664,000 tons. These amounts represent the estimated available supply under areas of which at present nothing is known.

Forest of Dean Coalfield.—This coalfield is considered to be an outlier of the South Wales Coalfield, from which it is separated by a broad expanse of Old Red Sandstone, broken through by the Silurian anticlinal inlier of Usk.

The Dean Forest Coalfield forms an example of a perfect coal-basin, with its margins completely defined by the massive conglomerate termed Millstone Grit, which succeeds the Carboniferous Limestone Series.

The Coal-measures occupy an area of thirty-four square miles, and are separated into three divisions known in descending order as: (1) Upper or Woorgreens Series, with two thin workable coals; (2) Middle

Series, containing eight seams over one foot in thickness; and (3) Lower Series, with six seams over one foot in thickness, containing the well-known Coleford Highdelf Coal. A sandstone 'horse,' two miles in length and from 170 to 340 yards wide, breaks the continuity of this seam.

The total thickness of measures amounts to 2,765 feet.

A thick mass of sandstone, comparable with the Pennant Sandstone of South Wales, lies between the Coleford Highdelf and a seam known as the Churchway Highdelf. It contains large quantities of water, and forms one of the chief obstacles in pits sunk to the 'deep.'

The Coal-measures of this coalfield are noted for the number and excellent preservation of the fossil plants, specimens of *Pecopteris arborescens* and *Alethopteris serli* being particularly abundant. The whole assemblage of plants is considered to indicate a somewhat high position in the Coal-measure sequence of the Southern Province.

The seams at present worked are applicable to household, manufacturing and gas-making purposes, but it is expected that the undeveloped seams to the 'deep' will furnish second-class steam coal.

Deducting loss in working, etc., the total available supply remaining unworked is estimated at 258,533,447 tons. The average output amounts to a little under one million tons per annum.

Somerset and Gloucestershire Coalfields.—The detached areas constituting these coalfields differ essentially from those of South Wales and the Forest of Dean, of which the latter forms an outlier of the

FIG. 11.—GEOLOGICAL MAP OF THE EXPOSED AND CONCEALED COALFIELDS OF GLOUCESTERSHIRE AND SOMERSETSHIRE (AFTER G. E. J. MCMURTRIE).

larger South Wales coal-basin. The limits of the Welsh basin and those of the Forest of Dean are formed by older rocks; the boundaries of the exposed areas of the Somersetshire and Gloucestershire coalfields are surrounded entirely, or almost entirely, by strata newer than the Carboniferous; indeed, mining is being chiefly carried on under these newer formations, and four-fifths of the coalfields belong to the concealed class.

Including the exposed and concealed areas, these detached coal-basins may be grouped as: (1) The southern or Nailsea area, with twelve seams, giving a total thickness of 23 feet of coal; (2) the central area, containing thirty-five seams, yielding an average of 65 feet of coal; (3) the northern area, with seven seams, giving 10 feet of coal. The total available quantity of coal from all three, at depths not exceeding 4,000 feet, is estimated at 4,198,301,099 tons.

The Coal-measures are divided into two portions by a thick bedded sandstone termed Pennant Rock, which is considered to be the equivalent of the Pennant Sandstone of South Wales.

The measures above the Pennant Rock are further subdivided into two groups. The upper or Radstock Group contains in ascending order the Bull, Little Slyving, Slyving, Middle and Great seams, averaging from 1 foot 2 inches to 2 feet 2 inches in thickness; the group attains a thickness of 1,000 feet, and is separated by about 150 feet of red shale from the lower group. The lower or Farrington Group, about 700 feet in thickness, contains about six or eight seams, but usually not more than four or five are workable, these in ascending order being the Church-Close, Middle, Farrington Top, and Cathedral seams, varying in thickness from 2 feet to 3 feet 10 inches.

The Pennant Rock, from 2,000 to 2,500 feet thick, contains a few thin seams averaging a total of 5 feet of coal. One of these, known as the Graces Coal (3 feet thick), has been worked in the Nailsea area, but on the whole the Pennant must be regarded as barren and heavily watered ground.

The strata below the Pennant are divided into an upper Kingswood or New Rock Series, and a lower Vobster Series. They attain a thickness of from 3,000 to 3,500 feet in the Nettle Bridge Valley, and about 2,000 feet in the Bristol area. The New Rock Series is by some regarded as the equivalent of the Lower Pennant of South Wales—that is, of the strata lying between the base of the main mass of Pennant Sandstone in Glamorgan and Monmouth, and the top of the White Ash Series. This correlation makes the Vobster Series equivalent to the White Ash or the lower portion of the Steam Coal Series of South Wales. This comparison is based on the distribution of fossil plants.

The New Rock Series contains several seams from 6 inches to 5 feet in thickness, but a considerable number are unworkable. The coals of the Vobster Series are the best, and have been extensively worked, some of them yielding smithy and coking coals of great purity.

Owing to the isolation of the various coal areas, and to the adoption of different names for the same seam, it is impossible to correlate the coals of one district with those of another. In the southern coalfield the seams of the New Rock Series correspond to those of Kingswood and Bitton, and those of the Ashton

Vale of the Bristol coalfields to those of the Vobster Series of Somersetshire. In the northern coalfield the seams appear to rapidly diminish in number, until at Yate and near Cromhall twenty-nine seams of the Kingswood Colliery are represented by only four seams at Yate and by two seams at Cromhall.

The coals of the Radstock Series belong to the bituminous class, and are suitable for household use and also for gas manufacture. The Farrington Series contains some bituminous coals, while others are adapted for steam raising. In the Kingswood and Vobster Series the Ashton Great Seam gives a very hard and good coke; the Kingswood or Bedminster Great Seam furnishes a good house coal, and to a great extent supplies the Bristol market.

In 1906 the output for the entire area amounted to 2,532,266 tons, that from the Gloucestershire Coalfield being over 400,000 tons in excess of the yield from Somersetshire, but an increased output from the Somersetshire Coalfield for use on ocean-going steamers is expected.

The Somersetshire and Gloucestershire coalfields may be collectively regarded as an isolated basin surrounded by an uprise of Lower Carboniferous and Devonian rocks, the outcrops of which are mainly concealed beneath the Secondary formations. At Kingswood an anticline, accompanied by an east-and-west overlap fault, separates the Somersetshire Coalfield on the south from the Bristol and Gloucestershire coalfields on the north. On the south and south-west the east-and-west Mendip anticline—or, more strictly speaking, anticlinorium, for the anticline is in reality built up of several folds—terminates the known coalfield by raising to the surface rocks of Lower Carboniferous and Devonian ages.

In the northern coalfield the chief dislocations are four longitudinal faults traversing the district from north to south, and throwing up the measures to the west. In the southern or Somersetshire coalfields faults are more numerous, and on approaching the Mendip Hills the strata become overfolded and faulted to such an extent that the same seams may be passed through two or three times in succession in a single shaft. Along the Nettle Bridge Valley the Lower Coal-measures are completely inverted. Overthrust faults, with hades

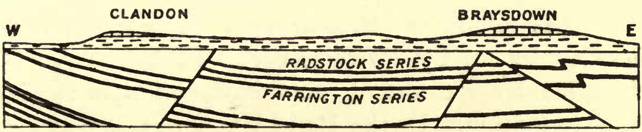


FIG. 12.—SECTION ACROSS THE RADSTOCK COALFIELD SHOWING THE RADSTOCK OVERLAP FAULT (ON THE RIGHT) AND THE UNCONFORMABLE MESOZOIC COVER.

approaching horizontality, are also met with in the Radstock coal-basin four miles north of the Mendip Hills. The overlap of one of these faults, known as the Radstock overlap fault, amounts to 140 yards in the Great Vein Coal and to 300 yards in the Bull Vein Coal, 30 yards below the Great Vein.

The thickness of a seam of coal may be thus doubled or trebled by a series of overlap faults piling up the coal.

Most of the folding and faulting in this district was completed before the deposition of the Secondary rocks, which rest almost horizontally on the tilted, dislocated, and denuded edges of the Carboniferous strata (Fig. 12,

p. 159). The Secondary rocks, therefore, betray few or no signs of the complicated structure found in the Coal-measures, bearing in this respect a close analogy to the coalfields of northern France (Fig. 20, p. 241). By some authorities the lateral movement of the Radstock overlap fault is considered to have commenced before the deposition of the upper seams, and to be in part of inter-Carboniferous age.

Fossils prove of little service in the determination of exact horizons in this area. Mollusca are of rare occurrence in the Coal-measures, though a marine band, rich in these fossils, is known to occur at the base of the Lower Coal-measures in one locality. Marine bands have been found in other areas, though the horizons have not as yet been determined. The plants, on the other hand, are extremely abundant, and have received much attention. In the Radstock Series some of the commonest plants are *Pecopteris arborescens*, *P. miltoni*, *P. oreopteridea*, *P. unita*, *Alethopteris serli*, *Sigillaria tesselata*. All these forms are found in the Farrington Series, and are also met with below the Pennant Rock, but in much less abundance. *Alethopteris serli* occurs in great profusion in the Radstock measures, but appears to be absent in the Vobster Series. On the other hand, *Alethopteris lonchitica* is abundant in the Vobster Series, but is unknown in the Radstock Series.

Colliery operations and the general disposition of the visible coalfields show that the Carboniferous rocks of Gloucestershire and Somersetshire occur in isolated basins formed by earth-movements later in age than the Carboniferous formation, but newer than the Trias.

The Secondary formations, as stated, bury up, and in many cases conceal, the extent of the separate basins, though mining has to a considerable degree revealed the structure, and more or less accurately determined their hidden boundaries. The overlying newer foundations do not attain to any great thickness within the coal-basins, but outside the basins the different members ot the Mesozoic formation are estimated to reach a united maximum thickness of 3,420 feet, distributed as follows: Trias, 2,000 feet; Rhætic, 50 feet; Lias, 1,200 feet; Inferior Oolite, 170 feet.

Of the partially exposed coalfields, that of the Nailsea coal-basin has an unknown extension to the south under the Triassic red marls and alluvial marshes, but, as the seams in the Nailsea district vary in quality from place to place, the value of this unproved area remains problematical. A buried coalfield also lies beneath the Severn River.

Since the Mendip anticline was raised after the deposition of the Coal-measures, it is deemed probable that a coalfield lies to the south and south-east under the Secondary rocks. A boring at Witham passed through 287 feet of Oxford Clay (considered by some to be Lias), and 29 feet of strata doubtfully referred to the Cornbrash, and was continued to a depth of 600 feet without meeting any signs of Coal-measures. Another boring was put down in the early part of last century at Compton Dundon. It commenced in Keuper Marl, and was continued without success down to a depth of 519 feet.

Objections to the suggested existence of coal to the south of the Mendips have been brought forward. On the southern slopes of the Mendip Hills the newer formations rest directly on Lower Carboniferous or older strata, and it is therefore inferred that the same relation will be found farther south. This argument is based on an erroneous conception of the great unconformity between the Coal-measures and newer formations, the latter being often in direct contact with the Carboniferous Limestone or older strata in the near neighbourhood of the rich coal-bearing strata in the proved coal-basins to the north of the Mendips. Adverse opinions on the existence of coal to the south have also been based on the supposition that the unproductive Culm measures of Devonshire are the southern equivalent of the Somersetshire productive strata.

These opinions receive considerable support from the discovery in the Culm measures of Devon and Cornwall of such distinctly Upper Carboniferous plants as *Alethopteris serli*, *A. lonchitica*, *Mariopteris muricata*, *Lepidodendron obovatum*, and *Sigillaria tesselata*. The occurrence of these fossils favours the opinion that the upper barren Culm measures are equivalent to the Middle Coal-measures of other coalfields, and that they do not, as for a long time believed, represent the Lower Carboniferous. The Upper Carboniferous age of the Culm measures does not, however, preclude the existence to the south of the Mendips of the Farrington and Radstock series, which, on plant evidence, are considered to be of Upper Coal-measure age.

Besides plants, the Upper Carboniferous rocks of Devon and Cornwall contain *Gastrioceras carbonarium*, *G. listeri*, *Dimorphoceras gilbertsoni*, and *Pterinopecten papyraceus*, but two of these fossils have a wide vertical range among the Carboniferous rocks (p. 61).

Some geologists consider that the cover of the coal-bearing strata will in many places be too thick to allow the coals beneath to be at workable depths, but positive data on this subject are not available, and possibly the maximum thickness of 3,420 feet, as previously given (p. 161), may be found excessive.

Because the upper Culm measures in Cornwall and Devonshire are barren of workable seams, it does not necessarily follow that the northerly extension of these measures into Somersetshire, south of the Mendip Hills, will also be barren.

There remains the possibility of hidden coalfields to the west of the Bristol area. At Burford a boring proved 226 feet of Coal-measures under a cover of 1,184 feet of Secondary rocks, including Trias (467 feet), Lias (627 feet), and Oolite (90 feet). Coal-measures have also been proved at Batsford. Again, farther south at Swindon, a boring, 736 feet in depth, ended in the Forest Marble, while another at Wytham, 633 feet deep, was finished in Lias, after passing through 185 feet of this formation. Borings near Northampton, to the north-east of Batsford, prove the absence of Coal-measures, since the Secondary rocks were found resting on the Lower Carboniferous strata.

If the irregular pre-Carboniferous floor of the Midland Province (p. 136) and the denuded and consequent isolated character of the Gloucestershire and Somersetshire coalfields be kept in mind, it is evident that these few borings, situated at wide intervals, do not permit of any definite conclusions being drawn as to the existence of concealed coalfields to the north of the prolongation of the Mendip anticline, or to the south of the Staffordshire and Warwickshire axes. This broad region indeed affords an illustration of a possibly concealed coalfield, where the methods adopted to prove its existence, given in a previous chapter, may be applied. The failure of two or three borings to prove productive measures does not imply that these do not exist even at a short distance from a boring, in which rocks older than the coal-bearing strata are found immediately beneath newer rocks.

South-Eastern England.—The Hercynian folds in the Palæozoic rocks cease to be visible in the southern counties owing to the on-coming of the Secondary and Tertiary formations. These, however, have been affected by folding later than the Hercynian, but having the same general direction. According to Godwin Austen's theory it might therefore be reasonably expected that folded Carboniferous rocks lay beneath the Secondary formations between Somerset and Kent.

The first attempt to demonstrate the correctness of Godwin Austen's view was by a boring commenced in 1872 at Netherfield, near Battle. The boring finished in Oxford Clay at a depth of 1,905 feet, the formations passed through being Purbeck (177 feet), Portland (115 feet), Kimmeridge Clay (1,273 feet), Corallian (241 feet), and Oxford Clay (99 feet).

A subsequent boring at Meux's Brewery, in the Tottenham Court Road, proved that the Secondary rocks here rested on the Devonian. It is generally assumed that in the borings at Streatham and Richmond rocks older than the Carboniferous were entered. These three borings therefore proved that no buried coalfields underlie the Thames basin in Middlesex and this part of Surrey.

In 1886 a boring was commenced at Shakespeare's

Cliff, Dover, and was successful in striking Coal-measures at a depth of 1,100 feet 6 inches. The boring was continued to a depth of 2,330 feet, passing through thirteen coal-seams calculated to be from 15 inches to 4 feet in thickness.

The plants obtained between 1,819 feet and 2,274 feet depth are such as have a wide range in the Coal-measures, consisting of *Neuropteris rarinervis*, *N. tenuifolia*, *Lepidodendron aculeatum*, *L. lycopodioides*, *Stigmaria ficoides*, *Carpolithes corculum*, and *Lepidostrobus variabilis*. From the absence of *Pecopteris arborescens* it may, however, be concluded that the Upper Coal-measures are absent.

Following the successful trial at Dover, other attempts to prove the extent of the coalfield have been made or are in progress. At Ropersole, eight miles north-west of Dover, a boring reached Coal-measures under a thickness of 1,580 feet of Secondary rocks; another boring at Ellinge, four miles north-west of Dover, also entered Coal-measures under 1,685 feet of Secondary rocks; while a third boring at Brabourne met with rocks older than the Coal-measures, and so limits the coalfield in a south-westerly direction.

The coals are considered to belong to the Somerset type, and are of a bituminous character.

The nearest proved coalfields to Kent occur in Belgium and northern France. In Belgium three synclinal folds trending east-and-west contain Carboniferous rocks. Bordering the Ardennes on the south lies the basin of Dinant, occupied by Lower Carboniferous rocks. The Dinant syncline is succeeded to the north by the Crête du Condros, an anticline composed of Devonian and Silurian. To this there succeeds the syncline of the Liége Coalfield, which has been traced westwards into the Pas de Calais and Bas Boulonnais. The Liége syncline is again succeeded to the north by a buried ridge of older rocks, forming the southern boundary of the recently discovered coalfield of the Dutch Limburg.

The Kent Coalfield is considered to be a prolongation eastward of the middle or Liége basin, of which the structure has been proved to be even more complex than that of the Pembroke Coalfield. Whether the Kent Coalfield possesses a similar intricate structure will be shortly proved at Dover Colliery, where the shafts have now reached coal-seams.

The question of the possibility of there being concealed coalfields north of the Thames Valley has been partly answered by the results of borings at Harwich, Culford, Stutton, Ware, and Turnford, in all of which the Secondary formations rest directly on rocks older than the Carboniferous; but it is considered that at Gayton, in Northamptonshire, Lower Carboniferous rocks immediately underlie the newer formations; while at Burford and Batsford, in Gloucestershire, the Secondary rocks rest on Coal-measures.

In south-eastern England the problems not as yet definitely solved are: (1) the horizons attained in the present explorations; (2) the thickness of cover at various points; (3) the probable areas of the concealed coal-basins and their structure.

Borings and shaft-sinkings have certainly proved the existence of a buried coalfield in the south-eastern counties. Some of the recent experimental borings have to some extent fixed the probable boundaries of one of the coal-basins. If, however, the illustration showing the exposed and concealed Somersetshire and Gloucestershire Coalfield be studied, it will be readily understood that a considerable number of borings and shaft-sinkings were necessary before even the approximate boundaries of the concealed areas could be determined. If the whole of the Carboniferous, including the productive portions, had been concealed, how much greater would have been the task of fixing the boundaries of the concealed and separate coal-basins. Explorations in this case would give very divergent results, and it might be a long time before it would be understood that the chief coal-basin lay to the east and not to the west of Bristol.

From information obtained in a series of borings in the south-west it might be supposed that the Bristol and Somersetshire Coalfield stretched east and west instead of north and south. Not only would the general structure of the concealed area remain for a long time in doubt, but it is reasonable to expect that the complexity of individual areas would only be proved by actual underground workings. General inferences might be drawn from a comparison with the South Wales Coalfield or that of the Forest of Dean, supposing these to be exposed, but this would involve a considerable knowledge of the structure of these coal-fields and an acquaintance with the succession and the means, palæontological, stratigraphical, and lithological, by which one portion of the sequence could be distinguished from another.

Exploration work in these known but concealed coal-fields affords therefore an object-lesson on the structure of the later coal-bearing Palæozoic formations where these are concealed under the Secondary rocks.

Realizing the difficulties in delineating the boundaries of the concealed coal areas in the south-eastern counties, the recent Royal Commission on Coal Supplies did not include this area in the estimates of future available supply.

CHAPTER XI

COALFIELDS OF GREAT BRITAIN, MIDLAND PROVINCE

Introduction.—It is generally accepted that over an area exceeding 10,000 square miles in the Midland Counties the Coal-measures were laid down in an almost continuous sheet extending from the Welsh hills and Irish Sea on the west, to the borders of the German Ocean on the east, and possibly beyond. It is also agreed that this area was originally connected on the north with the Durham coal-basin, and that on the south the minimum of deposition was reached along the borders of a tract of elevated land of which the Malvern and Lickey Hills, the Nuneaton Ridge, and Charnwood Forest form visible peaks.

As a whole, this area was undergoing depression throughout Carboniferous times. At its close a period of active earth-movement ensued, and the recently formed sediments were bent into alternating elevations (ridge folds) and depressions (basin folds).

These tectonic movements proceeded along two lines. A thrust from the east buckled the Carboniferous strata into a number of folds having their axes directed north and south or north-east and south-west. Of these folds those forming the composite Pennine Anticlinal resulted in the most important change, since they caused the separation of the eastern (Nottinghamshire and Yorkshire) basin from the western (Cheshire) basin.

Simultaneously, or possibly in part successively, a series of east-and-west transverse folds were produced by a thrust from the south; one of these, stretching from Pendle Hill, in Lancashire, eastwards along the valley of the Wharfe, divided off the coal-basin of the northern counties from the Midland basin on the south.

Another east-and-west anticlinal ridge in the latitude of Stone, Castle-Donnington, and Ruddington divides the eastern Midland basin into two unequal portions—a northern half containing the coalfields of the Yorkshire, Derbyshire, and Nottinghamshire basin, and a southern half containing the coalfields of the Leicestershire platform.

The term 'Midland Coal-basin' is applied to the area of Carboniferous strata defined by these post-Carboniferous movements.

During the period of earth-movement an immense quantity of material was swept away from the crests of the ridge folds, amounting to as much as 8,000 feet of Carboniferous strata near Harrogate. On the other hand, the strata in the basin folds were preserved from denudation: and it is these that now constitute the concealed and partly concealed coalfields.

At a much later period the Midland area became covered by the deposits of the Permian and Triassic formations, and subsequently by the later Mesozoic sediments, which buried up the highly inclined and eroded edges of the Carboniferous rocks.

The Mesozoic cover was in turn denuded off the crests of the anticlines, but has to a great extent escaped destruction over the synclines.

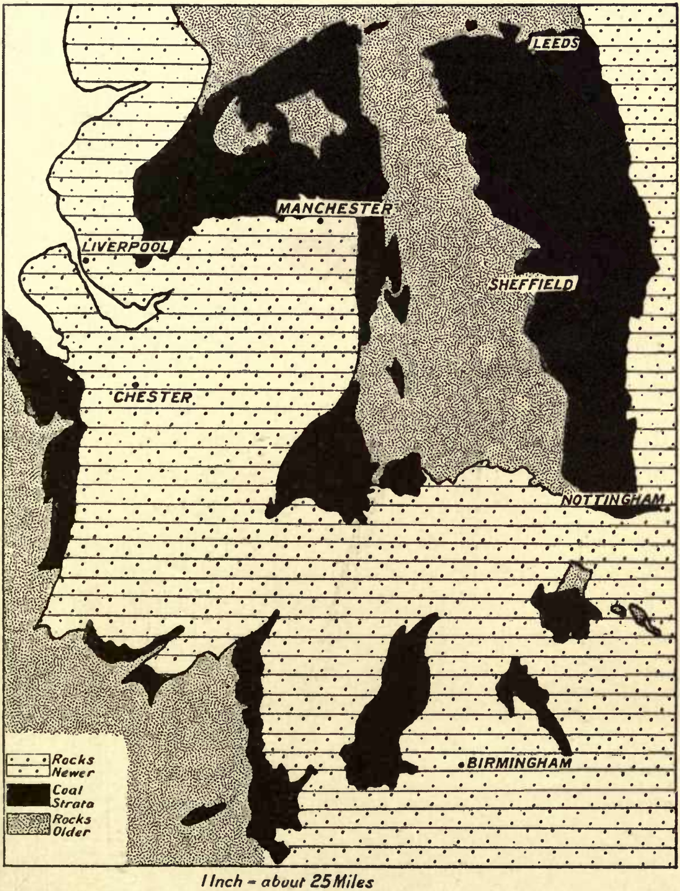


FIG. 13.—THE COALFIELDS OF THE MIDLAND BASIN.

In this way the discontinuity of the Carboniferous areas caused by pre-Permian folding and denudation has been accentuated, and the present outlines of the visible coalfields determined.

The separated coalfields group themselves in relation to the Pennine, Stone and Castle-Donnington anticlinals.

North of the Stone-Castle-Donnington anticline we have on the east of the Pennine Anticlinal the large coalfields of Derbyshire, Nottinghamshire, and Yorkshire; on the west side of the anticline we meet with the coalfields of North Staffordshire, Lancashire, and North Wales.

South of the Stone-Castle-Donnington anticline lie the coalfields of Coalbrookdale, South Staffordshire, Warwickshire, and Leicestershire.

The general Carboniferous sequence met with in the Midland basin is given in the table opposite, commencing with the newest strata.

Geologists are as yet far from agreed as to the nomenclature to be adopted for the different subdivisions. Among miners the Keele, Newcastle, and Etruria Marl groups are termed Upper Coal-measures, but Mr. Kidston, from palæobotanical evidence, considers that the Keele Group alone represents the Upper Coal-measures of continental geologists, and for the two remaining groups he has suggested the term 'Staffordian.' He also adopts the term 'Westphalian' for the Middle Coal-measures, and 'Lanarkian' for the Lower Coal-measures.

In the following pages the terminology in general local use will be adopted, and the distinguishing characters of the divisions and subdivisions mentioned for each coalfield.

From the Millstone Grits upwards each break in the

THE CARBONIFEROUS SEQUENCE IN THE MIDLAND BASIN.

	Divisions and Subdivisions.	Thickness in Feet.	
		Central and North.	South.
Upper Carboniferous.	Keele Group (so-called Permian) - - - - -	700 +	2,000 +
	Newcastle (Newcastle-under-Lyme) or Halesowen Group	350	400
	Etruria Marl, or Brick-Clay Group - - - -	1,100	400
	Middle Coal-measure Series -	6,000	800
	Lower Coal-measure Series -	2,000	Absent?
	Millstone Grit Series - -	1,000	Thin or absent
Lower Carboniferous.	Carboniferous Limestone Series - - - -	5,000	Thin or absent
	(*a*) Limestone Shale (Yoredale) or Pendleside Series.		
	(*b*) Carboniferous Limestone.		

regular continuity of the sequence which may occur is only local. The Keele Group (so-called Permian) has not been determined in all the coalfields, and some of the so-called Permian of the Warwickshire and Shropshire areas may be of post-Carboniferous age, and therefore unconformable to the Coal-measures.

The Lower Carboniferous rocks and Millstone Grits, with a few exceptions, do not contain workable seams. The chief coals are universally met with in the Middle Coal-measures. The Etruria Marl, Newcastle, and Keele groups are without workable seams. The covering formations newer than the Carboniferous occur in fullest sequence in the Yorkshire basin, but the Triassic strata are thickest over the Cheshire and Staffordshire basins.

The following table gives the sequence and maximum thickness of the Secondary rocks:

SECONDARY FORMATIONS OF THE MIDLAND BASIN.

Formations.	Thickness in Feet.	
	North-West and Central.	South-East.
Cretaceous - - - - - - -	Absent	2,000
Jurassic: (*a*) Oolitic; (*b*) Liassic - -	Absent	3,300
Trias and Rhætic - - - - -	4,000	1,100
Permian (Magnesian Limestone Series)	300 to 2,000	Absent

The thickness of cover of newer formations in the north-west and central regions, therefore, amounts to much the same as in the south-east. In the Yorkshire basin the attenuation of the Triassic strata is counterbalanced by the presence of the later Secondary formations (Jurassic and Cretaceous), while the absence of these over the Cheshire basin is equalized by the greater thickness of the Permo-Triassic formations.

In the study of each coalfield it is evidently essential to investigate: (1) The Carboniferous sequence, the occurrence of the chief seams of coal, and the means of determining definite horizons; (2) the structure resulting from the post-Carboniferous but pre-Permian earth-movements; (3) the thickness and nature of the secondary rocks surrounding the exposed coalfields.

Attention will be given to general stratigraphical and palæontological principles rather than to details.

North Staffordshire or Potteries Coalfield.—This triangular-shaped coalfield includes an area of about 100 square miles, and affords the type region for the coalfields of the Midland basin, in which it occupies a central position.

On the west, south-west, and south the Coal-measures sink beneath the unconformable Triassic covering. To the north and east the coalfield is limited by the uprise of the Millstone Grits and Lower Carboniferous rocks.

The structure of the main coalfield consists of a shallow syncline to the east and a sharp anticline to the west, the axes of the folds rising to the north, and thereby causing the subdivisions of the Coal-measures to crop out one after the other in this direction, and to sink deeper and deeper to the south.

Of the numerous faults traversing the coalfield, one trending north-north-east and south-south-west, with a throw to the west exceeding 700 yards, bounds the anticline on the west. On the east the anticline is limited by a fault having about the same amount of throw, but in the opposite direction.

The chief seams of the Middle Coal-measures, which crop out in the anticline, are in consequence depressed to great depths on both sides of it.

The Carboniferous sequence is complete, and may be subdivided as follows:

THE CARBONIFEROUS SEQUENCE IN NORTH STAFFORDSHIRE.

Divisions and Subdivisions.		Thickness in Feet.
Red-and-grey Series.	Keele Group	700 +
	Newcastle Group	350
	Etruria Marl Group	1,100
Grey chief coal-bearing Series.	Black Band Group (Bassey Mine Coal at base)	400
	Middle Coal-measure Series (Winpenny Coal at base)	4.000
	Lower Coal-measure Series	1,200
Millstone Grit Series		—
Carboniferous Limestone Series.	Pendleside (Yoredale) Series	—
	Carboniferous Limestone	—

Other classifications, chiefly affecting the grouping and nomenclature of the Grey chief coal-bearing Series and the Red-and-grey Series, have been suggested, but no uniformity has been arrived at.

The Lower Carboniferous rocks contain no workable seams. In the Lower Coal-measures two seams near the base corresponding in position to the Mountain Mines of Lancashire have been worked along the eastern boundary.

The Middle Coal-measures contain the chief seams in the following descending order: Great Row, Ash, Moss, Yard, Four Feet, Five Feet, Ten Feet, Bowling Alley, Holly Lane, Hard Mine, Seven Feet Bambury, Eight Feet Bambury or Cockshead, Bullhurst, and Winpenny.

The Great Row Coal lies about 300 feet below the summit of the Middle Coal-measures, and the Winpenny between 3,000 and 4,000 feet below the summit of the Middle Coal-measures, and about 1,200 feet above the Millstone Grits.

Most of the seams average 6 feet in thickness, but rarely attain a greater thickness than 8 feet. In the Black Band Group three or more coals are worked in conjunction with the valuable Black Band ironstones, but the remainder of the Red-and-grey Series is barren, except four thin coals in the Newcastle Group.

The great majority of the coals in the syncline are used for house, steam, and manufacturing purposes, but over the eastern anticlinal area many of these seams are coking and gas coals, the change from one class to another being very abrupt on approaching the anticline.

Apart from the known order of the coals and the occurrence of sandstones or other distinguishing rocks, definite positions in the chief coal-bearing series may be determined by the order of occurrence of the estuarine Lamellibranchiata and the positions of marine bands. While, however, the study of the occurrence and distribution of the fossils undoubtedly possesses much practical value, it is evident that both the occurrence and distribution depend on the accident of preservation and upon the prevailing local conditions which were so variable throughout the Coal-measure period. Thus, a palæontological sequence holding good for one district may not be strictly applicable in another, and caution must be exercised in determining horizons by means of fossil evidence alone.

Among the estuarine Lamellibranchiata it is asserted that the different species of *Carbonicola* (*Anthracosia*), *Anthracomya*, and *Naiadites* (Fig. 1, p. 59) make their appearance in a definite order, attaining their maximum development within certain limits, and that a species, or an assemblage of species, may occupy restricted horizons.

Anthracomya phillipsi, for instance, appears towards the summit of the Middle Coal-measures, becomes abundant in the Black Band Group, and dies out in the Etruria Marl Group. *Carbonicola subconstricta* is restricted to the roof of the Five Feet Coal. *Anthracomya adamsi* is confined to the horizon of the New Mine Ironstone 500 feet above the Ash Coal. An assemblage of *Naiadites carinata*, *N. modiolaris*, *N. quadrata*, *Anthracomya modiolaris*, and *A. williamsoni*, characterizes the roof of the Hard Mine Coal, and *Carbonicola acuta* var. *rhomboidalis* the roof of the Eight Feet Bambury Coal. *Carbonicola robusta* appears at the base of the Coal-measures, attains its maximum development about the horizon of the Eight Feet Bambury Coal, and does not ascend above the Ten Feet Coal.

Marine fossils are met with at nine horizons in North Staffordshire. They occur in bands generally only a few feet in thickness, fairly evenly distributed in the strata between the base of the Coal-measures, and about 700 feet below the Bassey Mine Coal.

Lingula and *Discina* are common to all the horizons, but three of the beds contain a distinctive fauna, and have, moreover, been traced over considerable areas. The lowest of these occurs above the Crabtree Coal, and contains *Pterinopecten papyraceus*, *Posidoniella lævis*, *Schizodus antiquus*, and *Gastrioceras listeri*.

A bed above the Seven Feet Bambury Coal contains the first two of these fossils, and, in addition, *Myalina compressa* and *Glyphioceras paucilobum*.

The most interesting bed is one a few feet below the Twist or Gin Mine Coal, about 1,100 feet below the Bassey Mine Coal and about 1,300 feet above the Seven Feet Bambury Coal. The band is rich in genera and species of Lamellibranchiata, Gasteropoda, and Cephalopoda, of which some characteristic shells are figured on Fig. 2, p. 63, and also contains a rich and peculiar fish fauna, including the rare genera, *Edestus* and *Listracanthus*.

The Black Band Group bears a close lithological resemblance to the grey measures below, in which division it is usually included; but the great profusion of *Anthracomya phillipsi* in the Black Band ironstones, and the occurrence of several bands of earthy limestones with *Spirorbis* and *Carbonicola vinti*, distinguish it at once from the beds below.

Excepting four thin seams in the Newcastle Group, the Red-and-grey Series is apparently barren, but the different groups may be satisfactorily recognized by their individual lithological or palæontological characters.

The bands of green grits (Espley Rocks) are restricted to the Etruria Marls, and form a reliable index of this group.

The lithological characters of the Newcastle Group somewhat resemble those of the Black Band Group, but are on the whole more arenaceous. The absence of the genus *Carbonicola*, and the restriction of the small shell *Anthracomya calcifera* to the lower 60 feet of the strata, readily distinguish the group from the rest of the Coal-measure sequence.

In the Keele Group the red sandstones and marls taken as a whole are distinct from the red Etruria Marls, and also from the red measures occasionally met with in the chief coal-bearing series. Some bands are, however, lithologically indistinguishable from the older red Coal-measures, and in the absence of fossil evidence great caution must be used. The presence of *Pecopteris arborescens* and the entire absence of *Carbonicola* and *Anthracomya* are reliable data in assigning a group of red measures to the Keele subdivision.

The Coal-measure strata of the Pottery Coalfield contain abundant plant remains. Those in the Lower Coal-measures differ from those of the Middle Coal-measures, but on the whole the vertical distribution of plants, with the exception of the restriction of *Pecopteris aborescens* to the Newcastle and Keele groups, has less practical significance to the miner than that of the Lamellibranchiata.

The net available quantity of coal remaining unworked was estimated by the Commissioners in 1905 at 4,368,050,347 tons, including that of Cheadle and Shaffalong. Of this large amount the chief supplies lie beneath the Red-and-grey Series, different members of which occupy the centre of the syncline, and spread out in concentric layers along the southern margin of the coalfield.

Since very little coal has been obtained from beneath the red measures along the southern margin, the day is probably far distant when any attempt will be made to reach the deeply-seated seams beneath the Trias.

To the west of the Boundary Fault, especially in the north between Harecastle and Congleton, the case

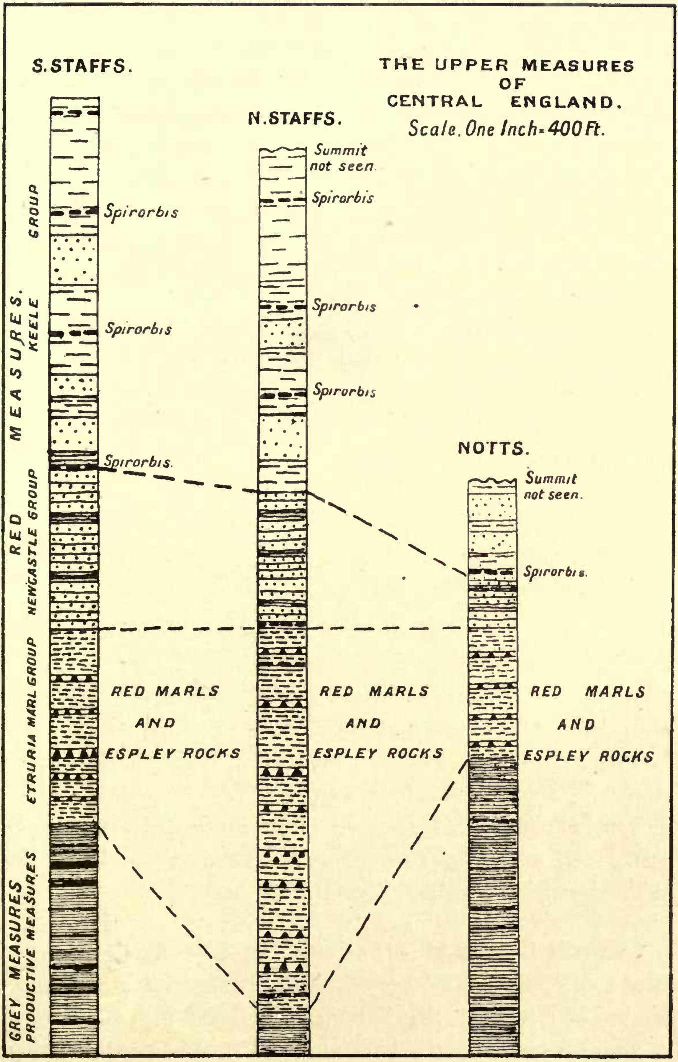


FIG. 14.—THE RED-AND-GREY SERIES OF THE MIDLAND BASIN.

is different. This large fault brings Trias and Middle Coal-measures on the west against the lower seams on the east. It would therefore appear feasible to drive a heading from the lower seams on the east and reach the higher seams on the west. The success of this operation would depend on the throw of the Boundary Fault, which is, however, unknown between Harecastle and Congleton.

A nearly vertical dyke of a close-grained basaltic rock traverses the Triassic strata and the Keele sandstones between Swynnerton and Keele, but has not as yet been encountered in any of the coal-workings. The dyke is seldom more than a few feet wide, but expands to a much greater width near Swynnerton Park. The unweathered rock contains large phenocrysts of olivine, many of them ideally fresh, but showing thin films of serpentine along cracks and on the surfaces. There is no porphyritic felspar or augite. The ground mass of the rock is made up of a granular mixture of a purplish augite and lath-shaped crystals of plagioclase felspar. Dark grains of iron oxide are abundant, and there are a few long needles of apatite.

The date of the intrusion is undoubtedly more recent than the Keuper Marl period.

The character of these newer intrusions should be compared with those of the older intrusive rocks of the Warwickshire Coalfield (p. 189).

Cheadle Coalfield.—The folding of the Carboniferous strata east of the Pottery Coalfield introduces the coal-basins of Cheadle, Shaffalong, and Goldsitch Moss.

The Cheadle Coalfield is alone of importance. Except on the south, the productive measures are here defined by the outcrop of the Millstone Grits. The Coal-measures have been subdivided into (1) Lowest Coal-measures; (2) the Woodhead Coal and Sandstone Group; (3) the Lower Pale Group, with the Rider, Cobble, and Dilhorne coals; and (4) the Upper Pale Group with several coal-seams, the Four Feet Coal forming the base.

A marine band, rich in fossils, occurs between the Four Feet Coal and the Dilhorne Coal, and another forms the roof of the Crabtree Coal near the base of the Coal-measures.

The fossils associated with the Crabtree are similar to those in the roof shale of the same seam in the adjacent Pottery and Shaffalong coalfields. The higher marine band forms the roof of a thin coal 140 feet above the Dilhorne or Six Feet Coal (1,400 feet above the Crabtree Coal). The fossils include *Pterinopecten papyraceus, Pt. carbonarius, Productus scabriculus, Leiopteria longirostris, Posidoniella lævis, P. sulcata, Lingula mytiloides, Myalina compressa, Pleuronautilus, Dimorphoceras gilbertsoni, Temnocheilus carbonarius, Gastrioceras carbonarium, Orthoceras, Bellerophon.* This list forcibly recalls the fossils obtained above the Gin Mine (p. 71) in the Pottery Coalfield; and the fossil band may be used as a datum line in comparing the sequence of the Cheadle Coalfield with that of the Potteries. It will also, no doubt, prove of great value in the determination of horizons met with in sinking in the unproved ground to the south of the visible coalfield.

To what distance the Coal-measures are continued beneath the Triassic rocks to the south is unknown.

The net available quantity of coal remaining unworked is estimated at 92,577,007 tons.

South Staffordshire Coalfield. — Including the present extensions, the total area of this field is estimated at 149 square miles.

The Coal-measure strata have been subdivided into three groups known in descending order as: (3) Upper Division (Halesowen Sandstone Group); (2) Middle Division (Brick-clay or Espley Group); (1) Lower Division (Productive Coal-measure Group). The Lower Carboniferous Rocks and the Millstone Grits are absent, and it is doubtful if the Lower Coal-measures are present except in the north.

The visible coalfield is divided by the Great Bentley Fault into a northern and a southern section. In the northern section the Lower Division reaches a thickness of about 2,000 feet, and contains many workable seams. The names of the seams vary from place to place. In the Cannock district the chief coals in ascending order are: Deep, Shallow, Cinder, Bass, Yard, Old Park, Four Feet, Five Feet, and Brooch, with a few thin upper seams.

In the southern area the productive Coal-measures diminish in thickness to between 500 and 600 feet, and about fourteen seams of the northern district unite to form a single seam, the famous Thick Coal, which reaches 30 feet in thickness.

The South Staffordshire coals are suitable for household, smelting, and manufacturing purposes, but true steam coals do not occur.

Very little attempt has been made to identify horizons in the productive measures by means of the fossils. Reliance has been placed, as usual, chiefly on the coal-seams, of which the Brooch Coal affords an excellent datum from its occurrence over the whole field, and from the peculiar character and red colour of the overlying shales. *Carbonicola robusta* has been recorded 30 feet below the Deep Coal of Cannock and Rugeley. Marine fossils were found 195 feet above the Thick Coal at Hamstead; in the white ironstones between Rowley Regis and Halesowen; in the Pennystone Ironstones at Oldbury; and below the Cannel Coal at Cannock Chase.

Information about the fauna and distribution of these marine bands is at present too scanty to warrant their use in the determination of horizons.

The strata of the Middle Division, from 600 to 1,000 feet thick, cover a large area in the southern part of the coalfield and a small area near Aldridge. The green grits (Espley Rocks) are sufficiently distinctive to assign the Brick-clay subdivision to the Etruria Marl Group of North Staffordshire.

The Halesowen Sandstone Group, 500 to 600 feet thick, only occurs in the southern section. It graduates upwards into the red rocks of the so-called Permian, of which the lower 900 feet may certainly be compared with the Keele Group. Similar red rocks are faulted against the productive measures along the eastern and western boundaries of the coalfield.

Three thin limestones with *Spirorbis* occupy definite positions in the Keele Group.

Igneous intrusions in the Productive Coal-measure Group occur in several districts, and form conspicuous hills in the Rowley Regis district. The rock of Pouk Hill is a typical ophitic olivine dolerite, in which the plagioclase felspar occurs in long prisms. The augite, in the form of irregular grains, varies from yellow to purplish brown, and is slightly dichroic.

Olivine is very abundant, and nearly, or even quite, unaltered; but some of the crystals are partially serpentinized along cracks and on the edges. Magnetite is fairly abundant, and there are a few crystals of apatite.

When in contact with a seam of coal the dark colour of the rock changes into white, and is known as 'white trap.' Though the igneous intrusions spoil the coal when in actual contact, such loss of good coal is usually trifling, and the Thick Coal has been mined under the dolerite of Rowley Regis.

The post-Carboniferous movements have given the Coal-measure strata an anticlinal form. On the east and west the visible coalfield is limited by the Eastern and Western Boundary faults.

The cover of the productive measures consists of the Middle and Upper Divisions of the Coal-measures, the so-called Permian, and of the Bunter and Keuper divisions of the Trias.

In the northern district a productive area of nearly twenty square miles has been shown to exist under Cannock Chase beneath the overlying Bunter Pebble Beds. At Essington the seams have been followed for some distance to the west below the so-called Permian and Pebble Beds, and a boring at Four Ashes has proved Coal-measures under the Trias.

In the southern district shafts have been sunk to the Thick Coal at Baggeridge, and the productive measures proved in a boring at Claverley, five and a half miles beyond the Western Boundary Fault. On the eastern side of the coalfield the Thick Coal is worked at Hamstead and Sandwell.

No development can be looked for along the southern margin of the coalfield, for the coals rapidly deteriorate and become worthless south of a line drawn from Birmingham to Stourbridge, but workable seams have been proved for limited distances, both east and west of the Boundary faults.

In exploratory work in this area, the chief points to be noted are the occurrence of marine and other fossils, the *Spirorbis* limestones of the Keele and Newcastle groups and the presence of the Espley Rocks.

The net available quantity of coal remaining unworked is estimated at 1,415,448,072 tons.

Warwickshire Coalfield. — This lies between the towns of Coventry, Nuneaton, and Tamworth. The Carboniferous succession is a replica of that of the South Staffordshire Coalfield. In South Staffordshire the so-called Permian occupies comparatively limited areas; in the Warwickshire Coalfield it covers a broad expanse.

Including the so-called Permian, the Warwickshire Coalfield has a superficial area equal to that of South Staffordshire.

As in South Staffordshire, the Carboniferous Limestone and Millstone Grits are absent, the productive measures reposing directly, but unconformably, on Cambrian strata.

The productive measures attain their maximum development in the north, where the seams are also most numerous. As the intermediate strata dwindle in thickness to the south, some of the coals tend to unite and form seams of exceptional thickness—a feature also common to the South Staffordshire and Leicestershire coalfields.

The chief coal-seams are, in ascending sequence: Bench, Double or Deep, Seven Feet, Slate, Ell, Bare, Ryder, Two Yard, and Four Feet, distributed in the north among 1,000 feet of strata. In the south the Ryder, Bare, Ell, and Slate unite together and form the compound Hawkesbury Seam.

The Middle Division of South Staffordshire is here represented by the Nuneaton Clays, about 300 feet thick; the Upper Division by the Haunchwood sandstones and marls, about 400 feet thick; and the Keele Group, or so-called Permian, by a succession of red sandstones and marls estimated at over 2,000 feet.

Even less than in South Staffordshire has any attempt been made in this coalfield to distinguish definite positions in the sequence by means of the distribution of the fossils.

In the productive measures the coals alone are used to identify horizons; the Seven Feet Coal has apparently been identified over the entire field.

The Nuneaton Clays contain the characteristic Espley Rocks; the Keele Beds two or more Spirorbis limestones.

The Coal-measures of Warwickshire lie in a broad syncline. Along the eastern and north-western edges the strata turn up rapidly, but become almost flat towards the centre of the basin. The major syncline is broken by an east-and-west anticlinal ridge in the neighbourhood of Arley, where the Upper Division—Haunchwood Sandstones and marls—rises to the surface in the midst of a tract of red sandstones and marls of the Keele Group.

Fault dislocations are of no great moment. The coalfield is surrounded by Triassic rocks, but it is by no means certain what is the relation of the Trias to the higher strata of the so-called Permian, or how much of the Permian may be of Triassic age and how much is to be relegated to the Upper Coal-measures (Keele Group).

At present it appears as if there were an exceptional development of the so-called Permian in the Warwickshire district, but it may be found that much of it appertains to the Trias and not to the Keele Group. In other words, it was deposited on the eroded edges and in the hollows of the Carboniferous strata, and not in conformable sequence, as were the Keele beds, with which the lower 700 feet of the so-called Permian may be confidently correlated.

The coalfield is being developed under the so-called Permian in the Arley district. Coal-measures have also been proved in borings to the east of Coventry and to the west at Four Oaks.

It would appear advisable, before making more ambitious attempts at development in the Triassic areas, to first determine the exact geological position and character of the so-called Permian.

The Warwickshire Coalfield affords a field for the study of igneous rocks newer than the Cambrian strata, but older than the Carboniferous period. These intrusive rocks (often termed greenstones), in the form of dykes, cut across the Cambrian quartzites and black shales near Nuneaton. Porphyritic olivine is frequently present, but always in the form of pseudomorphs. In undecomposed specimens the hornblende is fresh and brown in colour, but is frequently replaced by augite. Orthoclase and plagioclase felspar are present. These rocks are usually called diorites, and belong to a type intermediate between the acid and basic igneous rocks. When fresh they differ markedly in appearance from the dolerites of later age, and differ also in containing hornblende as an essential constituent.

Volcanic rocks older than the Cambrian quartzites occur at Caldecote.

Leicestershire Coalfield.—In South Staffordshire the Coal-measures are found resting on a Silurian platform, in Warwickshire on one of Cambrian age, the Carboniferous Limestone and Millstone Grits being absent from both.

In the Leicestershire Coalfield the sediments of the Carboniferous were deposited in hollows worn in a platform of rocks older than the Cambrian. These depressions were deep enough to be within reach of the seas of the Carboniferous Limestone and Millstone Grit periods, and to have remained below sedimentation level until late Coal-measure times. Whether at this period the Leicestershire platform was elevated, or whether the Upper Coal-measures were denuded before the Trias was deposited, has not been demonstrated.

The coalfield, with an area of about thirty square miles, is surrounded by Triassic rocks, under which the productive measures form a concealed coalfield with an estimated area of fifty-four square miles.

The Millstone Grits graduate upwards into the Coal-measures, and what are considered to be the lowest measures occupy the central portion of the field. They contain no important seams, and are called the 'Unproductive Series.' This series forms an anticline, the axis of which ranges north-west and south-east through Ashby-de-la-Zouch. On the west, separated by the

Great Boothorpe Fault, lie the coalfields of Moira and South Derbyshire.

The chief coals are, in ascending order: Kilburn, Clod, Stanhope, Eureka, Stockings, Woodfield, Slate, Main or Moira (14 feet average thickness), Five Feet, Dickey Gobler, and Ell.

On the eastern side of the anticline the Coal-measures are mainly hidden beneath the Trias, but seams are worked in many collieries, and have been proved by borings as far south as Hathern and Desford. This district is known as the Coleorton or Eastern Coal-field, in which the coal-seams in ascending order are Roaster, The Three Lounts, Main (6 feet average thickness), Yard, and Slate.

The Leicestershire coals chiefly belong to the bituminous types. The Main Seam in the eastern area is a good steam coal, while in the western area the same named seam is a free-burning house coal. It is here made up of several layers of coal receiving different names at the various collieries.

The determination of horizons and the correlation of the seams by means of fossils has yet to be worked out. Marine fossils are recorded from an unknown horizon at Leather Mill, and from four different beds between 453 and 663 feet depth below the Main Coal.

Among the freshwater Lamellibranchiata *Carbonicola acuta* and *Carbonicola aquilina*, as in the other Midland coal-basins, have a wide vertical distribution. *Carbonicola robusta* ranges from the Clod Coal to the Woodfield Coal, and *Carbonicola turgida* from the Clod Coal to above the Main Coal. *Naiadites modiolaris* has even a wider vertical range.

The marine fossils include species of *Pterinopecten*, *Sanguinolites*, *Naticopsis*, *Gastrioceras*, *Glyphioceras*, and *Orthoceras*, but none of the bands so far discovered are comparable in variety of fossils with that below the Gin Mine Coal of North Staffordshire, or that between 600 and 700 feet above the Top Hard or Barnsley Coal of the Nottinghamshire and Yorkshire Coalfield.

A considerable number of fossil plants has been collected. These afford evidence that the stratigraphical position of the Coal-measures at Ashby, taken together, is lower in the sequence than that of the measures proved in the eastern and western districts, and that the measures of the eastern district from the Main Coal down to the lowest seams worked belong to the same horizon as those between the Main Coal and the lowest seam worked in the western district. The plant evidence, also, by the non-occurrence of *Pecopteris arborescens*, indicates the total absence of Upper Coal-measures over the Leicestershire Coalfield.

At the Whitwick Colliery, and as far south as Ellistown, a sheet of dolerite overlies the Coal-measures. It is 81 feet thick in the Whitwick Colliery, but thins out towards the north-west and south, and is absent at Snibston Colliery on the west, and at Nailstone and Bagworth on the south. The molten rock came up along the line of the boundary fault, and when in contact with a coal-seam, the coal is found burnt to a cinder, while the overlying Triassic strata do not appear to be changed even when in actual contact. The intrusion, then, is apparently earlier than the Trias period, but later than the Middle Coal-measures, and is considered to belong to the period of the higher Coal-measures. When in contact with Coal-measure strata the rock is altered into 'white trap,' an igneous rock originally a dolerite, but with the original minerals replaced by carbonates and kaolin.

The mineralogical character of the Whitwick igneous rock serves as a good example of the igneous intrusions of doubtful age, which, while not more ancient than the Middle Coal-measures, may yet be older than the Trias. In the Whitwick rock the olivine grains are rounded, passing into serpentine along the edges of the crystals and in their centres. The augite forms large ophitic plates, is of a purplish-brown colour, and encloses many lath-shaped plagioclase felspars. Iron oxides and apatite are present as accessory minerals, and as secondary products there occur chlorite, serpentine, analcime, and other zeolites.

This igneous rock should be compared with the pre-Carboniferous diorites of the Warwickshire Coalfield (p. 189), in order to appreciate the difference between the mineral characters of the igneous rocks older than the Carboniferous, and between those like the Whitwick intrusion of doubtful Carboniferous age and those of much later date. Hornblende, it will be observed, is usually present in the pre-Carboniferous intrusions.

On the west the Leicestershire Coal-measures pass for an unproved distance beneath the Trias. To the east they extend as far as the fault that runs from Whitwick, by Thornton, to Desford.

Putting aside for the present the probability of there being a buried coalfield along the Valley of the Soar to the east of the Archæan rocks of Charnwood Forest, what prospects are there, it may be asked, of the Coal-measures extending westwards, beneath the Trias towards the Valley of the Trent, south-westwards towards the Warwickshire Coalfield, and in a south-easterly direction.

In the Netherseal Colliery the productive measures are thrown down to the west by the Linton Fault. Borings to the south-west show that the pre-Triassic surface descends at an abrupt angle to the south-west, and that the Triassic rocks shortly attain a thickness of over 1,200 feet. Borings round Market Bosworth prove that the pre-Carboniferous rocks rise up in this direction, and that a ridge of older rocks separates the coalfield of Leicestershire from that of Warwickshire. The presence of a tongue of Coal-measures, extending between Desford and the visible eastern coalfield, is proved by several coal-shafts, but borings to the south-west of Desford proved that only the Lower Carboniferous strata lie between the Trias and the buried ridges of the older rocks, and so the limits of the concealed coalfield are fixed in this direction.

Due west of the coalfield, therefore, Coal-measures exist, though at considerable depths. Southwards it is evident that spurs of older rocks are concealed under the Trias, between which coal-bearing strata may occur, but the exact position of these buried coalfields can only be proved by trials, as also can the extent of the Coal-measures beneath the Trias. One fact is evident—that the pre-Carboniferous floor underlying the Triassic rocks of Leicestershire is of great irregularity, and presents a series of rocky ridges stretching northwards, with intervening hollows in which the productive measures may or may not be preserved. Individual efforts to prove the sites of these buried hollows may in some cases be successful, but co-operation and the publication of the results obtained by separate undertakings is needed before a reliable picture can be figured of the configuration of the pre-Carboniferous surface, or the extent to which the pre-Triassic surface had suffered denudation.

On the east side of the Charnwood range borings put down at Crown Hills near Leicester entered pre-Carboniferous rocks. Of two borings near Hathern, one reached rocks older than the Carboniferous strata, and another strata older than the Coal-measures. The Leicestershire Coal-measures, it would therefore appear, do not occur under the Valley of the Soar, and how far to the east the productive measures exist remains to be proved; but a boring at Ruddington seems to show that to the east of the Charnwood range the Lower Carboniferous rocks form the first Carboniferous belt underneath the Trias, but how wide the lower unproductive belt may be has not been ascertained.

Yorkshire, Derbyshire, and Nottinghamshire Coalfield.—This is the largest and, next to South Wales, the most important coalfield in Great Britain, while the concealed coalfield contains the largest reserve of coal in the British Islands. In 1906 the output amounted to about 60,000,000 tons, or nearly twice that of South Wales.

The general Midland sequence of the Carboniferous System is present, though the Upper Coal-measures are for the most part concealed beneath newer formations, and the highest groups of these have only been met with in a boring at Thurgarton.

Geologists are not generally agreed as to the nomenclature of the different divisions and subdivisions of the Yorkshire Carboniferous sequence, but the following classification has been generally adopted:

THE CARBONIFEROUS SEQUENCE IN YORKSHIRE.

			Feet.
Upper Carboniferous	Upper Coal-measures (500 feet +)	Keele Group; Newcastle Group; Etruria Marl Group	Proved only in borings.
	Middle Coal-measures (down to the Silkstone Coal)		2,000 to 3,000.
	Lower Coal-measures (down to the Rough Rock)		1,200 to 1,600.
	Millstone Grits - - - - - -		—
Lower Carboniferous	Yoredale Rocks, Limestone Shales, or Pendleside Series - - - -		—
	Carboniferous or Mountain Limestone		—

Intrusive or contemporaneous igneous rocks are unknown in the Coal-measures, though they are well developed in the Carboniferous Limestone Series of Derbyshire. They have not as yet been met with in any of the coal-workings to the east of the coalfield; but there is no reason to suspect their entire absence, since they are known to be present at Owthorpe to the south-east.

The chief seams are confined to the middle division. In the lower division the only coals of importance occur towards the summit and base, the lower seam being known as the Alton, Halifax Hard, or Gannister Coal; that towards the summit as the Beeston Coal in Yorkshire and the Kilburn Coal in Derbyshire, though it is uncertain if these two coals are on the same horizon.

The middle division contains a great number of seams, the most important in ascending sequence being: Kilburn, Silkstone or Black Shale, Parkgate or Deep Hard, Flockton or Deep Soft, Barnsley, Warren House, or Top Hard.

Below the Barnsley Bed the seams are wonderfully persistent, with the exception of the Kilburn, a noted house coal, which is essentially a Derbyshire seam. Above the Barnsley Bed the coals, though numerous, are generally impersistent, seldom exceeding 4 feet in thickness, and usually of inferior quality. The best-known seams in ascending order are: Kents Thick or High Hazles, Wathwood or Clowne, Sharlston and Shafton. The alternative names chiefly apply to the Nottinghamshire district. Only a few of these seams have been persistently worked over large areas in the exposed coalfield, and scarcely at all in the deeper-seated and concealed areas, though attention is now being directed towards them.

The coals, according to the purposes for which they are most suitable, are classed as House, Gas, Steam, Manufacturing, and Coking, the term 'steam' being used in its strict sense for a coal good enough for use on locomotives, steam-vessels, and in the Royal Navy.

The quantity of steam coal available in the proved coalfield is estimated at 1,679,694,264 tons.

The Upper Coal-measures, so far as they have been proved in borings, do not contain any workable seams.

Horizons in the Lower and Middle Coal-measures can be often determined by the order of occurrence and character of the coals, and by the lithological character of the strata. The Lower Coal-measures contain definite groups of sandstones and the Middle

Coal-measures more or less persistent beds of sandstone, which can be traced over wide areas in close association with the coal-seams. The lithological characters of the individual sandstones, however, are not always sufficiently distinct to identify one from another, so that greater attention must be given to the fossils in the associated shales. So far the following definite order of their occurrence has proved reliable. The roof of the Alton Coal and Halifax Hard Bed invariably contains *Pterinopecten papyraceus*, *Gastrioceras listeri*, and *Gastrioceras carbonarium* in abundance.

Carbonicola robusta does not ascend above the Barnsley Seam, and is most abundant in the measures between the Silkstone and Deep Hard coals. It ranges, however, down to the Millstone Grits.

A marine band with *Goniatites*, *Pterinopecten*, *Myalina*, and *Productus* lies 300 feet above the Deep Hard Coal over the Chesterfield area, but has not been recorded elsewhere.

Throughout the Derby and Nottingham Coalfield two marine bands occupy definite positions in the measures between the Top Hard (Barnsley) Coal and the summit of the Middle Coal-measures. The lower occurs from 100 to 150 feet above the Clowne Coal (450 feet above the Top Hard), and contains a fauna, including *Syncyclonema carboniferum*, *Pseudamusium fibrillosum*, *Pterinopecten papyraceus*, *Pt. carbonarius*, *Nucula*, *Ctenodonta*, numerous species of *Goniatites* and spines of the rare fish *Listracanthus wardi*, and thus comparable with that above the Gin Mine in North Staffordshire (Fig. 2, p. 63). About 200 feet above this a blue shale (bind) yields *Lingula* and *Discina*.

The corresponding position of these bands in the

Yorkshire sequence has not been exactly defined, but four marine bands have been found high up in the measures between the Barnsley Coal and a sandstone known as the Ackworth Rock lying above the Shafton Coal. A very persistent bed, rich in fossils, lies between 650 and 700 feet above the Barnsley Coal.

Anthracomya phillipsi (Fig. 1, p. 59) is common in the strata above the highest marine band, but does not descend below the Top Hard Coal.

The Upper Coal-measures are only known to outcrop, and then only the lowest portion of the lowest group (Etruria Marls), in the neighbourhood of Conisborough, but the complete sequence has been met with in a boring at Thurgarton, north-east of Nottingham. In these measures the presence of *Pecopteris arborescens* determines their age just as the abundance of *Alethopteris lonchitica* (Plate IV., p. 55), in association with *Neuropteris gigantea* and other forms, indicates a Middle Coal-measure horizon for the grey measures down to the Silkstone Coal.

The red rock of Rotherham must not be mistaken for these red measures of the Upper Coal-measure Series. It was formerly considered to belong to this series, and even to be Permian, but it is now recognized that the name has been applied to different beds of reddish sandstones and shales occurring at different horizons in the Middle Coal-measures.

The coalfield lies in a basin fold. The western and small portions of the northern edges are exposed, but the remainder is concealed beneath the newer rocks. These steadily increase in thickness to the east and south by the successive in-coming of the different layers of the Mesozoic formations (p. 174). Beneath these the

Coal-measures are known to extend as far east as Haxey and Scarle, and as far south as Owthorpe. Thus an area of concealed productive measures, nearly equal in extent to that of the exposed coalfield, has been proved.

How much farther to the east and south-east the Coal-measures continue has not been determined, but a considerable east and south-east extension has been postulated by Professor Kendall, who considers that the eastern concealed margin lies in the neighbourhood of the Louth anticline, and that the southern concealed edge borders on the Fen country, thus making the concealed area about 3,885 square miles.

The eastern extension is based on the supposition that the fold in the Secondary formations is of the posthumous type, and that the Louth anticline marks the uprise of an ancient ridge, against which the Coal-measure strata rise up.

Outcrops of coal-seams on the bed of the North Sea have also been supposed, from the abundant fragments of coal dredged up from a trough, known as the 'Coal Pit,' fifty fathoms deep, and situated along the edge of the Dogger Bank. There seems no evidence, however, to justify the belief that this coal is derived from actual outcrops, and it is considered that the fragments may all have been swept from the numerous steam trawlers in rough weather.

The south-easterly extension is based on the trend of the Pre-Cambrian Charnian ridge which lies in this direction, and also on the fact that subsequent folding along this line may be regarded as the governing factor in the deposition of the Carboniferous rocks, and later formations up to the Cretaceous.

The northern limit of this great coal-basin is based upon the presence of an east-and-west anticlinal fold in the Millstone Grits, against which the Coal-measures in the visible coalfield rise up, and on the continuance of this upward movement throughout the Jurassic period and its continuance into Cretaceous times. There appears, however, to have been either a cessation of movement, or one in an opposite direction, during the deposition of the Permian and Triassic strata, for these rocks betray no signs of diminution in thickness on approaching the Market Weighton anticline, as do the Jurassic strata.

Over a great portion of the concealed coalfield the chief seams must lie at great depths, owing to the increasing cover formed by the Permian, Trias, Jurassic, and Cretaceous formations, and the presence of the Upper Coal-measures towards the centre of the basin, north-east of Gedling. In the south and south-east, however, not only does the Permian entirely disappear, but the Trias rapidly diminishes in thickness, while the Coal-measure strata rise to the south, and the Upper Coal-measures are either absent or are of no great thickness.

The importance of the area as a great national coal reserve justifies the insertion of a few data as to the proved depth to the productive measures beneath the newer formations.

In the south, a boring at Edwalton, three and three-quarter miles south-east of Nottingham, after penetrating a considerable thickness of Triassic strata, is supposed to have entered the Coal-measures a few feet below the Top Hard (Barnsley) Coal. At Ruddington, situated west of Edwalton, the Trias was found resting on Coal-measure strata a few feet below the horizon of the Kilburn Coal, or—with the exception of the Alton Coal—below the horizon of the lowest workable coal. Unless the strata roll over to the west of Ruddington, the productive measures must, therefore, be absent beneath the Valley of the Soar (p. 195).

North of Nottingham City, numerous pits, extending to Pontefract, prove the Barnsley Coal to lie beneath the Magnesian Limestone at depths varying between 1,250 and 2,300 feet.

Within the outcrop of the Trias, which forms the covering formation of the Magnesian Limestone, a shaft at Bestwood, near Nottingham, reaches the Top Hard Coal at a depth of 1,242 feet. At Scarle, north-east of Bestwood, the Coal-measures were entered beneath the complete Triassic sequence at a depth of 2,019 feet, but opinions differ as to the horizon attained in the Coal-measures. Since the core was only 0·9 inch in diameter, and only about 10 feet of Coal-measure strata were proved, positive evidence as to the horizon attained in the Carboniferous sequence cannot be said to have been satisfactorily determined. In the Thurgarton boring, thirteen miles south-west of Scarle, the Permian was found resting on the Keele Group.

The shafts of the Mansfield Colliery prove the Top Hard Coal at a depth of 1,577 feet, while the same seam at the Manton Colliery, west of Retford, is at a depth of 1,848 feet. Near Doncaster the Barnsley Coal has been proved to lie between 1,700 and 1,900 feet below the surface, and at Haxey (South Carr) this seam is considered to have been reached at a depth of 3,186 feet. A boring near Selby is considered to have reached the Middle Coal-measures at a depth of 1,305 feet.

These explorations show a marked increase in the thickness of the Permian and Triassic formations from south to north and from west to east.

In the determination of horizon in the Coal-measure sequence, reliance may be placed on the position of the fossiliferous marine band between 600 and 700 feet above the Top Hard Coal. The existence of the Upper Coal-measures in a boring will be indicated by the presence of the green grits (Espley Rocks) in the Etruria Marl Group, and of the fossil plant *Pecopteris arborescens* in the Newcastle and Keele Groups. When the Upper Coal-measures are proved to be present, it may be concluded that the full thickness of the Middle measures are present beneath them unless cut out by faulting.

Lancashire Coalfield.—This coalfield, with an area of 217 square miles of exposed Coal-measures, ranks next in point of size and importance to the Yorkshire Coalfield. It contains some of the deepest workings in the British Isles, coal being obtained at the Pendleton Colliery, near Manchester, at a total depth from the surface of 3,483 feet.

The Carboniferous formation here reaches its maximum development in the Midland basin. The Coal-measures rest on the Millstone Grits (3,000 to 5,000 feet thick), and these in turn on the Lower Carboniferous rocks several thousand feet thick.

The Coal-measures are usually subdivided into an Upper, Middle, and Lower Series. The Upper Series, containing purplish marls with thin limestones and shales (Ardwick Group), only crops out over a very limited area in the Manchester district, but has been met with in a boring to the west and in others to the east. Since the series is conformable to the Middle Coal-measures, it doubtless underlies the Permian and Trias to the south of the main coalfield. It contains no workable seams. The Middle Series (3,000 feet) contains the chief coals, the base line being drawn at the Arley Mine Coal. Beneath this comes the Lower Series (2,000 feet) with the important Mountain Mines towards the bottom.

The Mountain Mines consist of two seams: the Upper Mountain Mine, from 14 to 16 inches thick, and the Lower Mountain Mine (Gannister Coal), from 18 to 30 inches, lying from 60 to 75 yards below the upper seam. These two coals tend to coalesce, and undoubtedly represent the Halifax Hard and Halifax Soft coals of Yorkshire.

In the Middle Series some of the seams, though known locally under different names, extend throughout the coalfield. Other seams, such as the famous Cannel Mine, thin away in every direction from Wigan as a centre. The Arley Mine, known also as the Orrell, Four Feet, Royley, and Fulledge Main Coal (Burnley), is universally present, and constitutes one of the chief seams.

Between the Arley Mine and the succeeding Ince Group of coals several seams of importance occur, including the Cannel Coal of Wigan, a famous gas coal, and the Wigan Nine Feet, or Trencher Bone of Bolton, or the Roger Nine Feet of St. Helens.

The Ince Group at Wigan contains in ascending order the Seven Feet, Four Feet, and Yard coals corresponding to the Rams, Crumbourke, and Bin coals of Bolton.

Between this last group and the next important seam, called the Worsley Four Feet (considered by some to be the equivalent of the Parker Mine), a group of barren strata intervenes, thick in the east but diminishing to the west. Following the Parker Mine comes another barren interval, and above this the Bradford Four Feet Seam (formerly regarded as equivalent to the Worsley Four Feet), succeeded at intervals by a few seams, including the Charlotte and Openshaw Mines.

The strata of the Upper Series, beneath the Ardwick Group, consist of grey measures with thin limestones, attaining a thickness of over 600 feet around Manchester. They contain occasional Black Band ironstones, but no workable seams.

Among the fossils the following will be found to serve a useful purpose in attempting to identify horizons in the Coal-measures; but except the band above the Mountain Mines, the knowledge of the fossil sequence is admittedly most imperfect.

The roof of the Upper Mountain Mine, or, as it is sometimes called, the Bullion Coal, contains a marine fauna, *Goniatites* and *Pterinopecten*. *Carbonicola robusta* characterizes the Lower Series, but ascends some distance above the Arley Mine. A bed with *Lingula* and *Goniatites* occurs at some distance, not yet determined, above the Arley Mine. About 200 feet below the Bradford Four Feet Coal, marine fossils, *Ctenodonta*, *Nuculana*, *Pseudamusium*, among others, occur at Ashton-under-Lyme, but have not been recorded in any of the shaft-sinkings. *Anthracomya phillipsi*, frequently found in great abundance, characterizes the Upper Series, and is a common fossil in the thin limestones and Black Band ironstones.

The Coal-measures occupy a trough, closed on the south and west by the Permian and Trias, and rising on the north and east until the Millstone Grits are at the surface.

Numerous faults traverse the South Lancashire Coalfield, having a general north-west and south-east direction. A fault with an estimated downthrow of 1,000 yards forms the western boundary of the coalfield. The Irwell Valley Fault, to the east of Manchester, is also calculated to possess over 1,000 yards throw.

The Burnley Coalfield, to the north of the South Lancashire field, is brought in by a synclinal fold.

The newer formations covering the Coal-measures to the south and west are as follows:

Trias	Keuper Marl. Keuper Sandstone. Bunter Sandstone and Conglomerate.
Permian	Marl and Dolomites. Sandstone (Collyhurst).

The area occupied by these formations, as well as a great part of the exposed coalfield, is thickly covered with Glacial Drift, which in many cases obscures the outcrops, and often makes it difficult in the absence of borings or sinkings to determine what strata lie immediately beneath it.

The Trias increases in thickness westwards from 1,600 feet on the east to 2,300 feet near Liverpool, reaching its maximum thickness in the south near Northwich, where a boring failed to reach the base of the Bunter at a depth of 2,610 feet. The Permian marls and sandstones vary in thickness from nearly

2,000 feet at Heaton down to 280 feet near Leigh. Besides the covering of red rocks, the unproductive portion of the Upper Coal-measures must be taken into account, and also the thick barren zone lying between the Bradford Four Feet and the Parker Mine coals.

Reference has been previously made to the thick deposits of Drift. To what extent these deposits conceal the geology is shown by the boring at Heaton Park, where these surface rocks are 143 feet thick, and rest on 1,447 feet of Trias and Permian, while the capriciousness of their distribution is shown by the outcrop of solid rocks a short distance to the south.

The borings put down in the search for coal along the southern margin of the coalfield afford good examples of the value of fossils in the determination of horizon. Thus, in one of these borings, some red sandstones and marls were found beneath the Permian formation. These red beds closely resembled the Keele Group of North Staffordshire, but were found resting on grey measures containing *Anthracomya phillipsi* in abundance, whereas if the underlying grey strata appertained to the Newcastle Group, as they would do if the red beds belonged to the Keele Group (see p. 178), this fossil would not have been met with. Moreover, *Anthracomya phillipsi* occurred in the red measures, which indicates that they belong to an horizon lower than the Keele and Newcastle groups, and are most likely some portion of the Ardwick Series.

The net available number of tons remaining unworked is estimated at 4,238,507,727.

Denbighshire and Flintshire Coalfields.—The Coal-measure sequence in Denbighshire and Flintshire closely resembles that of Lancashire, but the Upper Coal-measures—the subdivisions of which may be grouped as in North Staffordshire—attain a fuller development, the highest, or Keele Group (so-called Permian), coming to the surface between Oswestry and Wrexham.

The Coal-measures rest on the Millstone Grits, and these in turn on the Lower Carboniferous Strata. The Coal-measures may be divided as follows:

THE UPPER CARBONIFEROUS SEQUENCE IN NORTH WALES.

		Feet.
Upper Coal-measures	Keele Group: Wrexham red sandstones and marls	600+
	Newcastle Group: Coedyrallt grey sandstones and marls, with Morlais Main Coals and Spirorbis Limestones	350
	Etruria Marl Group: Ruabon red clays, with Espley Rocks and Spirorbis Limestones	840
Middle Coal-measures	Grey sandstones and shales, with the chief coals	800
Lower Coal-measures	Grey sandstones and shales, with a few thin seams	1,000

Millstone Grit Series.

The chief seams of the Flintshire Coalfield are: Lower Four Feet, Main (7 feet thick), Brassy, Hollin, and Four Feet coals; of the Denbighshire Coalfield, Main Brassy, Two Yard, Powell, Drowsalls, and some higher sulphurous coals.

The Upper Coal-measures closely resemble those of North Staffordshire, except for the greater number and increased thickness of the limestones in the Ruabon Clays. As in North Staffordshire, the lithological characters of the groups are sufficiently distinctive.

The Coal-measures dip sharply to the east or north-east. Numerous faults cross the coalfields, one of which, named the Wrexham Fault, was formerly considered to bound the Denbighshire Coalfield on the east, but workable seams have now been proved to the east or downthrow side.

Between Oswestry, and a little north of Wrexham, the Bunter formation rests on the Keele Group, but in Flintshire it appears to transgress on to the Middle Coal-measures. Owing, however, to a thick covering of sands and clays, belonging to the Glacial Epoch, the boundary between the two formations has been imperfectly determined. The extent and depth of the concealed Coal-measures, which undoubtedly exist to the east of the Denbighshire and north of the Flintshire Coalfield, can therefore only be determined by sinking or boring through these glacial deposits.

At Sealands, in the Estuary of the Dee, two borings put down within short distances of each other show how very different results may be obtained. One boring, half a mile south-east of Ferry Bank Farm, reached the Main Coal at 376 feet depth; while the other, less than a mile farther east, failed to reach the Middle Coal-measures at a depth of 1,632 feet, having penetrated 932 feet of New Red Sandstone and 700 feet of Mottled Marls, with seven bands of limestone, presumably belonging to the Ruabon Clay Group. These diverse results forcibly illustrate the great unconformity of the Trias, and show how essential it is, in exploratory work, to be able to distinguish the different members of the Coal-measure sequence by the lithological and palæontological characters.

Scarcely any attempt has been made to identify horizons by means of fossils, but the sequence of the type region (p. 178) will serve as a reliable guide for future workers.

The productive measures are probably continuous across the broad basin of red rocks, extending from the Denbighshire Coalfield to North Staffordshire, but are beyond workable depths, since the Trias formation exceeds 4,000 feet, and below this about 2,000 feet of upper unproductive measures may be expected.

The net available number of tons remaining unworked is estimated at 1,736,467,829.

A small area of productive Coal-measures, partly hidden under red rocks, exists in the island of Anglesey, and a few seams were formerly worked.

Shrewsbury and Le Botwood Coalfields.—Coal-measure strata with a few impersistent seams rest unconformably on the edges of Pre-Cambrian and older rocks along the southern margin of the Cheshire basin south of Shrewsbury. The presence of bands of *Spirorbis* limestone and the passage upwards of these coal-bearing strata into the so-called Permian (Keele Group) places them in the Upper Coal-measures. These upper measures must either have overlapped the Middle Coal-measures, or, as is more likely, they were deposited in a hollow which was not depressed until Upper Coal-measure times. The existence of the productive measures beneath the so-called Permian, or beneath the overlying Trias, is therefore problematical.

Coalbrookdale Coalfield.—The Middle or Grey Coal-measures follow in conformable succession upon the feeble representatives of the Millstone Grits and Carboniferous Limestone. They are separable into two divisions—a Lower Series about 400 feet in thickness containing the chief coals; and a Higher Series about 400 feet thick with only thin seams, and passing upwards into the Permian of Pemberton.

In the Lower Series the coals, all of a bituminous character, occur in the following ascending order: Clod, Best, New Main, Flint, Top, and Fungous.

The measures associated with the Pennystone Ironstones, 300 feet below the Fungous Coal, contain a rich molluscan fauna, and afford an important marine horizon in the coalfield.

The Higher Series of red and grey marls, grey sandstones and shales, with a band of *Spirorbis* limestone, rests on an eroded surface of the Lower Series. This relationship is locally known as the Symon Fault.

The Coal-measure strata dip as a whole to the east, passing in this direction beneath a broad band of red rocks (so-called Permian), but there is some uncertainty as to whether these red rocks belong to the Keele Group or are of later age. In the north-west the Coal-measures are faulted against Triassic strata. To the south they rest on Old Red Sandstone or Silurian strata.

Forest of Wyre Coalfield.—Relatively unimportant as a coal-producing area, this coalfield illustrates the filling up of an irregular pre-Carboniferous hollow by Coal-measures. The Lower Series, containing the Sweet Coals of Highley and Kinlet, occupies the deeper portions of the hollow. The strata never crop out, as they are overlain by the Higher Series (Sulphur Coal Group), which dips eastward under Triassic strata and to the west and south-west rests on Old Red

Sandstone, overlapping the edges of the Sweet Coal Group, so that this does not crop out. The red strata at the summit of the Higher Series undoubtedly belong to the Keele Group, and contain *Spirorbis* limestones, and at least one thin seam of coal.

CHAPTER XII

COALFIELDS OF GREAT BRITAIN—NORTHERN PROVINCE, INCLUDING IRELAND

On crossing the Wharfe anticline, the Lower Carboniferous rocks to the north gradually assume different lithological characters. The massive Carboniferous Limestone becomes split up by the intercalation of shales and sandstones; coal-seams make their appearance, increasing in thickness and quality until, in Northumberland, they become workable.

The Limestone Shale, or Pendleside Group, either thins out or, by the development of limestone bands, becomes indistinguishable from the Carboniferous Limestone Series, and, under the name of 'Yoredale Group,' has been placed with this series.

The Pennine uplift extends northwards across the Wharfe anticline, and continues to be the dominant structural feature separating the Northumberland and Durham coalfields on the east from that of Cumberland on the west.

Igneous rocks, contemporaneous with or intrusive into the Coal-measures, rare or absent in the Southern and Midland provinces, are of frequent occurrence in the northern coalfields, but do not seriously interfere with mining.

Cumberland Coalfield.—The Coal-measures rest on representatives of the Millstone Grits, and these again on the Carboniferous Limestone Series, which contain a few thin coals.

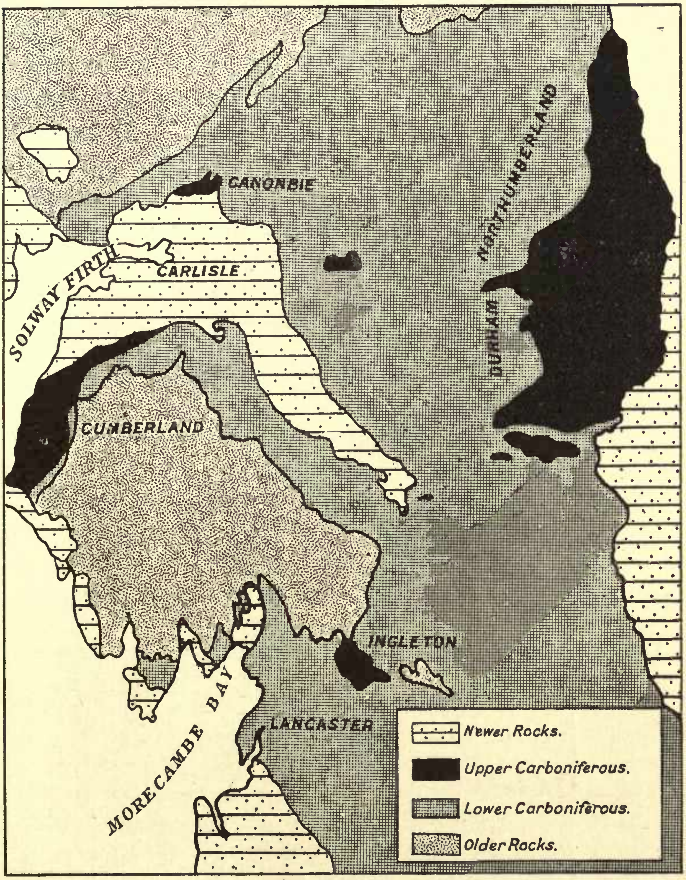
The Coal-measures have been divided into: (3) An Upper Series, consisting of reddish sandstone (Whitehaven Sandstone) and shales, with a band of *Spirorbis* limestone, considered to be unconformable to the productive measures; (2) a Middle Series, with seven workable seams, of which the most important in ascending sequence are the Main Band (9 feet thick), Bannock Band, Cannel or Metal Band; (1) a Lower Series, with five inferior coals.

The determination of definite horizons by fossil evidence has not been attempted.

The Coal-measure strata are inclined to the west and north-west, and are crossed by many large faults, which do not affect the overlying Permian and Triassic formations that form the cover on the south and north-west.

Extensions of the coalfield may be looked for seawards, and beneath the Secondary rocks of the Carlisle basin to the north-west. On the northern margin of this basin the Coal-measures have been proved at Canonbie. The district is a highly faulted one, and the productive measures appear to be overlain by a great thickness of Upper Coal-measures.

Ingleton Coalfield.—At Ingleton, in the West Riding of Yorkshire, a small area of productive Coal-measures, forming an isolated coal-basin partly hidden in the central area beneath the Permian, and for the most part covered by Glacial Drift, occurs on the south-west



1 inch = about 25 miles.

FIG. 15.—THE COALFIELDS OF NORTHERN ENGLAND.

or downthrow side of the Dent Fault. The coalfield is divided by the River Greete into a northern and a southern district. Coal-mining on a limited scale has taken place in the southern field, and boring is in progress north of the Greete.

The Coal-measures consist of an upper series of red sandstones and clays without coal-seams, and of a lower grey series containing two or three workable seams. Near Bentham some seams lying either in the Lower Millstone Grits or upper part of the Carboniferous Limestone Series were formerly worked. The limits of the basin are clearly defined as regards the Coal-measures, so there can be no large extension, though the field may attain a local importance.

Northumberland and Durham Coalfield.—The coal-bearing strata of this well-known coalfield may be divided into two series—that of the Upper Carboniferous rocks, comprising the Coal-measures and Millstone Grits, and that of the Lower Carboniferous rocks, including the seams contained in the Carboniferous Limestone Series.

The complete Carboniferous sequence is as follows:

THE CARBONIFEROUS SEQUENCE IN NORTHUMBERLAND.

			Feet.
Upper Carboniferous	Upper Coal-measures (?)		900
	Middle Coal-measures (Brockwell Coal at base)		2,000
	Lower Coal-measures		150
	Millstone Grits		400
Lower Carboniferous	Bernician	Shales and thin coals; Limestones, shales and coals	2,000
	Tuedian:	Conglomerate and grits (without coals)	1,200

The coals of the Bernician Series in Northumberland are less persistent than those in the Coal-measures, but increase in number and thickness going from south to north.

The Fells Sandstone forms the base of the Bernician coal series. Between this and the Dun Limestone, 500 feet above the Fells Sandstone, there lies the important group of seams known as the Scremerston coals. These range from 2 feet 2 inches to as much as 5 feet in thickness, and, in ascending order, include the Wester, Cooper Eye, Three-Quarters, Bulman, Hardy, Blackhill or Scremerston Main, and Fawcett coals.

Above the Eelwell Limestone, 400 feet above the Oxford Limestone and about 800 feet above the Dun Limestone, is a well-known seam of the central district called the Shilbottle Main Coal. A seam worked extensively in the Tyne Valley, and known as the Little Limestone Coal, lies above the Dryburn Limestone, and forms one of a group named the 'Lickar coals.'

Two seams, known as the Cowden and Gunnerton coals, occur below the horizon of the Shilbottle Main Coal in the Belsay district. In Tynedale, below the Scar Limestone, seams are worked under the name of Lewisburn, Splint, Shilburnhaugh, Greeneyes, Plashetts, and Thirty-Inch coals in ascending sequence.

The quantity of coal down to a depth of 2,000 feet remaining unworked in the exposed Bernician Series is estimated at 1,523,750,000 tons, and that in the same series concealed beneath the Coal-measures at 305,041,668 tons, in seams from one foot in thickness upwards, after deduction is made for the amount not able to be worked.

Numerous dykes of basalt, with a general north-north-east and south-south-west trend, traverse the

Lower Carboniferous rocks, and some of them extend into and cut across the Coal-measures. The Great Whin Sill is an intrusive sheet of basalt which has forced its way sometimes along the bedding planes of the Carboniferous rocks and sometimes across them. The amount of coal lost by the destructive action of this igneous material is seldom great.

The Millstone Grits and Lower Coal-measures contain a few thin workable seams.

The Coal-measures cover an area of about 800 square miles. They extend seawards, and are considered to be workable for a distance of three miles eastwards from the coast-line.

Twenty-three seams out of a total of sixty are regarded as workable. In ascending order the chief seams are: The Brockwell (Denton Low, Low or Main), Three-Quarter, Five-Quarter, Low Main of Northumberland and Hutton Seam of Durham, Bensham or Maudlin, High Main (Wallsend). These range from 3 to 7 feet in thickness, and are mostly of the bituminous type, the field being especially famous for its house and gas coals.

The structure of the coalfield is that of an irregular basin, with its axis directed north and south. The strata rise at a fairly constant angle to the north-west, but flatten out eastwards, and in some cases rise towards the surface. The basin structure is interrupted on the south by the Butterknowle Fault, with an upthrow to the north of 80 to 140 yards.

West of the main coalfield, and extending into Cumberland, limited areas of Coal-measures occur on the downthrow side of the Stublick Dyke Fault, forming the small coalfields of Stublick, Plainmellor, Coanwood, and Midgeholme.

South of Tynemouth the Coal-measures disappear beneath the Magnesian Limestone Series. The two formations are quite discordant, and it is evident that the earth-movements affecting the older strata were almost completed in pre-Permian times. Thus, the fault known as the 90-fathom dyke possesses a throw of only a few feet in the Magnesian Limestone. Considerable areas of the coalfield are thickly covered by Glacial Drift, which frequently fills up and conceals the pre-Glacial hollows and valleys, as in the case of the 'Team Wash,' which is an old valley between the Tyne and the Wear, fifteen miles wide, and in places filled to a depth of 300 feet with gravel and clay, against which the coal-seams abut.

The Coal-measures are rich in fossils, but the coalfield has not been systematically zoned, or the fossils as a whole collected with this object in view. Distinctive fossil horizons appear to be: (1) A band with *Carbonicola robusta* in the roof of the Brockwell Seam; (2) a marine bed with *Cephalopoda*, 888 feet below the Hutton Seam; (3) a marine bed with *Brachiopoda*, 17 feet above the Five-Quarter Coal; (4) the Zone of *Anthracomya phillipsi* in the highest visible measures.

In Northumberland the Coal-measures down to a depth of 2,000 feet contain an available supply of 3,680,833,973 tons. Of this quantity, 1,112,910,292 tons lie beneath the bed of the North Sea. In Durham, down to a depth of 3,000 feet, 4,401,087,735 tons remain available under the mainland, and 870,028,611 tons under the sea.

SCOTLAND.

The coalfields of Scotland occur in about a dozen more or less separate basins, occupying the central low-

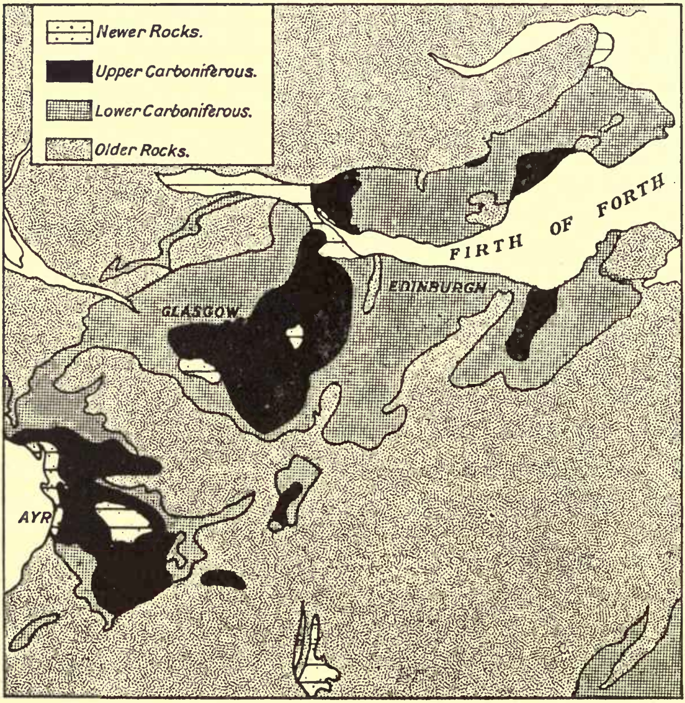


FIG. 16.—THE COALFIELDS OF SCOTLAND.

lands and stretching from the Firth of Clyde to the Firth of Forth. Numerous coal-seams occur in the Lower as well as in the Upper Carboniferous Series, more than one-quarter of the coal still remaining to be worked lying in the Carboniferous Limestone Series.

The original area over which the Carboniferous strata were deposited lies between the Ochil and Lennox Hills on the north, and the Lammermuir and Southern Uplands of Ayrshire on the south. Owing to earth-movements in operation during the Carboniferous period, the sediments were deposited in an irregular manner, and it is a matter of speculation as to what extent these separate coal-basins were originally connected, and how much of their present isolation has been brought about by post-Carboniferous folding and denudation. It is, however, usually considered that the Upper and Lower Carboniferous strata once continuously covered an area of 3,600 square miles, which has been reduced by subsequent denudation to about 1,680 square miles.

The complete Carboniferous succession in Scotland is as follows:

THE CARBONIFEROUS SEQUENCE IN SCOTLAND.

		Feet.
Coal-measures	Red sandstone and shales	600
	Upper Coal Series	300
	Lower Coal Series	800-1,500
Millstone Grits: Roslin Sandstone or Moorstone Rock		0-700
Carboniferous Limestone Series	Upper Series of limestones	—
	Sandstone, shales and coals	—
	Lower Series of limestones	—
Calciferous Sandstone Series: sandstones and conglomerates		—

Old Red Sandstone.

The term Lower Coal-measures is sometimes, though erroneously, applied in Scotland to the coal-bearing portion of the Carboniferous Limestone Series, while the measures above the Millstone Grits are frequently alluded to as Upper Coal-measures. The equivalent of the Upper, Middle and Lower Coal-measures of England are, however, the coal-bearing strata above the Roslin Sandstone, while the Carboniferous Limestone coals of Scotland are unrepresented in England south of the Wharfe anticline. The Lower Carboniferous rocks of the Midland and Southern provinces, as before mentioned, contain no workable seams.

Mr. Kidston considers that in Scotland the coal-bearing strata above the Roslin Sandstone include the representatives of the Lower Coal-measures (Lanarkian) and the Middle Coal-measures (Westphalian).

The overlying red sandstones and shales with the *Spirorbis* limestones of Fife and Midlothian have been grouped with the Upper Coal-measures of England; but this correlation, resting solely as it does on partial lithological resemblances, has not been generally accepted, the red measures being placed in the Middle subdivision of the English Coal-measures.

The palæontology of the Carboniferous formation of Scotland has been examined in much detail.

A distinct subdivision of the Carboniferous sequence into an Upper and Lower portion has been established on the evidence of the vertical distribution of the fossil plants and fishes. The species, and in many cases the genera, found in the strata below the Roslin Sandstone are distinct from those met with above it. The vertical distribution of the mollusca, however, differs from that of the English Carboniferous Series. On the whole, the genera and species tend to appear lower down in the sequence in Scotland, and such genera as *Carbonicola* and *Anthracomya*, unknown below the Millstone Grit in England, are found in the Carboniferous Limestone Series. Whether the distribution of the mollusca, marine or estuarine, will serve the same useful purpose in the determination of horizon in Scotland as it does in England remains to be proved. It is, however, certain that the order of their appearance is somewhat different among the Carboniferous rocks of Scotland.

Igneous intrusions, in the form of dykes and sills rarely met with in the Carboniferous formation of England, except in Northumberland and among Lower Carboniferous rocks of Derbyshire, are very general in Scotland, and especially in Ayrshire.

The coalfields of Scotland are those of Ayr, Lanark (including the Douglas Coalfield), Renfrew, Dumbarton, Stirling, Linlithgow, Clackmannan, Midlothian, Fife, and the Firth of Forth, the most important being Midlothian, Lanark, and Fife.

In Ayrshire the Coal-measures and Lower Carboniferous rocks, though occupying considerable areas, are poor in coal, and much intruded into by igneous material. Occasionally, as at Guilt and Gosswater, pockets of thick coal have resulted from the union of two or more seams. The coals are generally bituminous, with a high percentage of volatile matter, but are sometimes locally converted by igneous intrusions into varieties of steam coal and anthracite.

Midlothian Coalfield.—The Carboniferous rocks here lie in a trough sunk in the Old Red Sandstone of the Pentland and Lammermuir Hills. In the centre of the basin the coals lie nearly horizontal (Flat Coals); at the margins they are highly inclined (Edge Coals). The Flat Coals occur at the surface in the Coal-measures and the Edge Coals in the Carboniferous Limestone Series, but traced from the outcrop towards the centre of the basin, the Edge Coals, from being nearly vertical, become inclined at 1 in 10, and ultimately become horizontal (Fig. 17).

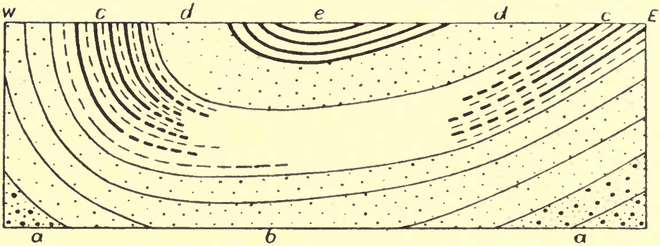


FIG. 17.—SECTION ACROSS THE MIDLOTHIAN COALFIELD.

(*e*) Coal-measures with Flat Coals; (*d*) Roslin Sandstone; (*c*) Carboniferous Limestone Series with Edge Coals; (*b*) Calciferous Sandstone Series; (*a*) Old Red Sandstone.

In the Carboniferous Limestone Series the seams deteriorate rapidly in thickness and quality towards the south, a united thickness of 100 feet in the north being reduced to a few thin seams of poor quality in the south.

In the north the coals can be grouped according to their occurrence in relation to the limestone bands. Between No. 6 and No. 5 limestones at the top of the sequence the seams are all thin; between No. 5 and No. 4 limestones two seams occur, averaging 2 feet in thickness; between No. 4 and No. 3 limestones over twenty seams are met with, the most important of these being the Great Seam and Stairhead Coal. The coals between No. 3 and No. 2 limestones are unimportant, and the North Greens is the only seam of any consequence between No. 2 Limestone and No. 1, or Index Limestone.

The Carboniferous Limestone coals usually contain bands of cannel, amounting, in the case of the Great Seam, to over 2 feet in thickness.

In the Coal-measures the seams are thicker and more numerous in the west than in the east, and, like the seams in the Carboniferous Limestone Series, deteriorate south of the Sheriffhall Fault, which traverses the coalfield from east to west between Dalkeith and Gilmerton. This fault introduces the highest measures, the red sandstones and clays of Dalkeith Park, formerly thought to be equivalent to the red clays—Etruria Marls (p. 176)—of the Midland coal-basin in England, but now usually referred to the Middle Coal-measures.

The chief seams in ascending order are: Seven Feet, Fifteen Feet, Nine Feet, Jewel, Diamond, Beefie, and Splint; and in the south a seam known as the Great Seam (not to be confounded with the seam bearing the same name in the Carboniferous Limestone Series) occurs towards the top of the exposed measures, and, though of poor quality, can be economically worked.

A nearly continuous section between the lower part of the Coal-measures and No. 6 limestone is exposed on the foreshore at Joppa. At Musselburgh, on the east side of the basin, a marine band, apparently absent at Joppa, is found some distance above the Millstone Grits. With the exception of these shore sections and those in a few quarries inland, the Coal-measure strata are rarely visible, being hidden for the most part under Glacial Drift. Towards the centre of the basin the banks of the Esk afford good sections of the highest red measures.

Fife Coalfield.—With an area of 170 square miles, this coalfield extends east and west parallel with the Forth River and Firth of Forth. Along the northern boundary, faults introduce lower formations. To the west the coalfield joins that of Alloa, and on the south unites itself with the Carboniferous strata of Linlithgow and Midlothian. Seawards its limits are not definitely known.

The area around Dunfermline furnishes the type region of the Carboniferous Limestone coals, the chief seams in ascending sequence being the Dunfermline Splint, Five Feet, Lower and Upper Eight Feet, Swallow Drum, and Six Feet.

The Dunfermline Splint yields a house and first-class steam coal, with a carbon percentage of 81.

The Coal-measure coals are chiefly confined to the sea border around Dysart and Leven. A coast section shows seventeen seams, giving a thickness of over 74 feet of coal. The workable seams from below upwards are Dysart Main, Earl's Parrot, Chemiss, Coxstool, and Barncraig.

A large quantity of coal lies beneath the Firth of Forth, but how much of this is obtainable depends to some extent on the character of the rocks beneath the sea sands. If these prove to be of impervious boulder clay, such as occurs over the workings opposite Bowness, it is reasonable to estimate that, within the three-mile limit, coal could be worked beneath the Firth to the extent of 1,000,000,000 tons. It is calculated that the lower seams underlie an area of thirty-nine square miles at a depth not exceeding 4,000 feet, and that the upper seams extend over an area of fifty-eight square miles.

Lanarkshire Coal-basin.—Famous for its black band ironstones and the boghead coals of Armadale and Torbanehill, this coal-basin forms the chief coal-producing area in Scotland, and embraces the coalfields of Glasgow, Lanarkshire, and Linlithgowshire. As much as 95 per cent. of the coal output comes from the Coal-measures obtained from 250 collieries, while only fourteen collieries work the seams in the Carboniferous Limestone Series.

The Coal-measures rest on the representative of the Roslin Sandstone with the Carboniferous Limestone Series below. At Hamilton and Bothwell, situated in the deepest portion of the basin, the Coal-measures are overlain by red sandstones, once believed to belong to the Old Red Sandstone, but now proved to be of Coal-measure age.

Among the Coal-measures, the Drumgray, Kiltongue, Virtuewell, Splint, Main, and Ell seams are the most important.

The well-known boghead gas coal or Torbanehill cannel coal, now nearly exhausted, proved to be of very irregular occurrence, seldom exceeding a few inches in thickness.

Argyll and Sutherland Coalfields.—A limited area of Carboniferous rocks occurs on the west coast of Kintyre at Machrihanish Bay. The seams are eight in number, the two lowest being 12 and 8 feet thick respectively. Three seams of anthracitic coal have been found at the north end of Arran, and may form a continuation of the Ayrshire Coalfield. In Sutherland there is a limited area of Oolitic and Jurassic coals along the sea-coast at Brora. The chief seam is the Main Coal; another below it, named the Parrot Coal, is a shaly coal of inferior quality.

The net available quantity of coal remaining unworked in Scotland is estimated at 15,681,456,356 tons.

IRELAND.

A geological map shows that the greater part of Ireland is largely composed of Lower Carboniferous strata resting on older formations. Coal-measures are represented in small detached areas in the north, and to a larger extent in the south.

The north-east and south-west structural lines determining the orientation of the coalfields in the Northern Province of Great Britain extend across the North Channel into Antrim and County Mayo, and the east and west tectonic lines of the Southern Province are continued across St. George's Channel into Queen's County, Limerick, Cork, and Kerry.

Coal-measures are found within the folds belonging to these general lines of structure, but the equivalents of the Coal-measures of the Midland Province of England have been entirely swept away, if, indeed, they ever existed over Central Ireland.

Concurrently with the distribution of the Carboniferous rocks the seams vary in character. In the north they are bituminous, and are found in the Lower Carboniferous strata as well as in the Upper Carboniferous. In southern Ireland the seams are semi-bituminous or anthracitic, and belong to the upper division of the Carboniferous, agreeing both in age and character, though much less developed, with the coals of South Wales.

The area of the productive Lower Carboniferous measures in northern Ireland, excepting possible extensions under the newer formations of Antrim, is of limited extent, while in Munster, where the Upper Carboniferous formation attains its greatest development, it is the lower or least productive subdivision that forms the greater part of the coalfield.

The extent of the coalfields of Ireland has been estimated at 79,090 acres, and the total coal tonnage at 204,107,700, or under 3,000 tons per acre—that is, less than the quantity contained in an acre of coal 3 feet in thickness. Between 1880 and 1892 the production amounted to 2,542,000 tons, an average of 110,521 tons per annum. In 1905 the output fell short of 100,000 tons.

Black shales, but containing impure, earthy limestones (calp), met with in the Lower Carboniferous rocks, so closely resemble the productive Coal-measures that they are still frequently mistaken for them; but they may be readily recognized by the presence of *Posidonomya becheri*, Goniatites of a Lower Carboniferous facies and other Lower Carboniferous fossils.

The principal Irish coalfields are those of West Munster, East Munster, Leinster, Connaught, and Tyrone of Upper Carboniferous age, and the small coalfield of Ballycastle belonging to the Lower Carboniferous formation.

In point of size the West Munster Coalfield is the largest, but the lowest measures (marine), rarely containing coals over 2 feet in thickness, occupy the greatest area. The highest measures in the Black Water Valley and County Cork contain two coals at the summit, known as South or Harris's Bulk Vein, and the Bulk Vein, from 5 to 7 feet in thickness, resulting from the union of two or more seams.

In East Munster the highest measures are estimated to be 1,300 feet thick, containing the Clashacona and Parknaclea seams at the top. The first-named, averaging 2 feet in thickness, is described as a good anthracite, but with a bad roof. The Parknaclea Coal, 4 feet thick, has been exhausted. In Leinster the highest measures are considered to occur in the Castlecomer Coalfield, which contains five seams, giving a total thickness of 9 feet of coal, distributed through 700 feet of strata. Between this coalfield and the districts of Coolbaun and Newtown is a fault with an upthrow west. Five seams are recognized at Coolbaun and Newtown, the best known being the Jarrow Coal, varying in thickness from 3 inches to 6 feet. Numerous fossils have been obtained from a thin band of carbonaceous shale forming the roof.

The chief coalfields of County Tyrone are those of Dungannon and Coal-island, containing several seams, among which are the Annagher Coal (7 to 9 feet), the Blackaveel Coal (5 feet), the Derry Coal (4 feet 6 inches), and the Drumglass Main Coal (4 feet). Very little coal-mining is at present being carried on in this district.

The Coal-measures of Ballycastle, County Antrim, are compared with the Edge coals of the Lower Carboniferous rocks of Scotland. Three seams were formerly worked, but the coalfield is now regarded as practically exhausted.

CHAPTER XIII

COALFIELDS OF CONTINENTAL EUROPE

THE chief coals on the Continent are of Carboniferous age, but coal is also met with in large quantities, though of inferior quality, in the Mesozoic and Tertiary formations.

In western Europe the distribution of the Carboniferous rocks has been chiefly determined by the two great earth-movements known as the Armorican and Hercynian disturbances.

The Armorican uplift resulted in the formation of mountainous ridges, stretching in a general east-and-west direction from Armorica to Bohemia, and of corresponding depressions in the north. In these hollows, to which the Carboniferous sea had access, the Carboniferous Limestone (Dinantian) and the Coal-measures (Westphalian stage) were laid down in Germany, Belgium, and northern France, but no deposition took place over the elevated regions to the south.

Succeeding the Armorican uplift, the Hercynian movement reversed the prevailing land features, elevating the northern areas while the central region became depressed, and a series of freshwater lakes was formed, in which the highest Coal-measures (Stephanian stage) of Europe were deposited.

Sedimentation and coal formation were therefore taking place over the central region, while the Westphalian Coal-measures in the north were being folded and denuded.

The combined results of these two great disturbances constituted the chief later Palæozoic mountain-building period of western Europe, known as the Variscan.

The Stephanian and Westphalian Coal-measures were subsequently covered up by the deposits of Permian age. These follow consecutively on the Stephanian Coal-measures in the central region, but rest with a great discordance on the upturned and denuded edges of the Westphalian Coal-measures in the north.

While western Europe was undergoing alternate elevation and depression in Carboniferous times, a depression to which the sea had access lay over eastern Europe throughout the period represented by the Carboniferous and Permian formations.

The Continent, therefore, presents two types of Carboniferous rocks—a western type composed of marine, estuarine and freshwater sediments, and an eastern type in which the sediments are wholly marine.

The main divisions of the Carboniferous formation of Europe, and the conditions under which they were laid down, may be expressed in tabular form (see p. 233).

Some British geologists consider the Stephanian stage to be represented by the Upper Coal-measures, but continental geologists are generally agreed that the Stephanian Coal-measures are absent in Great Britain.

The most important coalfields on the Continent are those of Westphalia, Belgium, and northern France.

THE CARBONIFEROUS SEQUENCE IN EUROPE.

Great Britain.	Western Europe.	Eastern Europe.
?	Stephanian—fresh-water. (Unconformity.)	Uralian—marine. (Conformity.)
Upper Carboniferous.	Westphalian—marine and estuarine. (Conformity.)	Moscovian—marine. (Conformity.)
Carboniferous Limestone Series.	Dinantian—marine.	Dinantian—marine.

BELGIUM.

As a result of folding and subsequent denudation, the Carboniferous rocks of Belgium occur in three basins, extending east and west, and separated from each other by ridges of older rocks. The central and most important basin—that of Namur and Liége—is flanked on the south by the Silurian ridge of Condros (Crête du Condros), and on the north by the partially concealed Silurian plateau of Brabant. South of the ridge of Condros an east-and-west fold introduces the Carboniferous basin of Dinant, the strata of which are chiefly Lower Carboniferous. North of the Silurian plateau of Brabant a fold again brings in the Coal-measures of the recently discovered but concealed coal-field of the Dutch Limburg.

The structure of the central basin of Namur and Liége is one of considerable complexity, the strata being thrown into sharp zigzag folds and crossed by numerous overthrust faults, as in the adjoining French coalfields of Valenciennes and Pas de Calais.

The Carboniferous strata fall into two main groups —a lower or Dinantian, and an upper or Coal-measure group.

The Coal-measures have been divided by Belgium geologists into a lower stage, Namurian (Lower Coal-measures), and an upper stage, Westphalian (Middle Coal-measures), these being subdivided as follows:

Division.	Subdivision.	Thickness in Feet.
Westphalian	Beds of Charleroi	3,000
	Beds of Chatelet	1,000
Namurian	Beds of Andenne	700
	Beds of Chokier	80

The strata bear a closer resemblance to the Coal-measures of the central than to those of the south-western coalfields of England. Shales predominate over the sandstones in the proportion of 260 to 70. Beds of impure limestone from 1 to 3 feet in thickness, and apparently unfossiliferous, occur in the Westphalian division, but are not met with in the Namurian Coal-measures.

As in England, two distinct faunas—the one marine, the other estuarine or freshwater—characterize the Westphalian division of the Coal-measures. Apparently, however, the estuarine and freshwater Lamellibranchiata do not adhere to the same general order of appearance as in the Middle Coal-measures of England. Thus, *Anthracomya phillipsi*, which is confined to the highest zones in England, is met with in the Namurian division, of which the fauna, with this exception, is

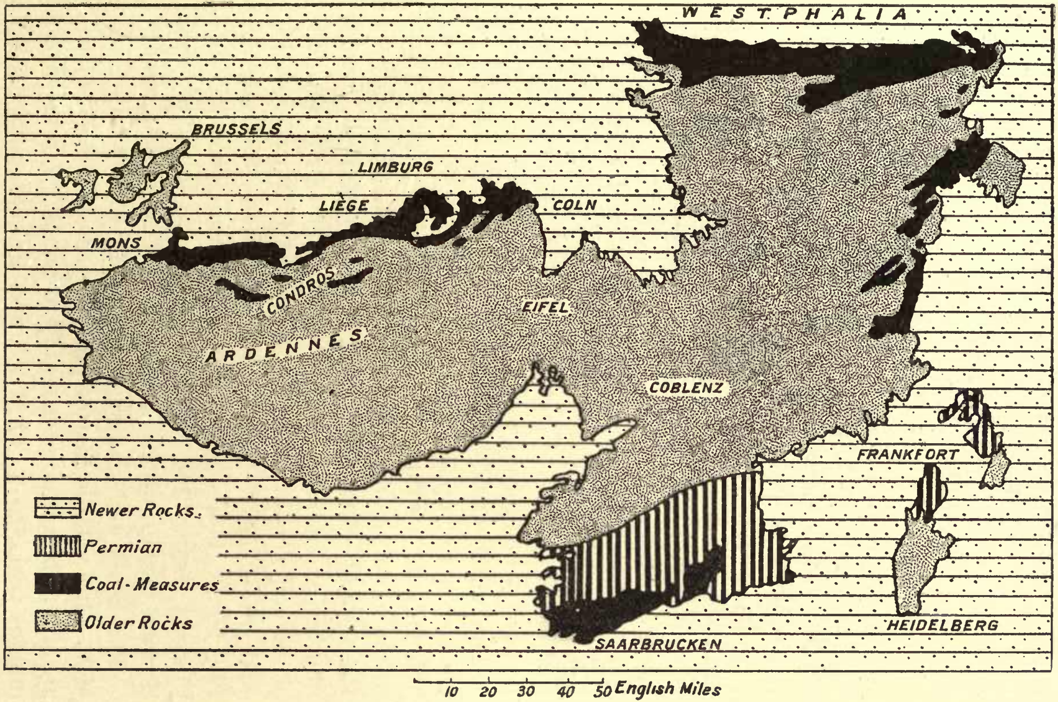


FIG. 18.—THE COALFIELD SURROUNDING THE ARDENNES *MASSIF*.

entirely marine. *Carbonicola turgida*, again, extends throughout nearly the whole of the Westphalian division, and cannot, therefore, be used as even an approximate index of position in the sequence.

The distribution of the lamellibranchs throughout the strata of the Belgian coalfields has not received the close attention that it has in this country, and possibly some parallelisms may be demonstrated on more minute examination.

Judging from the little at present known, it seems probable that the Coal-measures of the Namurian basin are altogether distinct from those of the Midland coal-basin of England.

The marine fauna met with at several horizons in the Westphalian division contains the same species of *Lingula*, *Pterinopecten*, and *Goniatites* as those of the Upper Carboniferous rocks of Britain.

The chief coal-seams are found in the Beds of Charleroi, the upper subdivision of the Westphalian. The Charleroi strata are again divided, and are known to the miner, in descending order, as the Saint-Gilles, Liége, and Seraing groups. The exploited seams number about fifty, of which forty are usually and ten occasionally workable. Out of a total of 133 feet of coal, the Charleroi Beds yield a united thickness of 123 feet. The seams are mostly thin, one of the thickest being the Grande-Veine-des-Dames of the Seraing Group, which averages 4 feet over large areas.

The coals are classified according to the value of M.V.—the volatile matter present—as gas coals (29 to 45 M.V.), bituminous coals (17 to 29 M.V.), semi-bituminous coals (10 to 17 M.V.), and short flaming coals, in which the value of M.V. falls below 10 per cent.

As a rule the seams highest in the sequence contain the greatest amount of volatile matter, which decreases in the deeper-seated coals, though the gradation is not everywhere uniform, and there are some notable exceptions.

The output of the Belgian coalfields in 1904 amounted to 22,761,430 tons, obtained from the Namurian basin.

A new but entirely concealed coalfield in the Campine in Dutch Limburg has, within recent years, been proved beneath the Tertiary and Secondary rocks in North Belgium. This coalfield, as previously men-

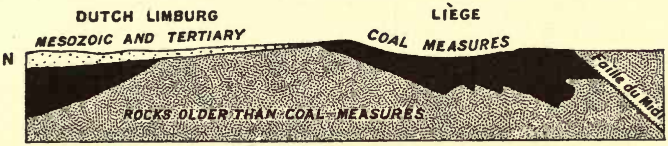


FIG. 19.—THE RELATION OF THE CONCEALED COALFIELD OF THE CAMPINE TO THE EXPOSED COALFIELD OF LIÈGE.

tioned, is separated from that of Namur by an uprise of Silurian and Devonian rocks. The area at present proved is estimated at 400 square miles. The southern margin of the basin has not yet been determined, but the Coal-measures are expected to extend westwards as far as Antwerp. From the Meuse up to Westerloo and Sauthoven over thirty borings have been put down. Three of these, situated in the north, ended in Triassic strata at great depths, but many others proved Coal-measures with seams having a high percentage of volatile matter, and considered to belong to the horizon of the *flénu* coals of Mons.

FRANCE.

Though fairly rich in coal, France does not produce sufficient for home consumption. For this reason seams of inferior quality, or those of a better class, but averaging little more than a foot in thickness, and often obtained with considerable difficulty, prove sufficiently remunerative to be worked.

The coalfields of France occur in about fifty isolated patches generally grouped as the northern, central, and southern coalfields. Many of them are of small size, and the richest and most extensive, that of northern France, belongs for the most part to the concealed coalfields, where the seams are obtained from beneath a thick covering of newer rocks.

The complete Carboniferous sequence consists of three divisions, known in descending order as Stephanian (Upper Coal-measures of England), Westphalian (Middle Coal-measures), and Dinantian (Carboniferous Limestone Series).

The Stephanian measures do not occur in the same region as the Westphalian, and, as before stated, a great unconformity is considered to separate these two divisions.

The coal-seams are confined to the Stephanian and Westphalian divisions, the Dinantian being unproductive.

The Westphalian Coal-measures are limited to northern France and Brittany, the Stephanian to the central and southern provinces.

The strata of the Stephanian and Westphalian divisions may be conformably or unconformably succeeded by strata, relegated to the Permian System;

or, again, they may be overlain unconformably by Mesozoic and Tertiary formations without the intervention of Permian strata.

In France, as in England, there seems to be great difficulty in determining whether certain strata immediately following the normal Coal-measure sequence should be included in the Carboniferous or relegated to the Permian System. At present it is the custom of French geologists to divide the Permian System into two groups: a lower or Autunian, and an upper or Saxonian. In one coalfield, strata conformable to the Stephanian, and containing many fossil plants found in this division, are placed with the Autunian group of the Permian. In another coalfield, strata without any fossil evidence, either plant or animal, and resting with a great discordance on the Stephanian measures, are also placed in the Autunian group.

Northern Coalfield.—The Northern coalfield is a westerly prolongation of the Namurian coal-basin of Belgium, and with some interruptions extends from the French frontier to Boulogne. It is divided into three separate areas: the Valenciennes Coalfield on the east, the Bas Boulonnais Coalfield on the west, and that of the Pas de Calais situated between the two.

While French geologists seem to be agreed that the Valenciennes and Pas de Calais coalfields belong to the Namurian stage of depression, the opinion has been expressed that the coalfield of Bas Boulonnais belongs to a western extension of the Dinantian basin, and that the Namurian basin would be found to the north. Numerous borings, however, put down along the littoral to the north of the Bas Boulonnais have failed to prove the existence of another basin. These borings either ended in rocks newer than the Coal-measures, or in rocks older than the Carboniferous formation.

The Coal-measures belong to the Westphalian division and appear at the surface in the Valenciennes basin, but those of the Pas de Calais and the Bas Boulonnais are hidden beneath the Secondary and Tertiary formations, which, either singly or collectively, are termed 'mortes terrains.'

The Hercynian disturbance, to which the complex structure of the coalfields is attributed, was superimposed on the Namurian depression in which the Carboniferous strata were laid down. This intense earth-movement took place subsequent to the deposition of the Coal-measures, but was completed and the Carboniferous strata were extensively denuded before the laying down of the earliest Mesozoic strata, so that a great unconformity intervenes between the Carboniferous and the newer strata. Again, earth-movements of a later age than the Mesozoic were superimposed on the earlier Hercynian folds, and these newer folds are often found to agree in direction and character with those of the Hercynian.

The Hercynian movement consisted of a powerful thrust from the south, which buckled up the Carboniferous strata into a series of overfolds trending east and west and sloping to the south. This overfolding has resulted in the complete inversion and constant repetition of the order of the strata by minor thrusts situated between the major thrusts (Fig. 20).

The overfolding naturally resulted in the formation of numerous thrust faults, and of these two major thrusts play an important part in the general structure of the coalfields. A major thrust known as the 'Faille du midi,' or 'Faille limite,' extends along and forms the southern boundary of the coalfields, while a complementary thrust fault, called the 'Cran de retour,' limits the coal-basin on the north.

Along the line of the 'Faille du midi,' Dinantian and even Devonian strata are frequently thrust over Westphalian Coal-measures, so that a shaft may enter Coal-

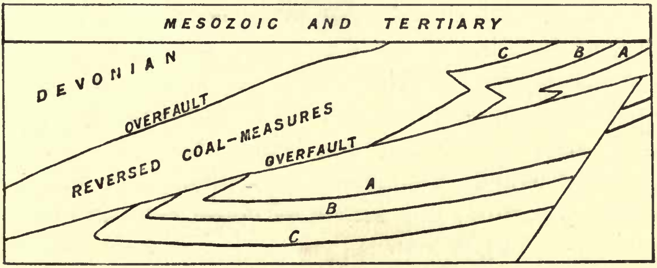


FIG. 20.—DIAGRAM TO ILLUSTRATE THE REPETITION OF COAL-SEAMS BY OVERTHRUSTS IN THE COALFIELDS OF NORTHERN FRANCE.

measures after penetrating these older strata. In other cases, as a result of overthrusting, a considerable thickness of Coal-measure strata may lie between two layers of Dinantian Limestone, the appearance of interstratification being so deceptive that for a long time the Coal-measures of northern France were considered to be of Dinantian age.

Again, in an overthrust area the order of the coal-seams becomes inverted, and the seat-earths or beds of clunch, which lie beneath the coals when in the natural order of sequence, come to lie over the seams, frequently causing the coals to have a bad roof for mining.

The seams of coal in the northern coalfields, though numerous and persistent for considerable distances, are mostly thin, the average thickness being about $2\frac{1}{2}$ feet; but by the union of two or more seams a thickness of 12 feet may be locally attained, as when the Beaumant and Leonard veins, of the Pas de Calais Coalfield, come together. The seams change their character from below upwards, the volatile matter ranging from 8 to 10 per cent. in the lowest seams to 40 per cent. in the highest; but, as in other coalfields, exceptions to this general increase occur. A thrust fault may also cause a series of coals of a semi-bituminous or anthracitic character to lie above seams rich in volatile matter.

The basin of Valenciennes contains four veins of anthracite, thirty-one seams of house coal, and thirty-one seams of gas coal.

The seams of the Pas de Calais Coalfield number about ninety, with a united thickness of 250 feet of coal.

Coalfields of Brittany and Normandy.—The small lineally arranged coalfields of Saint Laurs, Faymoreau, Vouvant, and Chantounay, which border the old Vendean massif, are of Lower Westphalian age. These coalfields are situated along a line of fracture, and the strata, especially the shales, are frequently so intensely folded and faulted that they often bear a close resemblance to the adjacent older rocks.

At Plessis and Littry, two small coal-basins, are considered to represent the highest beds of the Stephanian, for they are conformably overlain by strata of Permian

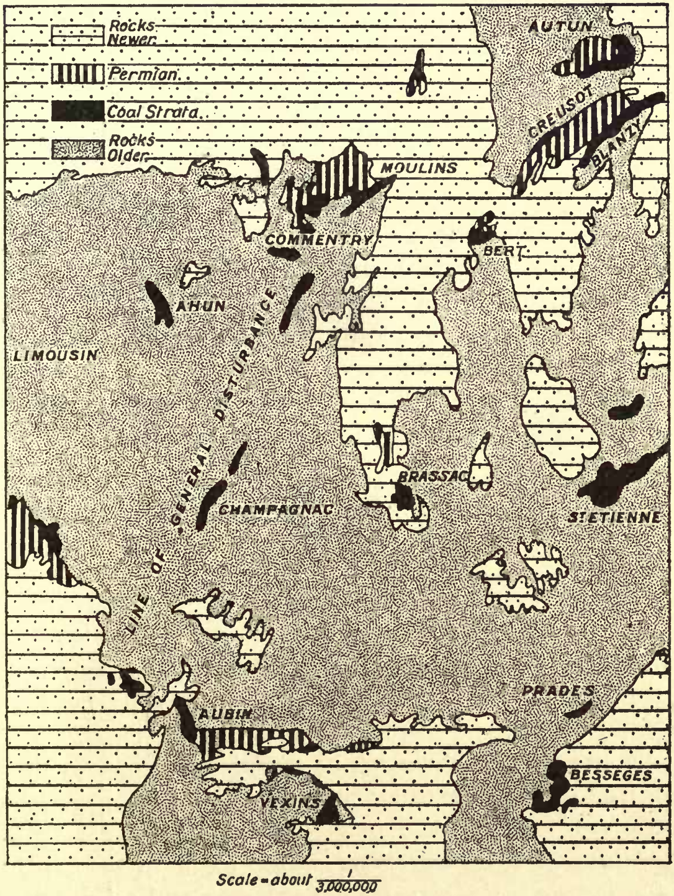


FIG. 21.—THE COALFIELDS OF CENTRAL FRANCE.

age. In the Laval basin the coal-bearing rocks of Saint Pierre de la Cour are of Middle Stephanian age, and rest discordantly on the Dinantian Series. The coals, numbering seventeen, are of a bituminous character, and range from 6 inches to 2 feet in thickness.

Coalfields of Central France.—Of the various small coalfields, all of Stephanian age, which lie scattered over the central plateau of France, the largest and most productive are those of Blanzy and Creusot, Saint Etienne, Commentry, Gard, and Brive. All these coalfields have more or less probable extensions beneath the Permian or later formations, but many of the smaller coal-basins are strictly limited by the surrounding crystalline rocks.

The separate coalfields are arranged along the western and southern margins of the plateau, and along the line of central disturbance.

On the western margin, in the north, the small basin of Décize yields eight seams of coal from 6 to 12 feet in thickness.

The lower portion of the sequence in the Autun basin contains workable seams at Epinac, while an upper portion, consisting of sandstones and conglomerates, contains a few thin seams, which are mined at Grand-Moloy.

In the Morvan basin, which includes the coal districts of Blanzy and Creusot, the Stephanian Coal-measures crop out for a limited distance from beneath a thick covering of Permian strata, which occupies the centre of a narrow basin, stretching north-east and south-west, and separated from the Autun Coalfield by an anticline of granite.

Four main seams of coal, varying greatly in thickness, have been recognized. At Creusot a seam, called La Grand Couche, attains a thickness of 90 feet. The seams are classified, according to the amount of volatile matter present, as:

> *Gras*, 20 to 26 per cent. of M.V.
> *Mi-gras*, 16 to 20 per cent. of M.V.
> *Maigre et anthracite*, 12 to 16 per cent. of M.V.

In 1900 the output amounted to 1,633,998 tons.

The structure of this coalfield appears to admit of two interpretations. According to some geologists, the Coal-measures, which crop out at Blanzy, are continued beneath the overlying Permian strata, from under

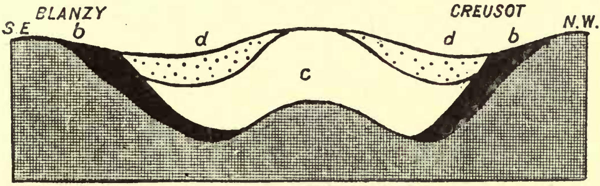


FIG. 22.—THE CREUSOT COALFIELD, SHOWING THE COAL-MEASURES (*b*) OVERLAIN BY THE AUTUNIAN PERMIAN (*c*), AND THESE BY THE SAXONIAN PERMIAN (*d*).

which they rise on the opposite side of the basin at Creusot. Other geologists maintain that the coalfield of Creusot is distinct from that of Blanzy, and that the Coal-measures do not exist over the central parts of the Morvan basin.

According to the latter theory, the Coal-measures were deposited in an eroded hollow of crystalline rocks. Subsequently, but long prior to the deposition of the Permian strata, the floor of this basin was bent up along a medial line, and two structural basins—the one of Blanzy and the other of Creusot—were thus formed. Denudation then took place on an extensive scale over these two areas, which were subsequently buried beneath the bituminous sandstones and shales of the Autunian or Lower Permian division. These Autunian measures were again denuded before the red sandstones and shales of the Saxonian Permian were deposited over them (Fig. 22).

The Creusot Coalfield is separated by an axis of Archæan rocks from the Dinantian basin of Roannais. To the south the Archæan rocks of Haut Beaujolais and Haut Lyonais isolate the narrow basin forming the small coalfield of Saint Foy from that of Roannais on the one side, and from the important coalfield of Saint Etienne on the other.

The base of the Saint Etienne sequence is a breccia, over 500 feet in thickness, which is conformably overlain by a conglomerate varying from 600 to 2,500 feet thick. This is succeeded by the productive Coal-measures of Saint Etienne, consisting of a lower group (Saint Chamond) 2,800 feet thick with twelve seams of coal; a middle group (Bérard) over 1,000 feet thick with nine coal-seams; and an upper group (Aveize) from 600 to 700 feet thick with twelve coal-seams.

The Saint Etienne Coalfield is prolonged beneath the Secondary and Tertiary formations towards the Jura.

Further south the basin of the Gard forms an important coal district, from its proximity to the maritime border and the possibility of its extension eastwards, though at considerable depths, beneath the Liassic and Triassic formations. The Coal-measures, all of Stephanian age, exceed 8,000 feet in thickness. The richest portion, 3,000 feet thick, forms the Bességes group, and lies about 1,000 feet above the base of the Coal-measures, which consists of a coarse conglomerate resting on rocks of Pre-Cambrian age.

A large fault bounds the coalfield on the east, and the strata are much folded and faulted, due in part to the Alpine movement.

From near Moulins on the northern margin to Aubin on the southern, a linear series of small isolated coalfields of Stephanian age extends across the central plateau. The most important is that of Commentry in the north, well known from the classic researches of M. Fayol into the origin of coal and the formation of the Coal-measures, and also from the presence of a seam of coal, La Grande Couche, exceeding 60 feet in thickness, and worked by open cast.

The Coal-measures which belong to the later stages of the Stephanian division consist mainly of loose, coarse-grained sediments, extremely false bedded and roughly stratified.

In Autun a considerable thickness of strata conformably overlies the coal-bearing Stephanian measures, but these higher strata are considered to belong to the Permian and not to the Carboniferous period. They are divided into three groups, each of which contains workable seams of boghead coal.

The lower group, about 1,200 feet thick, contains the seams worked at Ignornay, Saint Leger, Du Bois, and Lally. In the middle group, about 1,000 feet thick, the coals are worked at several localities, and those contained in the upper group are obtained at Millery and Sur Moulin.

In the lower and middle groups the flora has a Coal-measure facies, but the strata at Millery and Sur Moulin contain many specimens of *Callipteris* and *Walchia*, which occur, though rarely, in the Keele beds of central England.

On the assumption, therefore, that the Stephanian Coal-measures of Autun are of Upper Coal-measure age, the coal-bearing Permian strata of Autun are among the newest Palæozoic coalfields in France.

The area of the French coalfields is estimated at 2,500 square miles. In 1905 the output amounted to 35,869,497 tons.

Germany.

Germany not only possesses extensive areas of Coal-measures of Carboniferous age, but also very thick and widely distributed deposits of Lignite and Brown Coal belonging to the Tertiary period. These later coals are indeed of great importance, and form a large proportion of the total coal output of the Empire.

The principal coalfields of Carboniferous age are those of the Ruhr or Westphalian basin, those of Upper Silesia, the coalfield of Saarbrücken, and the smaller coalfields of Saxony; all these belong to the Westphalian division.

In the Ruhr basin, estimated to cover an area of more than 1,080 square miles, the Coal-measures of Westphalian age are exposed at the surface from near Dusseldorf to the south-east of Dortmund. Along the southern margin of the coalfield the Westphalian measures rest on Dinantian Carboniferous rocks or on Devonian, while along the northern margin in the latitude of Dortmund they gradually sink beneath a cover formed by the Cretaceous and Secondary formations. This concealed area has been traced to Dorsten, near Wesel, south-west of Münster, and to near Osnabrück on the north-east, where boring has proved the existence of seven workable seams.

The exposed and concealed coalfields are collectively known as the Münster basin.

Compared with the coalfields of Belgium and northern France, the structure of the Ruhr Coalfield is very simple. The strata are thrown into a series of folds having their axes directed generally east and west, but the folds are of a more or less open nature, except in the south, where in places they assume a complex arrangement.

Anthracitic coals are of more general occurrence in the more disturbed regions, but their presence may be attributed as much to the outcropping here of only the lower seams, and, therefore, in accordance with Hilt's law (p. 41), likely to be of a less bituminous character than the higher seams. The basin edge-folding of the strata happens in this case to correspond with the difference in character of the seams, induced before the folding took place, just as along the southern margin of the South Wales basin, folding was superinduced on seams having an original bituminous character, which the subsequent folding and earth pressure did not materially alter.

The general succession of the measures in the Ruhr basin is given in the following table in descending order of sequence:

THE COAL-MEASURE SEQUENCE OF THE RUHR BASIN.

VII. Measures over 2,400 feet, with twenty-one seams of anthracitic coals (Sandkohlen).
VI. Barren measures, 280 feet in thickness.
V. Group 400 feet thick, containing seven workable seams of semi-bituminous coals (Sinterkohlen, Esskohlen).

IV. Group 300 feet thick, containing nineteen workable seams of caking coal, including the seams Rottgersbank and Katherine.
III. Barren measures, 230 feet in thickness.
II. Group with gas coals, 1,000 feet thick; eight workable seams, the thickest being the Laura Seam, about 5 feet in thickness.
I. Group with long-flaming coals; 3,300 feet in thickness, with thirty-five workable seams, and containing the well-known Bismarck Seam.

The total thickness of coal is estimated at between 230 and 250 feet, distributed among ninety seams, giving an available supply down to a depth of 4,900 feet—the maximum limit of working assumed to be possible on the Continent—of 52,000 millions of tons.

Much further investigation is needed to determine the nature of the pre-Carboniferous floor, which, however, is known to immediately underlie the Chalk at Lippstadt. The faunal and floral succession has also to be elucidated, not only locally, but generally, before the fossils can be used as an index of exact position in the Coal-measure sequence.

The coalfields of Upper Silesia cover a wide area, and extend into Austria and Poland. The Westphalian measures stretch eastwards by Rbynik to Dombrowa. Of this extensive basin 2,500 square miles belong to Germany, 630 to Austria, and 300 to Russia. Coal-seams make their appearance in the strata immediately succeeding the Culm. The upper productive measures or Schatzlar group, containing twenty seams of coal, among which is the Bismarck Seam over 20 feet thick, are separated by 1,000 feet of sterile strata from the lower productive series containing about twenty seams of coal, the thickest being a little over 4 feet.

In eastern Pologne a coal, the Redan Seam, ranges from 24 to 45 up to as much as 60 feet in thickness. On the German border this seam yields coke, the coals above being gas coals, and the highest seams yielding steam coals; but in Poland all the seams cease to produce either gas or coke.

Numerous marine incursions are met with in the sequence, among the fossils found being *Phillipsia*, *Gastrioceras listeri*, *Bellerophon urei*. At Cracovie the Westphalian commences to assume the Moscovian or eastern marine type.

The Carboniferous Coal-measures of Zwickau and Lugau in Saxony occupy limited areas, but some of the seams are in places over 30 feet in thickness.

Though not equal in extent to the Silesian Coalfield, but of approximately the same size as that of Ruhr, the Saarbrücken Coalfield takes a high position among the coal-producing districts of the German Empire. The area is estimated at about 1,080 square miles. It contains seventy-seven workable seams—one seam being over 12 feet thick—with an aggregated thickness of 260 feet of coal. The measures among which these seams are distributed belong to an horizon higher than those of the Ruhr, Belgian, or northern French basins, and lie at the base of a great thickness of overlying barren strata, referable in part to the Stephanian Coal-measures and in part to the Permian. Above the productive series there succeeds a great thickness of red conglomerates and violet-coloured sandstones and shales (Geislautern Group), containing only thin and unworkable seams of coal. Above these again come the Ottweiler beds (Kohlenrothliegende), about 6,000 to 8,000 feet in thickness. This division consists of a lower group of grey clays, with thin beds of limestone and seams of coal; of a middle group of grey sandstones and conglomerates; and of an upper group of grey shales containing beds of coal. The fossil plant *Pecopteris aborescens* is abundant, and the genus *Carbonicola* survives in the Ottweiler beds. In the overlying Permian formation, the lowest beds (Cusel) consist of grey sandstones, shales, and red marls. Plants of Coal-measure species are met with, but associated with them are *Walchia pinniformis*, *Callipteris conferta*, and *Calamites gigas*.

The extension of the Saarbrücken Coalfield into French Lorraine has been proved within recent years. The barren cover is very thick, and the seams, as shown in the boring records, are mostly thin. At Pont-à-Mousson the first seam, 2 feet 6 inches thick, was found at a depth of 2,686 feet. Below this four other seams were passed through, one at a depth of 4,204 feet being about 4 feet thick. In the Atton boring the first seam, 23 inches thick, occurred at a depth of 2,600 feet. Below this again the boring notified the existence of six seams, but none of them attained 3 feet in thickness.

An output of over 52,000,000 tons per annum affords the best proof that the Tertiary coals of Germany rank high among the fossil fuels. According to their physical characters, these Tertiary coals are known as Lignite, Erdige Kohle, Gemeine Braunkohle, Blatter (leaf) Kohle, Peckkohle (Pitch Coal), Gaskohle, and Glanzkohle. The last-mentioned variety contains the highest percentage of carbon, and represents the highest class of the Tertiary Lignitic coals as shown in the following table of analyses:

	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ash.
Lignite	57·28	6·03	36·16	0·59
Erdige Kohle	57·43	5·58	24·83	11·86
Gemeine Braunkohle	61·20	5·17	21·28	12·35
Peckkohle	69·50	4·63	20·47	5·4
Gaskohle	70·54	6·67	13·81	8·98
Glanzkohle	82·00	4·20	5·9	7·9

All the Brown coals belong to the Tertiary period. The older are of Eocene age, and the younger of Miocene age.

The older (Eocene) Brown coals extend, though in isolated patches, from around Chemnitz and Leipzig to the west of Magdeburg. The Miocene Brown coals are met with around Cologne, Aachen, Frankfurt, Cassiland, and generally in the valleys of the Oder and Warthe. Many of the deposits are mined by open cast workings. The area of lignites around Cologne is estimated at forty-five square miles, and a seam is present which averages 100 feet and sometimes reaches 300 feet in thickness.

Austria and Hungary.

Austria possesses coals of Carboniferous age and extensive deposits of Brown coal belonging to the Jurassic and Tertiary formations. The output of Carboniferous coal amounts to over 11,000,000 tons per annum, and that of Brown coal to about double this quantity.

The most important coalfield is that of the Ostrau-

Karwin district in Silesia, where twenty-five of the chief seams give a total thickness of 72 feet of coal. Altogether there are 313 seams, varying from 18 inches to 12 feet in thickness, and of these 102 are workable. In Bohemia the main seam of the Kladno-Rakonitz basin attains a thickness of 20 to 36 feet. Bohemia is rich in Brown coal; some of the seams in the Taplitz basin reaching a thickness of nearly 100 feet. Styria comes next in importance, where the Miocene lignites attain a general thickness of 80 to 100 feet, and occasionally approach 200 feet. Lower Austria contains thin seams of Triassic, Liassic, and Cretaceous ages.

Hungary is poor in Carboniferous coals, but contains extensive deposits of Tertiary lignites along the Carpathians, and in Transylvania in the Zsill Valley.

Tertiary lignites are met with in Bosnia at Zenica, Kreka, Kakanj-Doboi, in seams of 33 to 52 feet in thickness. In Servia some important workings of Liassic coals occur at Dobra on the Danube.

Roumania and Bulgaria are together responsible for an annual output of about 270,000 tons of Tertiary lignite. The largest mine in Roumania is at Margineanca, which produces 51,000 tons per annum.

Turkey possesses coal in many places, but the only important mines are situated at Eregli. The annual output from Turkey amounts to about 450,000 tons.

Greece yields lignite of good quality in Coumi, Oropos, and Aliverion, and of inferior quality in several other localities. The total output from all sources does not exceed 12,000 tons per annum.

Italy.

Italy is said to be rich in coal in the provinces of Sienna and Grosseto in Tuscany and in Sardinia, as well as in Piedmont and Undine in the north. Along the flanks of the Alpine *massif* the coal deposits chiefly belong to the Stephanian Coal-measures; but rocks, highly altered by great pressure due to the Alpine folding, are referred to the Westphalian Coal-measures. In the Carnic Alps the Uralian and Stephanian phases dovetail. Coals situated along the Alpine *massif* have been often changed into anthracite or graphite, some of the veins of graphite in the Cottian Alps attaining a thickness of 6 to 10 feet.

Italy in 1905 raised 407,887 metric tons of lignite, 1,165 tons of anthracite, and 3,341 tons of bituminous shale.

Spain and Portugal.

Carboniferous coals occur in seven provinces, but out of an output of 3,371,919 metric tons in 1905 nearly two-thirds came from the coalfields situated in the province of Oviedo in Asturia.

In this province the coalfields cover an area of 460 square miles. The principal coals, belonging to the Westphalian division, occupy about 350 square miles, and are deeply dissected in the Nalon Valley, where several seams crop out along the precipitous slopes. The seams, averaging from 2 to 6 feet in thickness, range from bituminous to anthracite. A much dislocated Carboniferous coalfield, containing seams varying greatly in thickness, but occasionally being as much as 80 feet, is that of Sabero. Another important though narrow coalfield extends parallel with the Guadiato River in Cordova. The Coal-measures are flanked by older rocks, and are much intruded by quartz-porphyries and diabases. The coal-seams are of a pockety nature, varying from a few inches up to 130 feet in thickness.

Secondary and Tertiary lignites are found in several districts, an important district being Ultrillas.

The coal areas of Portugal are of very limited extent, and the amount raised in 1905 was less than 20,000 tons. Anthracite occurs in the Douro district and bituminous coal of Jurassic age at Cape Mondego.

Russia-in-Europe.

Carboniferous rocks occurring either at the surface or lying concealed beneath Permian deposits extend over great areas in Russia-in-Europe. There are also extensive deposits of Tertiary Brown coals.

The chief coalfields of Carboniferous age are those of the Donetz basin, the Moscow basin, and the Pologne basin, with smaller areas along the flanks of the Ural Mountains.

The important basin of Donetz in southern Russia covers an area of 30,000 square miles, but the productive portion is very much less. The workable seams, which rarely exceed 5 feet in thickness, lie in two zones, one towards the summit, and the other in the middle of the sequence, separated by a band of almost sterile measures. In the upper group the seams are of a bituminous character, while those in the lower group, confined to the south-east, are of a semi-anthracitic or anthracitic nature. The basin is capable of a great

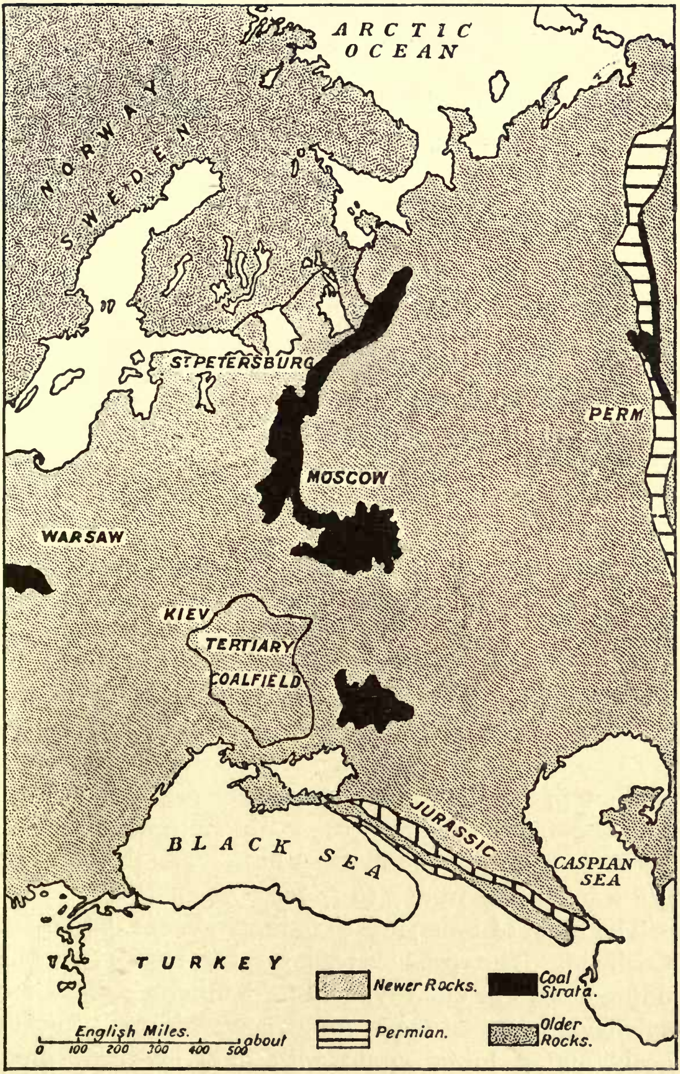


FIG. 23.—THE COALFIELDS OF RUSSIA-IN-EUROPE.

extension under the Permian formation to the east and west.

Above the highest measures containing the important bituminous coals over 3,000 feet of strata succeed, consisting to a great extent of limestone containing the fossil *Spirifer mosquensis* in association with *Productus cora* and *Fusulina ventricosa*, thus forming a passage between the Moscovian Coal-measures and the Uralian or eastern marine representative of the Stephanian measures.

The Carboniferous rocks of the Moscow basin cover an area of 150,000 square miles, but the coals only occur in the lower portion. The workable seams are intercalated between limestones containing *Productus giganteus*, and siliceous grits with *Lepidodendron veltheimianum*. Though the presence of these fossils shows the coals to be of Lower Carboniferous age, they are of the nature of boghead and lignites. The seams number over 200, but only twelve are at present worked. These vary from 24 to 60 feet in thickness, but are of a poor quality, and yield large quantities of ash. Some classes are extensively used for gas-making.

In the western Urals the coals occur in the same position in the Carboniferous sequence as in the Moscow basin, but they are true coals, anthracitic in the north and bituminous in the south. The thickness of the seams varies from 3 to 15 feet.

The basin of Pologne is a continuation of the Silesian Coalfield. The productive measures resting on the unproductive or culm-type of Carboniferous rocks are subdivided into an upper group containing the thicker coals, and a lower group with only inferior seams. The lower seams yield chiefly gas and coking coals and the higher seams give steam coal. One seam is said to attain a thickness of nearly 40 feet.

Besides Carboniferous coal, Russia-in-Europe possesses immense quantities of lignite of Tertiary age. The chief deposits are those of the basin of Kiev-Elizabetgrad, situated in the centre of the sugar-refining districts. The map (Fig. 23) shows the extent of the Tertiary basin, but the lignites occur only on the west side of the Dneiper, where they occupy an area of over 1,300 square miles in the Government of Kiev and Kherson.

Coals of Jurassic age crop out on both sides of the Caucasus. The beds are thin, but the coals on the northern flanks yield a good coke. On the southern side there are several seams giving a total thickness of over 40 feet of coal.

The total output of Russian coal in 1905 amounted to 19,628,008 metric tons.

CHAPTER XIV

NORTH AMERICAN COALFIELDS

No more striking proof of the dependence of modern civilization on coal can be adduced than that afforded by the great increase in the output of coal in the United States within recent years.

In 1880 Great Britain headed the list of the world's production of coal with 146,969,409 statute tons, the United States producing 63,822,830 tons in that year. In 1906 the output of Great Britain reached 269,929,379 tons, while that of the United States amounted to 344,912,205 tons. Of this enormous quantity the coals of Carboniferous age—chiefly bituminous coal from the Appalachian Coalfield—contributed by far the greatest amount, but no less than 70,296,000 tons of semi-bituminous and anthracitic coal were obtained from the Pennsylvanian anthracite region.

The visible coal-bearing strata of North America cover an area far exceeding that of any of the coal-producing countries of the world. The coals range in age from Carboniferous to Tertiary, and are found extending from within the Arctic Circle southwards into the Gulf States.

The comparatively recent date in the development of the coal resources of America is well illustrated by the fact that shafting or deep sloping, even in the extensively worked bituminous Appalachian Coalfield, has not exceeded a depth of 700 feet. In this vast area, in which workable seams at shallow depths occur, the coal-miner does not need an extensive geological knowledge, but in the development of the unexplored regions an acquaintance with the principles of the science will be found invaluable to the explorer. Within the Arctic Circle coal-bearing rocks, ranging in age from Carboniferous to Tertiary, occur within comparatively short distances of each other. The coals of the Carboniferous rocks are for the most part far superior to those of later age. The explorer, therefore, should be competent to recognize the difference between the fauna and flora of the Palæozoic period and that of the Mesozoic and later period.

In the highly inclined and folded strata, or in areas traversed by numerous igneous dykes, he must also be able, from a careful examination of the surface structure, to locate the most suitable position for an experimental boring or shaft.

United States.

Distribution.—The coal-bearing formations range in age from the Carboniferous to the Tertiary. The Carboniferous coals rank first both in extent and quality; the Mesozoic coals, chiefly of Cretaceous age, come next; and the Tertiary coals last.

The area of Carboniferous coals lies east of the 100th meridian. The Cretaceous coals are scattered between the 100th and 115th meridians, while the

Tertiary coals occur in small, widely separated regions between the 120th meridian and the Pacific coast. In point of time, therefore, the formation of coal in the United States proceeded, in the main, from east to west, though coal of Triassic age is found along the Atlantic border, and there are extensive deposits of Tertiary lignites in the Gulf States. In addition, coals of Carboniferous age have recently been discovered in Alaska.

Tertiary Coals.—The Tertiary coals of the Pacific slope vary in character from bituminous to lignitic, but they are of comparatively poor quality, as is shown by the extensive importation of foreign coals along this coast. The better-class bituminous coals are confined to the disturbed regions, the best being met with in Washington County, where the seams, said to exceed 100 in number, are found in the lower 2,000 feet of a thickness of strata estimated at 10,000 feet. Igneous dykes often locally convert the coals into a natural coke, but more frequently totally destroy the value of the seams in their proximity. In Alaska the Kenai Series of the Eocene formation contains some workable coals.

In the Gulf States the Tertiary coals of Eocene age are low-quality lignites with a high percentage of moisture and ash.

Mesozoic Coals.—The Triassic coals of the Atlantic coast, though of little commercial importance, were among the first to be worked in the States. The Triassic coalfields occupy an area of 10,000 square miles, but only the Richmond and Deep River districts are at present productive. The strata are much folded

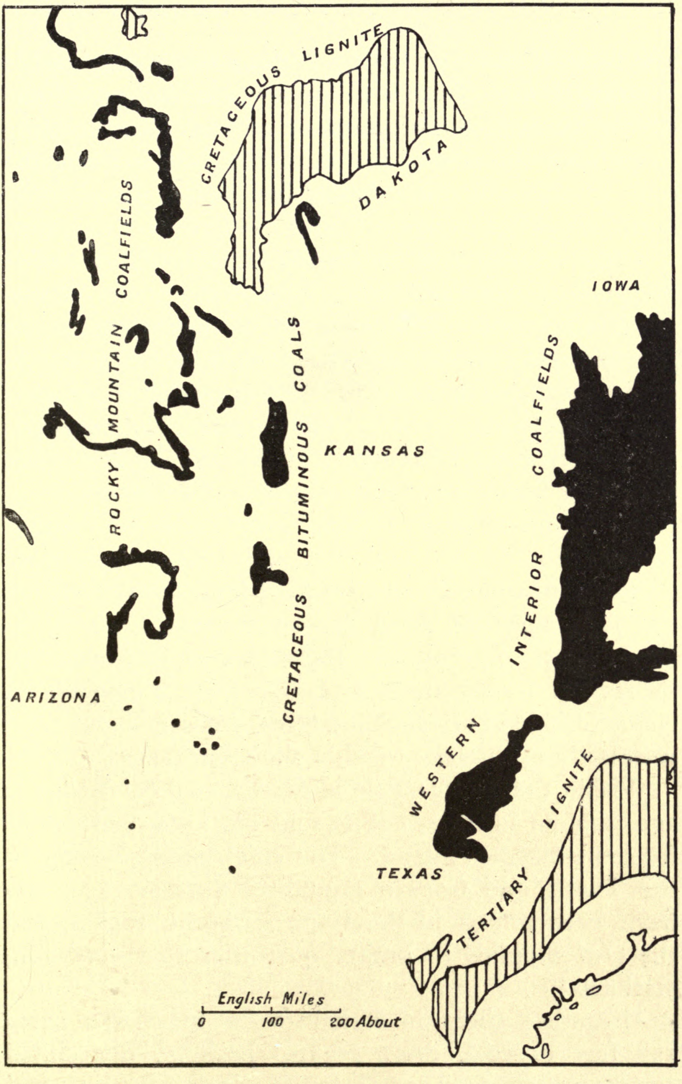


FIG. 24.—THE TERTIARY AND CRETACEOUS COALFIELDS OF THE UNITED STATES, AND THE CARBONIFEROUS COALFIELDS OF THE WESTERN INTERIOR.

and faulted, and invaded by igneous material. In the Richmond area there are three workable seams, one having an average thickness of 20 feet. In the Deep River area the seams are thin. In both regions the coal is normally bituminous, but passes locally into anthracite when in contact with the igneous intrusions.

The Mesozoic coals are chiefly found in the Laramie division of the Cretaceous formation in the Rocky Mountain region. The proximity of these coals to the rich metalliferous areas has led to their being extensively developed, but the difficulty of transport prevents their exportation to the Pacific coast. The coalfields cover a broad tract estimated at 100,000 square miles, extending from Canadian territory to New Mexico.

In Wyoming and Dakota the coals are chiefly lignitic; but in the disturbed and folded regions of Colorado the character varies from lignite to anthracite, the percentage of fixed carbon varying from 36 to 88 per cent. In Colorado the seams range from a few inches up to as much as 32 feet in thickness. A characteristic of all the Cretaceous coals is their great variability in thickness within short distances.

Within the Arctic Circle in Alaska, coals of Mesozoic age crop out in the sea cliffs, and are known to extend for some distance inland. The chief seams belong to the Thetis and Corwin groups of Jurassic age, and have been mined in the Cape Lisburne region, and the coal supplied in limited quantities to the whaling stations.

Altogether there is stated to be in Alaska some 150 feet of coal, more or less pockety, distributed among forty to fifty seams, ten of which are over 4 feet in thickness. An average of twelve analyses gives a fuel ratio of 1·21, which compares very unfavourably with the fuel ratio of the Carboniferous coals of these regions (p. 274); but unlike the coals of Carboniferous and later ages, they occur in undisturbed areas, and can therefore be more economically mined.

Carboniferous Coals.—The Carboniferous formation covers vast areas in the United States; the Coal-measures alone occupy an exposed surface, exceeding 230,000 square miles. At first sight the European coalfields appear insignificant in comparison; but the difference is less striking if we include the areas of concealed Coal-measures in Northern Europe and Russia-in-Europe, whereas only limited areas in America are hidden beneath a covering of newer rocks.

The Coal-measures of the United States lie as a rule at gentle angles, and large areas are in consequence occupied by barren strata, which compose much of the Coal-measures; so that sometimes only one-half of a coalfield can be regarded as productive, while a further reduction of the total available supply must be made for the great variability in thickness of many of the seams.

The Carboniferous System of North America falls into two main divisions. The Lower or Mississippian stage is of marine origin, and corresponds to the Carboniferous Limestone Series or Dinantian of Europe. The Upper or Pennsylvanian stage is partly marine and partly estuarine, and represents the Lower and Middle (Westphalian) Coal-measures of Europe. In the western States the entire Carboniferous System assumes a marine phase.

A widespread unconformity separates the Pennsylvanian from the Mississippian stage.

The coalfields are met with in five separate areas, named from east to west: (1) Pennsylvanian Anthracite Region; (2) Appalachian Basin; (3) Northern Interior Basin; (4) Eastern Interior Basin; (5) Western Interior Basin (Figs. 24, 25).

The anthracite region is the smallest, but most valuable; the Appalachian Coalfield ranks first in size, and contains the greatest variety of coals, besides yielding the largest output.

These two areas, now separated by wide intervening gaps, were once continuous, their present isolation being caused by folding and denudation. The folding is most intense along the line of the Alleghanies, and gradually dies away westward. Accompanying this difference in physical structure a change takes place in the nature of the coals. In the least disturbed regions the coals belong to the bituminous variety, and gradually attain a greater carbon percentage on approaching the folded region, until in Pennsylvania they become true anthracites.

This anthracitization has been attributed to the effect of pressure and heat, but some geologists consider that the character of the coals changed on approaching the original shore line, which certainly lay to the east.

The nomenclature for the subdivisions of the Pennsylvanian Group varies considerably. The table given on p. 268 is recognized for South-West Pennsylvania, West Virginia, and Ohio.

In northern Missouri and northern Texas beds of limestone and shale become more prevalent. Coal-seams are few and thin.

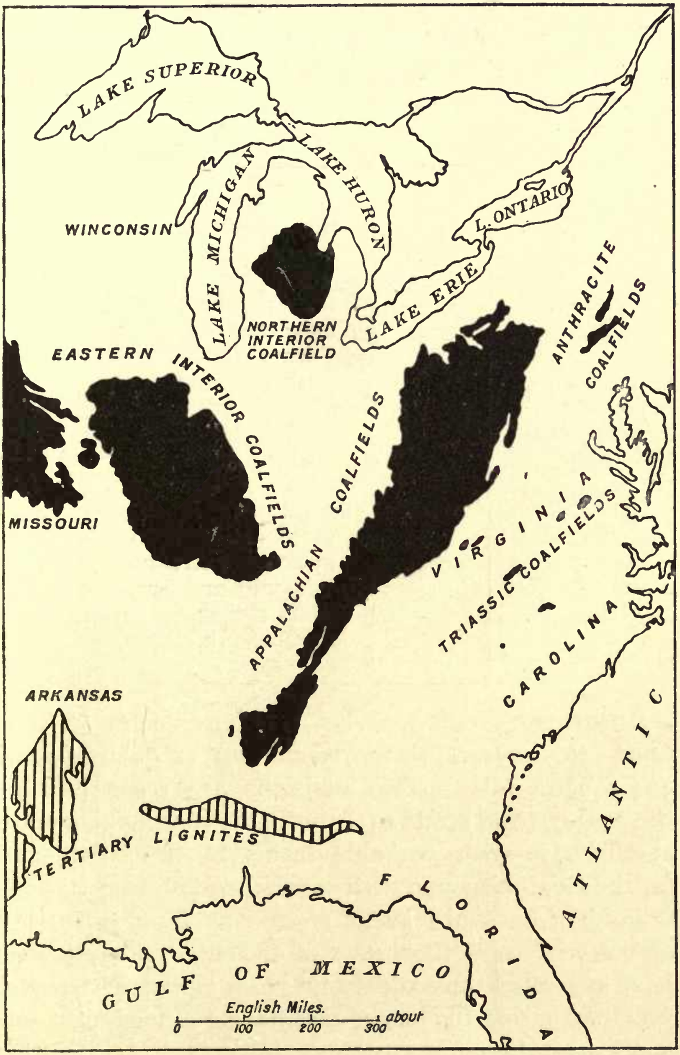


FIG. 25.—THE CARBONIFEROUS COALFIELDS OF THE UNITED STATES.

THE UPPER CARBONIFEROUS ROCKS OF NORTH AMERICA.

Name of Formation.	Thickness in Feet.	Characteristics.
Dunkard Series (? Permian).	400–1,000	Massive sandstones, red shales, thin limestones, and thin coals; not marine.
Monongahela Series.	200–400	Some limestone, sandstone, shale; important coals including the Pittsburg Seam; Permo-Carboniferous flora; freshwater fauna.
Conemaugh Series (Elk River).	400–600	Red and green shales, some sandstone and limestone; thin coals; Permo-Carboniferous flora; lower half marine.
Alleghany Series.	200–300	Shales, some limestone, sandstones; important coals; Coal-measure flora; marine fossils.
Pottsville Conglomerate.	60–4,500	Sandstone and conglomerate; some shale; important coals in the south.

Anthracite Region.—The anthracite coalfields, confined to eastern Pennsylvania, cover an area of 484 square miles. Two divisions are recognized in the coal-bearing strata: (1) the Pottsville Conglomerate at the base with workable seams in the south, and (2) the Coal-measures with several workable seams.

Folding and subsequent erosion of large quantities of material from the crests of the adjacent anticlines have separated the coalfield into four elongated, parallel synclinal basins, the longer axes having a north-east and south-west direction.

These basins are known as the Northern Field,

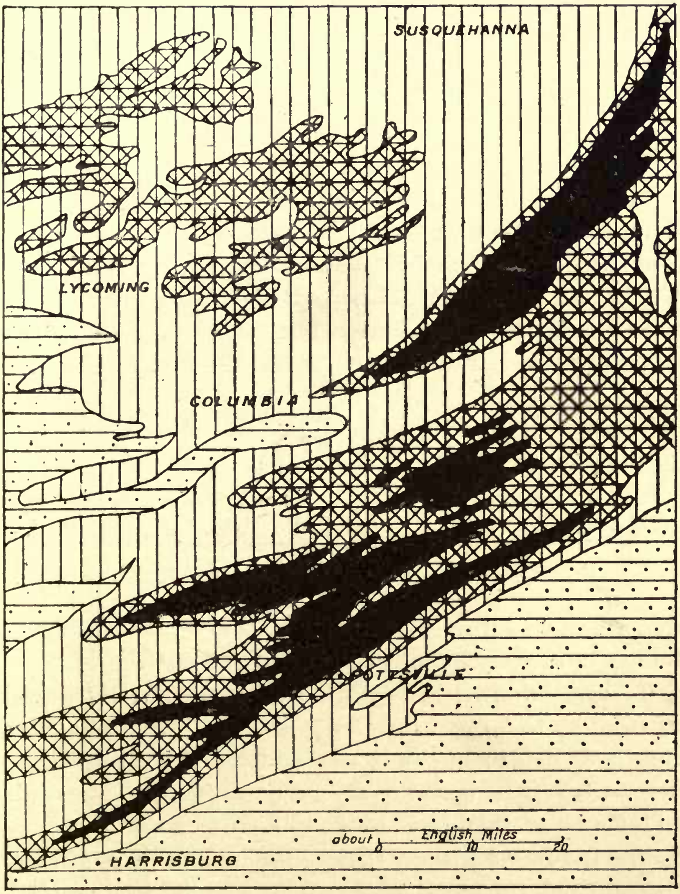


FIG. 26.—THE ANTHRACITE COALFIELDS OF PENNSYLVANIA.

Upper Carboniferous rocks in black; Lower Carboniferous rocks shown by lattice pattern; the remainder Devonian and Silurian.

Eastern Middle Field, Western Middle Field, and Southern Field, the limitation of each of these areas being sharply defined by the Pottsville Conglomerate, so that reports of the discovery of anthracite outside these known areas possess no foundation.

The Coal-measures attain an aggregate thickness of 2,500 feet in the deep basins of the Southern Field. The seams vary in number, thickness, and quality. The best known are the Mammoth Seam, Red Ash Coal, and Buck Mountain Bed. The amount of marketable coal decreases from 81 per cent. in the north to 72 per cent. in the south; the deterioration is largely

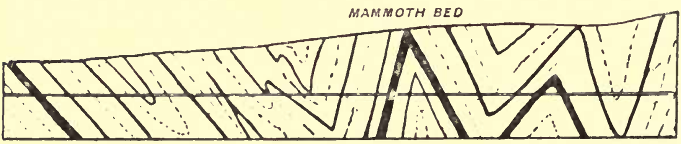


FIG. 27.—FOLDS IN THE ANTHRACITE REGION.

due to the southerly increase in the intensity of the folding and consequent crushing of the coal.

The well-known Mammoth Bed attains a thickness of from 50 to 60 feet over large areas in the Middle and Southern fields; but it is frequently divided into three beds with partings and layers of unmarketable coal, reducing the thickness of good coal to from 20 to 25 feet. In the Panther Creek Basin the bed attains the unusual thickness of 114 feet, with 82 feet of good coal.

In the Northern Field the great ice sheet from the north has left an undesirable legacy in the form of gravel deposits sometimes reaching a thickness of 200 feet. These superficial accumulations have levelled up the deep pre-glacial valley of Wyoming, and have proved to be a source of considerable danger in mining.

The percentage of fixed carbon in the fuel constituents ranges from 91 to 96, and the volatile combustible matter from 3 to 81 per cent.

The total original contents of the Anthracite fields has been estimated at 19,500,000,000 tons. In 1893 no less than 2,255,000,000 tons had been exhausted, thus leaving 17,245,000,000 tons available, of which it is expected only 40 per cent. will be won. The output in 1905 was 69,339,152 long tons.

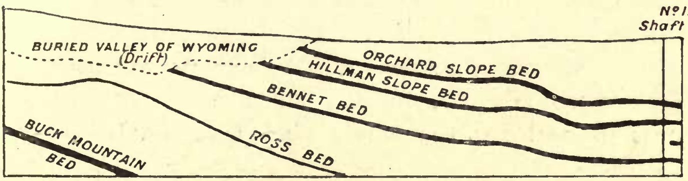


FIG. 28.—THE ANTHRACITE FIELD. COAL CROPS CONCEALED BY GLACIAL DRIFT.

Appalachian Coalfield.—This is the most productive coalfield in America, the output in 1905 amounting to 212,830,030 short tons.

The coalfield extends from the northern border of Pennsylvania to Central Alabama, a distance of 850 miles, and includes an area of about 70,000 square miles, of which about 75 per cent. contain workable coals.

A large portion of this field is strictly limited by older rocks, which crop out along the margins; but at the southern end the Coal-measures pass beneath the deposits of the central plains, and may connect beneath them with the Arkansas Coalfield.

Speaking in general terms, the strata of this field are horizontal or gently undulating. The inclination is steepest along the western edge, and in the south, where the measures reach their maximum thickness, the strata are folded. The chief coals lie in the Alleghany and Monongahela Series, though thin impersistent seams occur in the Dunkard and in the Pottsville Series. The Sharon Seam was especially sought for in the past, and is now largely exhausted.

In the two chief productive groups the seams are for the most part irregular, but the Pittsburg Coal, at the base of the Monongahela Series, has an average thickness of 6 feet over an area of fifty square miles, and in varying thickness it has been proved over an area of 14,000 square miles. The average total thickness of coal for the whole field is estimated to be 25 feet.

The coals are bituminous, many yielding large quantities of coke. As a whole, there is a general increase in volatile matter from the semi-bituminous coals of Maryland in the east to the highly-bituminous coals in the west.

Northern Interior Coalfield.—This coalfield, covering an area of about 7,500 square miles in the southern peninsular of Michigan, appears never to have been connected with the other coal areas.

Seven workable coals, with an average thickness of 2 feet and rarely exceeding 4 feet, are recognized. The coals are bituminous, some yielding good coke.

A thick covering of glacial deposits conceals much of the outcrop, but the general structure appears to be that of a shallow basin, with a maximum thickness of 700 feet of Coal-measure strata at the centre.

The covering of glacial deposits, by concealing the outcrop of the Coal-measures, causes the limits of this coalfield to be ill-defined. In boring or sinking through the surface deposits, beyond the proved limits, rocks older than the Coal-measures may be reached, so that the prospector needs to be able to distinguish between the black shales of older formations and those of Carboniferous age.

Eastern Interior Coalfield.—This covers an area of about 46,000 square miles in Indiana, Illinois, and Kentucky. About 55 per cent. is productive. The field was formerly connected with the Appalachian and Western Interior coalfields, but is now separated from them by broad, low anticlines, from which the Coal-measures have been denuded.

The structure is that of an elongated basin, with the strata gently inclined towards the centre. Small faults, folds, and irregularities of several kinds are common.

The coal-bearing strata vary from 100 to 600 feet in thickness. They are underlain by a massive sandstone, and overlain by a maximum thickness of 400 feet of barren measures, thought by some to be of Permian age.

The workable coals seldom exceed three in number at any one point, and usually not more than one workable bed is found, while considerable areas contain no workable seams. The lower coals, though thin, are of better quality and more regular than the higher seams, the Bright Block coals being the best.

As gas coals they are unsatisfactory, but the Kentucky seams produce excellent coke.

Western Interior Coalfield.—The estimated area of this imperfectly surveyed coalfield varies from 66,000 to

94,000 square miles. The Coal-measures extend from Northern Iowa to Central Texas, and include parts of Iowa, Nebraska, Missouri, Kansas, Arkansas, Indian Territory, and Texas.

The coal-bearing strata belong to the Upper Carboniferous Series, which here rest unconformably on the Mississippian Series. In Kansas and Nebraska they are conformably overlain by Permo-Carboniferous, in Iowa by the unconformable Cretaceous, and in the northern part of the field by Glacial Drift.

The strata, consisting mostly of shale with some limestone, increase in thickness westward and from north to south, being estimated at 3,000 feet in Kansas.

In Arkansas and Indian Territory the beds are folded, but elsewhere the structure is simple.

The coals are very irregular in thickness, and appear to have been formed in channels eroded in the older rocks. They are exclusively bituminous, but are not adaptable for coking or gas-making.

Alaska.—Carboniferous coals have been recently found over a limited area in the vicinity of Cape Lisburne, in Alaska. The quality is of a high grade, but the crumpled and broken character of the strata renders it far more difficult to mine these coals than those of Mesozoic age.

Rhode Island.—Metamorphosed and intensely folded conglomerates and shales form a limited area in Rhode Island. The coal-seams are few in number, the thickest averaging 4 feet. They have so far proved to be of poor quality, containing a high percentage of ash, but being remarkably free from sulphur. They have been

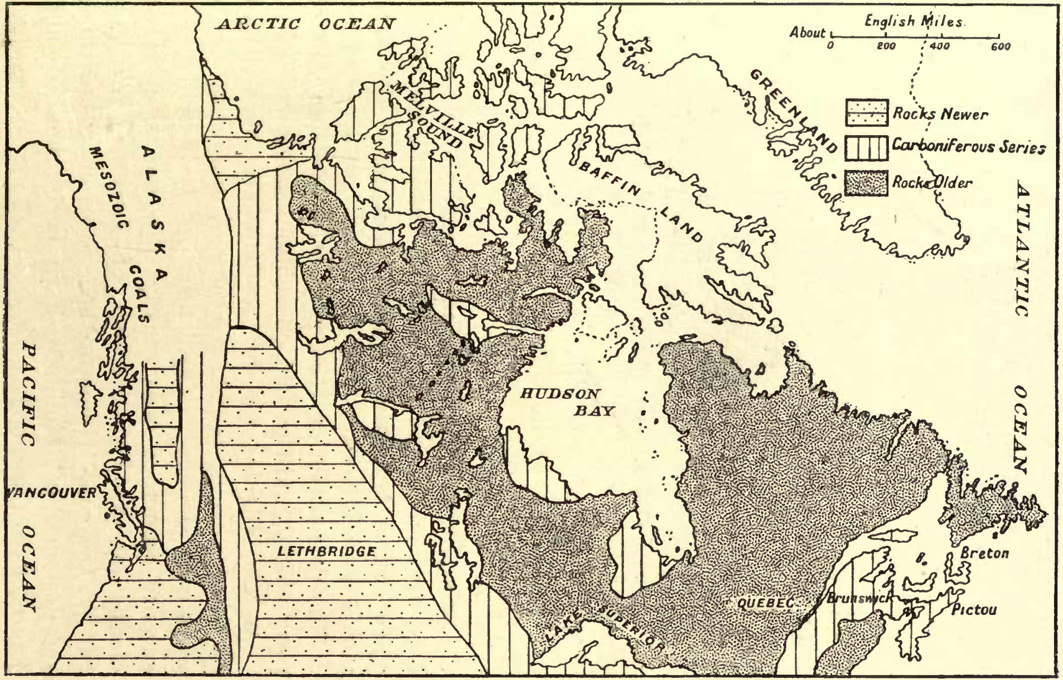


FIG. 29.—THE COALFIELDS OF CANADA.

anthracitized, and in many places converted into graphite. Their stratigraphical position appears to be high up in the Coal-measure sequence.

CANADA.

The coal-bearing strata occur in rocks of Carboniferous and Cretaceous ages. The Carboniferous formation covers a considerable area, but is for the most part unproductive. The coals are chiefly found in New Brunswick, and Nova Scotia, and are known to occur on some of the islets within the Arctic Circle.

Coals of Cretaceous age are met with in the western territories.

The areas of productive Coal-measures in Canada are thus seen to lie outside the regions of densest population.

Carboniferous Coals.—The Carboniferous rocks in New Brunswick and Nova Scotia extend over 18,000 square miles, but only a small proportion of this area yields workable coals.

The coal-seams of New Brunswick are thin and of poor quality, and the field gives only a small output.

At The Joggins on the northern arm of the Bay of Fundy, an unrivalled continuous section of Coal-measures, showing 14,570 feet of strata with over seventy seams of coal, mostly thin, has been made classic by the investigations of Logan, Lyell, and Sir W. Dawson. Numerous specimens of air-breathing reptiles and of Mollusca have been obtained and figured from these beds.

The coalfields of Nova Scotia include those of

Sydney on the east coast of Cape Breton, of Pictou in the centre, and of Cumberland in the west. These coalfields have been preserved in troughs produced by east-and-west folding.

The Pictou Coalfield is the richest, containing five or six good seams, including the Pictou Main Coal, which attains a thickness of 37 feet. The lower 1,300 feet of strata contain fifteen seams yielding 119 feet of coal; the upper 4,300 feet possess twenty-one seams giving 39 feet of coal.

In the Cumberland Coalfield only two of the seams are workable.

Denudation has swept away the upper portion of the Coal-measures in the Cape Breton area. In the remaining productive measures there are over thirty seams, but only four of these are workable. The coal here is more bituminous than that of Pictou and Cumberland.

The mineral Albertite (p. 16), once a valuable source of gas, was formerly extensively worked. The coal-like substance, Anthraxolite, of variable composition, occurring as veins in the Silurian rocks near Sudbury in Ontario, differs from Albertite in having lost its volatile constituents.

Cretaceous Coals.—Coals of Cretaceous age are chiefly confined to the Laramie Division. This formation occupies a considerable area in Manitoba, and extends at some points into the Rocky Mountains. The total area is estimated at about 60,000 square miles.

In the eastern part of the field the coal is a lignite containing a high percentage of moisture, but as the

Rocky Mountains are approached it gradually improves in quality, and in certain parts of the Rockies has been converted into a semi-anthracite.

The chief mining centres are at Estenan, Lethbridge, and Canmore, the mines of Lethbridge yielding by far the largest output.

Coal deposits of Cretaceous and possibly later ages have been also met with in several places in British Columbia. The coals are here of excellent quality, giving as much as 85 per cent. of fixed carbon. They are not, however, extensively worked, the mines at Nanaimo and on Vancouver Island being the most important producers.

CHAPTER XV

COALFIELDS OF AFRICA, INDIA, AUSTRALIA AND SOUTH AMERICA

THE continental land areas at the present day are situated in the northern hemisphere, but during the later stages of the Carboniferous period the distribution of land and sea was very different. While shallow seas, bordered by low-lying marsh lands, lay to the north of the equator, high land existed to the south.

Geologists disagree as to whether South America, Africa, India, and Australia, during the Carboniferous period, formed a connected land mass, but they recognize that the coal-bearing strata of these countries were laid down under continental conditions. Thus, while the strata associated with the Carboniferous coal-seams of the northern hemisphere show the close proximity of the sea, the later Palæozoic rocks of the southern hemisphere were deposited under continental lacustrine conditions in Indo-Africa and presumably South America, but at a lower altitude in Australia, where some of the sediments are marine.

The character of the flora and fauna of the later Palæozoic coal-bearing strata of the southern hemisphere is therefore, leaving geographical situation out of consideration, very different from that in the northern hemisphere. The remains of terrestrial organisms are abundant, while marine organisms, except in Australia, are entirely absent. The coal-seams also lack that uniformity of distribution and thickness so characteristic of the Carboniferous coals of the northern hemisphere.

Igneous rocks interrupt the continuity of the coal-seams of later Palæozoic age in the southern hemisphere, and frequently render considerable areas valueless; but the strata have not been subjected to intense earth-movements, and for the most part the coal-bearing strata lie at very gentle angles.

Africa.

General.—The coalfields of Africa at present known are all situated in the southern half of the continent. Whether coal-bearing formations occur in the great territory north of the equator remains to be proved, but the general geological structure, so far as it has been made out, does not favour the existence of coal in the north.

In South Africa the coal strata were deposited in hollows caused by the sinking down of the central portions of an old continent called Gondwana Land, which, continuing in existence in Mesozoic times, extended across the Indian Ocean, and included the peninsula of India. Detached fragments of the lacustrine coal-bearing deposits, laid down in this central depression, occur in British and German East Africa and along the margins of Lake Tanganyika; but it is uncertain how far this depression extended to the west, or what were its limitations in the north.

It is known, however, that strata of Devonian age cover wide areas in the regions of western Sahara, and still greater areas in northern Africa are occupied by marine deposits of Cretaceous and Tertiary ages, while, when not covered by volcanic material, the floor of the continent in Upper Egypt and in the Soudan is known to consist largely of rocks older than the Carboniferous. It would thus appear that the coal-bearing sediments terminated here, or, if they had a northerly extension, they have either been greatly denuded or lie concealed beneath newer formations.

It is possible that the marine Carboniferous strata of the western Sahara may be succeeded by the Westphalian or Stephanian Coal-measures of central France, but there is no evidence of the presence of the Karroo beds. The Cretaceous and Tertiary formations may contain beds of lignitic coal, as they are said to do along the west coast and in Algeria, from which 105 tons were obtained in 1904, but as the output for 1905 is only 85 tons, it would seem that either the coals are not extensive or they are of poor quality.

Workable lignites are also said to occur at Tégullet, Debra-Lebanos, and Ankober, in the Shoa district of Abyssinia.

Though the seams of coal are restricted to certain regions, and occur only at one or possibly two horizons in the sequence, South Africa may be regarded as one vast coal-basin. Deposition of arenaceous and argillaceous sediments seems to have been continuous over an area stretching from Worcester to beyond the Zambesi. Where fully developed, as in Cape Colony and Natal, the sequence presents an apparently uninterrupted succession of sediments approaching 20,000 feet in thickness. The whole of this great mass of strata is known as the Karroo System, and is usually regarded as representing the formations included in the Upper Carboniferous and Jurassic of Europe.

With some interruptions, caused by denudation, the Karroo beds extend in one sheet over the greater part of Cape Colony, through the Orange River Colony and the Transvaal into Rhodesia, and have been traced to the north of the Zambesi, while isolated masses, let into older strata by faulting, are met with in Nyassaland and about Tanganyika.

Cape Colony affords the type development of the Karroo System, and south of the Zambesi this Colony alone contains fossiliferous sediments older than the Karroo. The following table gives the formations met with in Cape Colony, and their probable European equivalents :

THE PALÆOZOIC AND LATER FORMATIONS IN SOUTH AFRICA.

Cretaceous System	Pondoland Cretaceous Series	Cretaceous.
	Uitenhage Series	

Unconformity.

Karroo System	Stormberg Series (9,300 feet)	Volcanic beds, 4,000 feet	Jurassic.
		Cave Sandstone, 1,800 feet	
		Red beds, 1,400 feet	Trias.
		Molteno beds, 2,000 feet	
	Beaufort Series (5,000 feet)	Burghersdorp beds	
		Dicynodon beds	Permian.
		Pareiasaurus beds	
	Ecca Series (2,600 feet)	Shales and sandstones	
		Laingsburg beds	Carboniferous.
		Shales	
	Dwyka Series (2,300 feet)	Upper Shales	
		Conglomerates	
		Lower Shales	

Conformity.

Cape System { Witteberg Series, 1,000 feet
Bokkeveld Series, ,, ,,
Table Mountain Series, 1,000 feet } Devonian.

Great Unconformity.

Pre-Cape Rocks.

Cretaceous rocks occur only along the coastal belt, and do not anywhere conceal the Karroo formation in

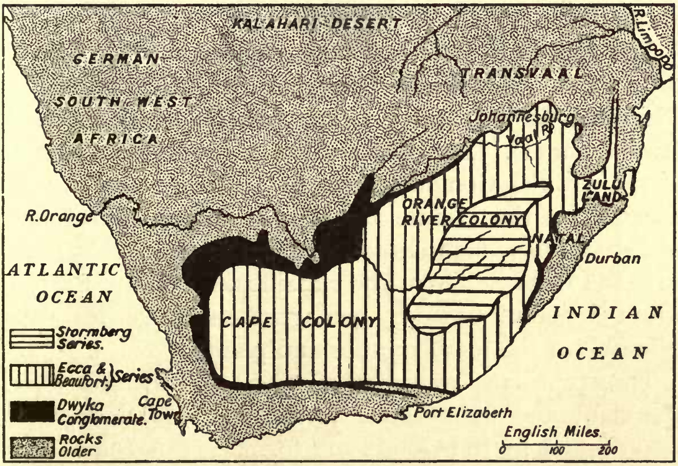


FIG. 30.—MAP SHOWING THE DISTRIBUTION OF THE KARROO SYSTEM IN SOUTH AFRICA.

the interior. In Cape Colony the Cape System passes conformably up into the Karroo, but in Natal the Dwyka Series rests unconformably on the Table Mountain Series, and elsewhere on the eroded and generally intensely folded pre-Cape rocks.

Workable coals are confined to the Molteno beds in Cape Colony. The Transvaal coals have been referred to the Ecca and Beaufort Series, and also to the Stormberg Series.

The South African coalfields owe their isolation for the most part to denudation, and seldom to earth-movement, the strata rarely departing more than a few degrees from the horizontal.

Cape Colony, Natal, and the Transvaal contain the chief coalfields, but Karroo coal is worked in South Rhodesia, and occurs in the Central African Protectorate and German East Africa.

The Karroo System has been divided into an Upper subdivision (Stormberg Series), a Middle subdivision (Beaufort Series), and a Lower subdivision (Ecca and Dwyka Series). The coarse character and glacial origin of the Dwyka Conglomerate distinguishes the Lower Karroo, but the Middle and Upper Karroo sandstones and shales have many lithological characters in common with the Ecca Series. The classification of the Karroo strata is mainly based by geologists on the vertical distribution of the fossil reptiles and plants.

The reptilian remains of the Karroo are very abundant and of peculiar forms, but identical with those found in the Gondwana formation of India, and in the Permo-Carboniferous rocks of Australia, where they appear in much the same order of occurrence as in South Africa. Allied forms are met with in the Permo-Carboniferous strata of Russia-in-Europe and in America.

Until recently reptilian remains were unknown in the Ecca Series, but they are now known to have existed at this period.

The chief reptilian remains are found in the Beaufort Series, where the following forms have been identified :

Pareiasaurus, *Oudenodon*, and large *Dinocephalians* in the Lower Beaufort beds; *Dicynodon* and many *Therocephalians* in the Middle beds; and *Cynognathus*, *Microgomphodon*, *Batrachosuchus*, and *Dicynodon latifrons* in the Upper beds.

The recently discovered crocodile *Notochampsa*, from the Red beds and Cave Sandstones, indicates the Jurassic age of the highest beds of the Stormberg Series.

Plant remains, though not so abundant as in the Carboniferous rocks of the northern hemisphere, form useful guides in determining the age of the major divisions of the Karroo System.

With the exception of certain species of *Lepidodendron*, *Bothrodendron*, *Sigillaria*, and *Cordaites*, the flora is distinct from that of the Upper Carboniferous rocks of Europe. On the other hand, the *Glossopteris* flora of the Karroo beds distinguishes the chief coal-bearing strata of India and Australia. Wherever the genus *Glossopteris* (Plate VIII., p. 291) is found in the strata of South Africa, they may be confidently referred to the Karroo System, and therefore may possibly be coal-bearing.

The chief plants met with in the Ecca Series are: *Bothrodendron lesli*, *Glossopteris browniana*, *Nœggerathiopsis hislopi*, *Gangamopteris cyclopteroides*, *Lepidodendron*, *Sigillaria brardi*, and *Phyllotheca*.

In the Beaufort Series, *Glossopteris browniana* and *Phyllotheca* ascend from the Ecca Series, but are mingled with species of *Glossopteris* not found in the beds below.

The genus *Glossopteris* is rare or absent in the Stormberg Series, where *Thinnfeldia odontopteroides*, *T. rhom-*

boidalis, *Stenopteris elongata*, *Tæniopteris carruthersi*, and *Callipteridium stormbergense* constitute the distinguishing flora.

Cape Colony.—The chief coalfields of Cape Colony are situated in the Stormberg-Indwe area, towards the southern outcrop of the Stormberg Series. The workable coals are restricted to the Molteno subdivision, which gives the following general section in descending order:

1. White sandstone and beds of shale and mudstone.
2. Coal horizon of Cala, etc.
3. Fine-grained sandstone.
4. Coarse pebbly sandstone (Indwe Sandstone).
5. Coal of Guba.
6. Fine-grained grey sandstone, 80 feet thick.
7. Coal of Indwe.
8. Fine-grained grey sandstone, with beds of buff-coloured shales.

The coal-bearing strata consist of sandstones and shales lying almost horizontally, but intersected by numerous dykes and intrusive sheets of dolerite, which generally exert a very deleterious effect on the coals, converting them into coke or soot.

Molteno coal is met with in the Stormberg Mountains and along the lower slopes of the Drakensberg up to the Natal border. The coals are of bituminous variety, containing from 45 to 70 per cent. of fixed carbon, and from 10 to 28 per cent. of volatile hydrocarbons. Like most South African coals, the ash percentage is high, ranging from 20 to 30. The sulphur percentage is generally low.

At Indwe, the centre of one of the most important coal-producing areas, the chief coal is known as the Indwe Seam. It is a composite seam, being made up of a number of shale bands, and seven distinct coals named: Lower Smith's Coal, Upper Smith's Coal, Cannel Seam, Twelve Inch Seam, Main Seam or Top Coal, Blue Coal, and Smith's Coal. These give a united thickness of 7 feet of coal. The Main Seam, about 2 feet thick, is divided into three by two thin partings of shale. A thick sandstone forms the roof of the Indwe Seam, and frequently cuts across one or more of the beds of coal forming extensive washouts. In the neighbourhood of the intrusive dykes, the seams are converted into coke. This develops a great heat in burning, which fuses the ash, forming much clinker. An analysis of the Indwe Coal shows: hydrocarbon, 12·54; fixed carbon, 63·03; ash, 24·42 per cent.

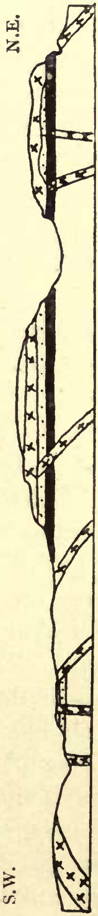


FIG. 31.—SECTION IN THE INDWE COALFIELD, SHOWING DOLERITE INTRUSIVE IN THE MOLTENO BEDS. THE GUBA COAL AND SANDSTONE LIE BENEATH A SHEET OF DOLERITE. (AFTER A. L. DU TOIT.)

In the Sterkstroom area a coal $2\frac{1}{2}$ feet thick gives an analysis: volatile matter, 25 to 30; fixed carbon, 46 to 58; ash, 11 to 18; sulphur, 0·75 to 1·20 per cent. This coal probably lies a little above the Indwe Sandstone.

At Matatiele a carbonaceous shale allied to Torbanite occurs below a seam of coal, but contains a large amount of ash (47·26 per cent.).

Considerable discussion has taken place as to the existence of coal beneath the Karroo desert. The Upper Dwyka black shales occur at Kimberley (Kimberley Shales), and are hence probably continuous with the coal-bearing rocks of Vereeniging in the Transvaal. These black shales, wherever they have been examined along the southern margins of the Karroo desert, are without coal. There seems no reason, therefore, to suppose that they are productive beneath the great thickness of Upper Karroo strata, which occupy the centre of the Karroo basin between De Aar and the outcrop of the black shales along the southern margins of the Karroo desert.

In 1905 the output of coal from Cape Colony amounted to 146,529 tons.

Natal and Zululand.—Both Natal and Zululand possess coal-seams very similar to those of Cape Colony, but many of them are of higher grade. Collieries in the Newcastle and Dundee districts are being actively worked, and the output is greatly in excess of that of Cape Colony. In 1905 the output amounted to 1,129,407 tons.

The geological formations, chronologically arranged, are given on the opposite page, but the stratigraphy of the Colony is far less known than that of Cape Colony.

Some doubt exists as to whether the coal-bearing strata should be included in the Ecca Series, some authorities placing them with the Beaufort Series. *Glossopteris* and *Phyllotheca* occur in the sandstones and shales associated with the coal strata, while in the Stormberg Series, in which only thin seams occur, the flora contain *Thinnfeldia odontopteroides* and *Pteroptyllum.*

Natal coals are bituminous, but those of Zululand are stated to be anthracitic or semi-anthracitic.

Coal occurs in large quantities in the three divisions of Natal and in the Vryheid and Utrecht districts, though at present they are mainly undeveloped. In Zululand, where the coal-bearing series is extensively developed, prospecting has only been carried on in a very desultory manner.

THE PALÆOZOIC AND LATER FORMATIONS IN NATAL.

Cretaceous: Umtavuna Beds.

Unconformity.

Karroo System:	Stormberg Series	Plateau Basalts. Cave Sandstones. Red Beds. Molteno Beds.
	Beaufort Series	Beaufort Beds.
	Ecca Series -	Ecca Coal-bearing Series. Ecca Shales.
	Dwyka Series -	Glacial Conglomerate.

Unconformity.

Cape System: Table Mountain Sandstone.

Unconformity.

Pre-Cape Rocks.

Transvaal.—The local demand for coal in the great mining and metallurgical industries has caused the coal-deposits of the Transvaal to assume an importance they might not otherwise have obtained. In 1905 the output from the Transvaal coal-mines and from the adjacent mines in the Orange River Colony amounted to 2,771,439 tons, of which the Transvaal contributed 2,606,799 tons.

Coal-bearing strata cover wide areas in the south-east, and mining is being extensively carried on at Viljoen's Drift, Vereeniging, Brakpan, and Springs in the Middle-

19

berg and Belfast districts, while the Ermelo and Carolina districts are now being opened up. Attention has also recently been drawn to the Koomati Poort Coalfield in the eastern Transvaal on the Portuguese borderland.

The total thickness of the Coal-measures does not exceed 600 feet, and is under 400 feet over large areas.

The Coal-measures of the Transvaal belong to the Karroo System. This rests in hollows on the upturned and eroded edges of a great variety of unfossiliferous sedimentary and crystalline rocks, which cannot be confounded with the plant-bearing and gently inclined strata of the Karroo System.

The Karroo System has been subdivided as follows:

THE KARROO FORMATION IN THE TRANSVAAL.

Stormberg Series: { Volcanic Rhyolites. / Bushveld Amygdaloids. / Bushveld Sandstone Series. }

Beaufort Series (?): Coal-measure Series.

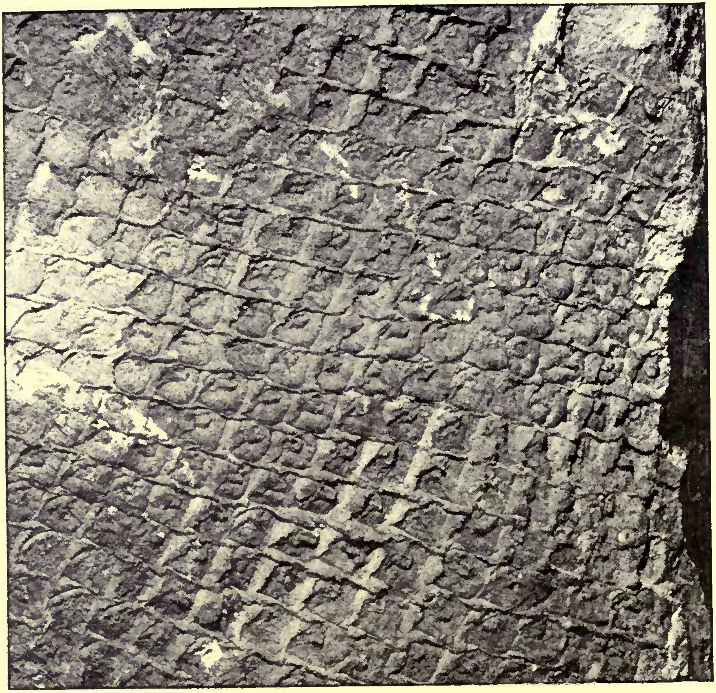
Ecca and Dwyka Series: Ecca Shales and Dwyka Conglomerate.

Great Unconformity.

Pre-Karroo Rocks.

The Stormberg Series, consisting of an immense thickness of sandstones and volcanic rocks, only crop out along the Portuguese border. Over the rest of the Transvaal they have either been denuded or were never deposited. Authorities differ as to the presence of the Beaufort Series, some geologists, on the evidence afforded by the plants, referring the Transvaal coal-bearing rocks to the Ecca Series. The following fossils found at Vereeniging certainly appear to support the

Plate VIII.



Photo] [A. C. Seward.

SIGILLARIA BRARDI, BRONGT. *Reduced.*

Photo] [A. C. Seward.

GLOSSOPTERIS BROWNIANA, BRONGT. *Reduced.*

Ecca age of the Coal-measures at this locality: *Schizoneura*, sp.; *Glossopteris angustifolia*, Brongn. var. nov.; *Glossopteris angustifolia*, Brongn.; *Glossopteris browniana*, Brongn.; *Glossopteris indica*, Schimp.; *Gangamopteris cyclopteroides*, Feist.; *Callipteridium*, sp.; *Neuropteridium validum*, Feist.; *Bothrodendron lesli*, Sew.; *Lepidodendron*, sp. nov.; *Lepidodendron podroanum* (Carr.); *Sigillaria brardi*, Brongn.; *Psygmophyllum kidstoni*, Sew.; *Cordaites* (*Nœggerathiopsis*) *hislopi*, Bunb.; *Conites*, sp.

Elsewhere in the Transvaal the plant evidence is too scanty as yet to permit a definite conclusion to be drawn, while the knowledge of the fossil plants of Natal, to which a comparison might be instituted, is as yet very imperfect.

The strata of the Karroo System in the Transvaal lie at gentle angles, and fill up hollows in much older rocks. They are little subjected to disturbance by faulting, but 'wash-outs' are frequent. These are commonly considered to be caused by contemporaneous erosion, but they are also explained by the action of percolating water which has oxidized the carbonaceous constituents, and removed the pyritic and soluble

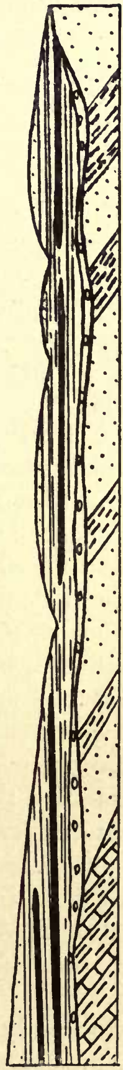


FIG. 32.—SHOWING THE RELATION OF THE HORIZONTAL KARROO TO THE INCLINED PRE-KARROO ROCKS IN THE TRANSVAAL, AND THE WEATHERING AWAY OF COAL-SEAMS NEAR THEIR OUTCROP AND BENEATH SPRUITS. (AFTER E. T. MELLOR.)

portions of the coal-seam. The chief interruptions in the sequence are caused by dykes and intrusive sheets of dolerite, which are general throughout the series except in the Witbank Coalfield.

Although some seams attain a great thickness, the amount of marketable coal rarely exceeds a few feet, as these thick seams are made up of intercalations of shaly material and dull, impure coal. With the exception of the narrow bands of good coal, the percentage of ash is seldom less than 7 per cent., and ranges as high as 21 per cent. The fixed carbon ranges between 50 and 60 per cent. The coals also contain much moisture.

In the Koomati Poort Coalfield the fixed carbon occasionally reaches 80 per cent., but the low percentage of the volatile constituents is probably due to the effect of the igneous intrusions which are general throughout the series. Unlike Welsh coals, these anthracitic coals of Koomati Poort contain a high percentage of ash, up to as much as 36 per cent.

A coal-seam in Swaziland, 6 feet in thickness, gives a carbon percentage of over 87, the ash being under 10 per cent.

In prospecting for coal in the Transvaal there can be no question that rotatory drills and trial shafts give the best results, since outcrops of coals are seldom visible owing to the perishable nature of coal near the surface. The coal-bearing strata rarely exceed a few hundred feet in thickness at any one spot, and so present little difficulty either in drilling or shaft-sinking.

Until recently the Dwyka Conglomerate lying at the base of the coal-bearing strata was considered to be the only conglomerate among the Karroo rocks, but it is now known that a conglomerate is frequently present above the productive measures of the Karroo, so that it is essential to determine whether a conglomerate reached in a trial sinking is above or below the coal strata. A conglomerate in which the pebbles are uniform in size and fairly evenly distributed may be taken as newer than the Dwyka Conglomerate, in which the pebbles are of all sizes, very unevenly distributed, and often striated. Since, however, neither of the conglomerates is of any great thickness, it is certainly advisable to continue any experimental boring through the conglomerate, and so prove the rocks below.

Rhodesia.—Coal of Karroo age is worked at Wankies, in the Zambesi basin, and was discovered at Tete by Livingstone. The Karroo formation, containing coal, occurs also in the basins of the Sabi, Sengwe, and Tuli rivers, but owing to their remote situation little is known about them.

A red and white felspathic sandstone (Forest Sandstone), with interbedded basalts like the Karroo, covers immense areas in Rhodesia and the Congo Free State. It is uncertain whether the Forest Sandstones belong to a formation newer than the Karroo, or whether some portions at least may not belong to the higher divisions of this formation.

The output of coal from Rhodesia, chiefly obtained from Wankies, amounted in 1905 to 98,751 tons.

India.

Since 1893 India has taken her place as one of the important coal-producing regions in the East. In 1905 the output amounted to nearly 8,000,000 tons, obtained from pits of comparatively shallow depths, situated chiefly in Bengal. The quantity annually being raised is, however, a very small fraction of the available supply, estimated at 9,085,000,000 tons, contained in the 35,000 square miles that the coalfields are estimated to cover, and the coal-mining industry is yet in its infancy, though permanently established.

The coal-bearing strata of Peninsular India occur in numerous isolated basins, and though some are of considerable size, others do not attain to more than a few square miles in extent.

The area of the exposed coalfields is small when compared with the vast extent of the continent, and there seems little possibility of India possessing concealed coalfields to any extent.

The continent is, in fact, built up largely of crystalline gneisses and schists, or of rocks older than the Carboniferous, and in which, therefore, it is useless to look for coal.

Besides these older rocks, more than 200,000 square miles in the Deccan are covered with basalts attaining a thickness exceeding 6,000 feet. The immense plain, exceeding 300,000 square miles, of the Ganges, Indus, and Brahmapootra is thickly covered with alluvial deposits, completely burying the solid rocks over the whole of this area.

The chief coalfields of India belong to the lower division of the Peninsula development of the Gondwana System, which more or less corresponds to the Upper Carboniferous, Permian and Triassic periods of Europe.

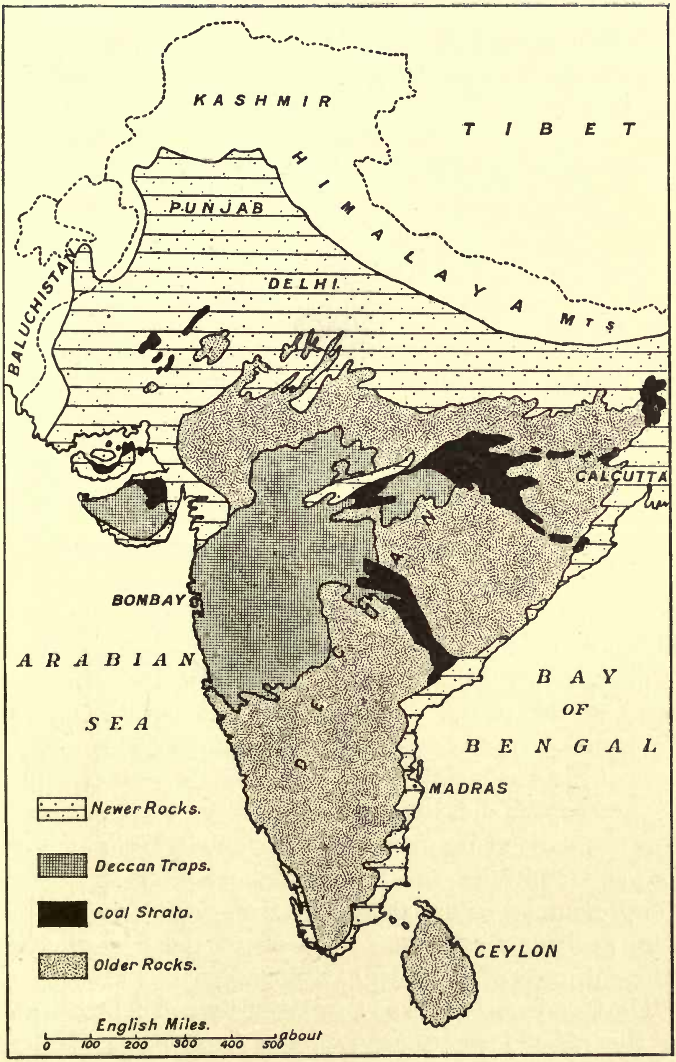


FIG. 33.—THE PERMO-CARBONIFEROUS COALFIELDS OF INDIA.

The Gondwana System has been subdivided as follows:

THE GONDWANA SYSTEM IN INDIA.

Upper Gondwana	Umia and Jabalpur.	
	Rajmahal and Mahadeva.	
Lower Gondwana	Panchet, 1,800 feet.	
	Damuda	Raniganj, 8,000 to 10,000 feet.
		Barakar, ,, ,, ,,
	Talchir	Karharbari, 800 feet.
		Talchir, ,, ,,

The Upper Gondwana is considered to be the homotaxial equivalent of the Rhætic, Lias, and Oolitic formations. The comparison, however, is not a close one, and it is far preferable to compare the strata with those of the Karroo System of South Africa, in which the fossils are of the same types as those occurring in the Gondwana.

There is little doubt that the Gondwana beds, like those of the Karroo, were laid down in lakes. There is the same irregularity in the coal-seams and arrangement of the strata, while the fauna in both is either terrestrial or freshwater. A thick conglomerate at the base of the Talchir division unquestionably corresponds to the Dwyka, and, like this, is of glacial origin.

A comparison between the other subdivisions of the Lower Gondwana and those of the Karroo must for the present be regarded as tentative, since, as we have said, geologists are not agreed as to the age of the different parts of the Karroo System.

The Gondwana rocks occupy basin-shaped depressions in the older formations, and the boundaries of the coalfields are usually rigidly defined by the outcrops of these older strata. Few of the coalfields, therefore, have any possible extensions beneath newer formations. Some of the depressions correspond to the existing river valleys and have a linear extension; but different opinions are held as to the extent to which this present mode of occurrence is due to earth-movements, and how far the basins represent the original hollows in which the sediments accumulated. Many of the coalfields were unquestionably once connected, and owe their present isolation to denudation and faulting.

There is a general conformity between the different members of the Gondwana System, but the Upper division rests unconformably on the Lower.

The rocks of the Karharbari group consist of sandstones, grits, conglomerates, and coal-seams. The latter are somewhat variable in thickness, but undergo comparatively little change in composition. Sandstones and shales form the chief rocks of the Damuda and Panchet Series, but the latter contain beds of red clay absent in the Damuda, while the carbonaceous shales, present in the Damuda, are wanting in the Panchet Series.

The character of the flora of the Upper Gondwana is very distinct from that met with in the Lower Series. In the upper measures, cycads chiefly prevail; in the lower, equisetums and ferns of the *Glossopteris* type are most abundant. Among the flora of the Lower Gondwana the commonest forms other than *Glossopteris* are species of *Gangamopteris*, *Schizoneura*, and *Vertebraria* (now admitted to be a root of *Glossopteris*). Like the Karroo formation, the Lower Gondwana contains numerous reptilian remains, among them being *Dicynodon*.

Indian coals of the Gondwana period resemble those of South Africa in composition, in irregularity of thickness, and in the amount of ash, which is usually much greater than in European coals. Besides the ash, many of the thicker seams contain bands of dirt and shale, so that though a seam may reach 100 feet in thickness the available quantity of good coal may be much less than this amount.

Most of the seams belong to the bituminous varieties, and several yield good metallurgical coke, of great importance considering the quantity of rich iron deposits in the country.

The chief coals occur in the Karharbari and Barakar groups, those found in the former being of excellent quality, and generally superior to the majority of the Damuda seams. Nearly all the coalfields of the Indian Peninsula, however, belong to the Damuda Series.

In the Barakar group the coals, as is usual in lacustrine deposits, show a general tendency to vary in thickness and quality within short distances, some of the seams, including the partings of shale, ranging between 35 and 90 feet in thickness.

The most important coalfields of India are those of Raniganj, Giridhi (Karharbari), and Jharia, situated in Bengal. In 1900 the output from these fields amounted to nearly 5,000,000 tons out of 6,118,692 tons for the whole of India.

The Raniganj Coalfield, 130 miles from Calcutta, with an area of over 500 square miles, is one of the most important in India, the total available amount of coal being estimated at 14,000,000,000 tons. The fixed carbon ranges from 50 to 60 per cent., the ash averaging 10 per cent.

The Giridhi Coalfield, 200 miles from Calcutta, covers an area of about eight square miles, and is estimated to contain 136,000,000 tons of coal. One of the lower seams varies from 12 to 30 feet in thickness. It is of good quality, the fixed carbon amounting to 67 per cent., and the ash ranging from 5 to 12 per cent.

The Jharia Coalfield, situated a few miles to the west of that of Raniganj, has an area of about 200 square miles, and is estimated to contain 864,000 tons of coal. Analyses give an ash percentage of over 10 per cent., but the coal is nevertheless of good quality.

Other coalfields, though little development has yet taken place, are those of Bokaro, with an area estimated at 220 square miles, and Karanpura, estimated at 472 square miles in extent. In addition there are the smaller coalfields of Ramgarh, Daltonganj (Palamau), Talchir, and Rajmahal.

The Central Provinces contain the little developed coalfields of Mohpani and Warora, both of Gondwana age.

In the Nizam's dominions, coals occur in the Barakar group, but the only area worked is Singareni in the Godavery Valley. One seam here attains a thickness of over 40 feet.

Coals of Cretaceous age occur in Assam, in the Garo, Khasi and Jaintia Hills, but the coal is of inferior quality, resinous and woody. In Burmah, Cretaceous coals, from 4 to 5 feet thick, are worked on the west bank of the Irawaddy, about sixty miles from Mandalay, and near Kaliwa, on the Chindwin River. The percentage of ash is small, but in quality the coals resemble those of Assam.

The Tertiary coals appear to be the next best in quality to those of the Gondwana System. They are met with in Baluchistan, the Punjab, Sind, Assam, and Burmah.

In Baluchistan, thin seams of bituminous coking coals of fair quality, but usually sulphurous, are worked in the neighbourhood of Quetta. Coals are also known to exist at Khost and Much.

The Makum Coalfield, in Assam, contains a seam of coal 100 feet in thickness, of which 75 feet are said to consist of solid coal of a superior quality. There are also several small seams less than a yard in thickness extending over large areas. Analyses of the coals give an average composition of fixed carbon, 60·0; volatile matter, 36·2; ash, 3·8 per cent. The Assam Tertiary coals are stated to be among the best steam coals in India.

Australia.

The name of New South Wales at once suggests the presence of coal in this important region of Eastern Australia, and, in fact, the Colony gained this title from the discovery of coal as early as 1797 at Coal Cliff, Wollongong, south of Sydney.

The geological succession in Australia is, on the whole, more complete than that of South Africa and India. Fossiliferous, Cambrian, Silurian, and Devonian strata are well represented, but in the chief coal-bearing regions of New South Wales the later Mesozoic and Tertiary formations are of no great thickness, and chiefly consist of loosely stratified sands and gravels, or of volcanic rocks. In Victoria the Tertiary sea covered a large area south of the Murray River and north of the

Great Australian Bight, but no marine beds of Tertiary age are known in New South Wales or Queensland east of the main dividing range.

The following table gives the general succession of the Australian stratified rocks:

THE GEOLOGICAL FORMATIONS OF AUSTRALIA.

Post-Tertiary	Gravels, sands, alluvial flats and great plains of the interior.
Pliocene	Alluvial deposits capped by basalt. Western Victoria, Queensland. Marine limestones of Adelaide.
Miocene	Marine beds of Arumpo, Coria Bay. Lower volcanic group of Queensland.
Eocene	Freshwater beds, New England. Muddy Creek beds, Victoria. Table Cape beds, Tasmania.
Cretaceous	Desert sandstones and Rolling Downs formation, Queensland, New South Wales, and West Australia.
Jurassic	New South Wales; Champion Bay, West Australia.
Trias-Jura	Wianamatta shales, Hawkesbury sandstone, Clarence River beds (Artesian water-bearing beds?), Ipswich and Burrum beds; Upper Coal-measures of Tasmania.
Permo-Carboniferous	Coal-measures, Newcastle; Upper and Middle Bowen River formations. West Australia, Tasmania. Contemporaneous lavas and tuffs.
Carboniferous	Gympie, Lower Bowen and Star formations; Lower Coal-measures of Tasmania.

Devonian - - -	Mount Lambie and Wollongong sandstones, New South Wales; Mount Tambo beds, Victoria; Burdekin beds, Queensland. Fingal slates, Tasmania. Intrusive granites.
Silurian - - -	Graptolite beds, Victoria; New South Wales, South and West Australia and Tasmania.
Cambrian - - -	Olenellus beds.
Pre-Cambrian - -	Metamorphic rocks.

Brown coal and lignite are obtained from the thin deposits of Tertiary rocks around Kiandra Bay. At Lal-Lal, in Victoria, a bed of lignite 100 feet in thickness occurs. Coals from 1 to 6 feet thick, containing little ash and with a percentage of fixed carbon from 61 to 69, occur in the Burrum Coalfield, and seams between 3 and 7 feet thick in the Broadsound Basin. The evidence as to the age of these coals points to their being certainly older than the Desert Sandstones by which they are unconformably overlain, but newer than the Permo-Carboniferous rocks on which they rest unconformably.

In Queensland the Ipswich Coalfield, estimated at 12,000 square miles in extent, belongs to the Upper Trias-Jura formation, the measures being the probable equivalents of the Lower Clarence Series of New South Wales. The seams are numerous and often thick, but have an ash percentage varying from 6 to 50. It is, however, from the Permo-Carboniferous rocks that the chief supply of coal is drawn, over 80 per cent. of the total output for the Commonwealth being obtained from this formation in New South Wales alone. Taking 16,550 square miles as the area of the coal-basin, and an average of 10 feet of coal over the whole area, it is estimated to contain 115,346,880,000 tons of available coal after subtracting about one-third for the loss in working.

A great thickness of the Hawkesbury Series, belonging to the Trias-Jura formation, conceals the productive measures over much of the region between the coast and the great dividing range. In the south the Hawkesbury Series is divided into the Wianamatta Shales, the Hawkesbury Sandstone, and the Narrabeen Shales, and are considered to be represented in the north by the Upper, Middle, and Lower Clarence shales and sandstones. The Middle Clarence Series is also considered to cover vast areas west of the dividing range, and to form the reservoirs of the Artesian water, though some geologists consider the water-bearing sandstones to be of Cretaceous age.

Thin seams of coal are found in the Hawkesbury Sandstone and Wianamatta Shales, and seams varying from 2 to 37 feet in thickness occur in the Lower Clarence Series (Ipswich Beds, p. 302); but the thick coals are made up of numerous layers of dirt and shale, the individual seams of clean coal seldom exceeding one foot in thickness. They contain a high percentage of carbon, but the percentage of ash is great, and the coals are only suitable for local use. Coal fragments are obtained from the drills used in boring for water on the western plains, but if seams of workable thickness and of good quality should be found to occur, in mining them there will always be a difficulty owing to their close association with strata bearing water under pressure.

Since the Hawkesbury and Clarence Series cover up the valuable Permo-Carboniferous measures, it is important to know their stratigraphical relation to the older formation, and how they may be distinguished from it.

With the exception of a few though striking instances, the Hawkesbury Series rests conformably on the Newcastle or highest strata of the Permo-Carboniferous System. The great tectonic movements of Australia which resulted in the formation of the north and south dividing range, followed, therefore, the Trias-Jura period instead of preceding it as in Europe.

Though the Hawkesbury Series is thus closely connected stratigraphically with the Permo-Carboniferous formation, there is a very marked difference between the fauna and flora, enabling the two formations to be readily distinguished one from the other.

The Hawkesbury Series is wholly of freshwater or estuarine origin; the Permo-Carboniferous is largely a marine formation, but contains the important estuarine coal-bearing beds. Between the different strata of the two systems a marked distinction exists in the fauna and flora, as will be seen by comparing the following lists of the common fossils of the Hawkesbury Series with those of the Permo-Carboniferous rocks (p. 307). In the Hawkesbury Series the fauna contains *Mastodontosaurus platyceps* among the Labyrinthodonts; the fishes *Palæoniscus, Cleithrolepis, Myrolepis;* and the curious gasteropod *Tremanotus*. The flora contains true cycads of the genera *Podozamites* and *Otozamites* and conifers, but the most characteristic fossil plants are *Tæniopteris daintreei* and *Thinnfeldia odontopteroides*, genera, it will be remembered, common in the Upper Karroo formation of South Africa (p. 285) and in the Upper Gondwana rocks of India.

The Permo-Carboniferous formation of New South

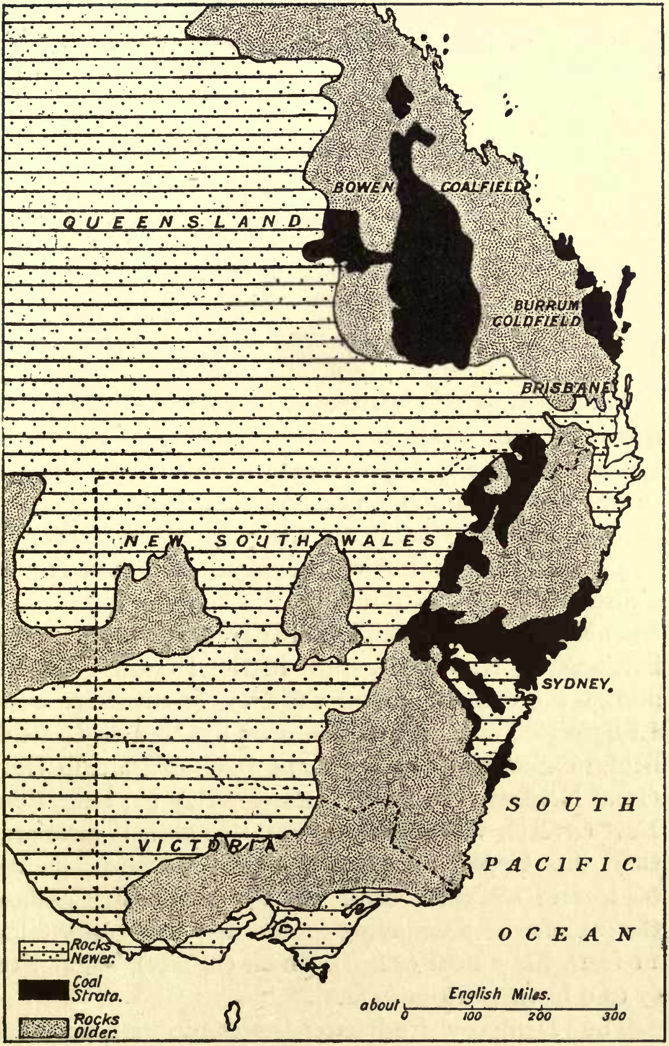


FIG. 34.—THE PERMO-CARBONIFEROUS COALFIELDS OF EASTERN AUSTRALIA.

Wales is divided, in descending order of sequence, as follows:

	Thickness in Feet.
Upper or Newcastle Coal-measures (50 to 60 feet workable coal)	1,150
Dempsey Series (unproductive)	2,000
Middle, Tomago or East Maitland Series (20 feet workable coal)	570
Upper Marine Series (*Productus brachythærus*)	5,000
Lower and Greta Coal-measures (20 to 40 feet workable coal)	130
Lower Marine Series (*Eurydesma cordata*)	4,800

The Permo-Carboniferous rocks lie in a shallow open syncline, the productive measures extending longitudinally from Four Mile Creek to the Clyde River, a distance of over 200 miles, and latitudinally (Fig. 34, p. 305) from the coast to the outcrop of Devonian strata and the granites of the Blue Mountain region, a distance of over fifty miles.

The Newcastle Series is well developed in the neighbourhood of Newcastle, Bulli in the Illawarra district, and on the western side of the Blue Mountains around Lithgow. The principal seams of the Newcastle Coalfield, in ascending order, are the Borehole (6 to 8 feet), Great Northern (20 feet), Catherine Bay (14 feet), Four Feet (4 feet), Wallarah (11 feet). In all it is estimated that the Upper Measures contain between 50 and 60 feet of workable coal. In the Wallarah Coalfield the seams in descending order are the Bulli (2 to 11 feet), Four Feet (4 feet), Thick (14 feet), Eight Feet (7 to 9 feet), Bottom (6 feet).

The Dempsey freshwater series do not occur in every coalfield, but rest on the Middle or Tomago Coal-measures in the neighbourhood of East Maitland, where the principal seams of the Tomago Series occur in the following order, commencing with the highest seam: Four Feet (4 feet), Seven Feet (7 feet), Six Feet (6 feet), Three Feet (3 feet), Two Feet Six (2 feet 6 inches), Rathluba (4 to 8 feet), Morpeth (4 to 6 feet), the total average thickness of workable coal being estimated at 20 feet.

Between West Maitland and Greta, the Greta coal series contains two seams varying respectively from 3 to 11 and from 14 to 32 feet in thickness. From Inverell up to the Queensland border a long coalfield about a quarter of a mile broad contains a seam of coal about 27 feet thick, considered to belong to the Greta Series, here often much disturbed. This seam is of excellent quality, in places anthracitic, and said to be suitable both for steam-raising and smelting purposes.

Contemporaneous sheets of basalt, andesite, and volcanic tuffs, reaching a thickness of 1,600 feet near Kiama, lie between the Upper Marine and Newcastle Series. Intrusive dykes of basalt and dolerite are common, and locally cause a seam to become anthracitized, but frequently, when numerous, render a district worthless. At Mitagong a seam is locally converted into a typical anthracite by the intrusion of a mass of syenite. There is no evidence to show the age of the intrusions, but since the Mesozoic period was one of volcanic quiescence in Australasia they possibly belong to the great Tertiary volcanic period.

The coal horizons of the Permo-Carboniferous lie above the Lower and Upper Marine Series. The fossil characteristic of the Lower Marine Series is the lamellibranch *Eurydesma cordata*, in association with *Platy-*

schisma and *Pachydomus*. In the coal-bearing horizons, remains of *Glossopteris browniana*, *G. angustifolia*, *Gangamopteris*, and *Vertebraria*, are the most characteristic fossils, as they are in the Lower Karroo and Lower Gondwana Series. In the Newcastle Series numerous silicified trunks of trees belonging to the genus *Dadoxylon* (allied to the modern *Araucaria*) occur at several horizons in close association with seams of coal.

The carbonaceous mudstones of the Upper Marine beds, where about to give place to freshwater beds, contain crystals of the remarkable pseudomorph Glendonite from 2 to 20 inches in diameter. Consisting now essentially of carbonate of lime, they may be pseudomorphs after salts of calcium and sodium. These pseudomorphs occur only at a few horizons in the Upper Marine Series, and nowhere else in Australia.

Explorations to prove the deep-seated coals in the Newcastle basin have taken place from time to time, the best known and most important being the Cremorne boring in Sydney harbour. At a depth of 2,917 feet a seam 10 feet thick of nearly pure coal, containing 71·09 per cent. of fixed carbon, 17·57 per cent. of volatile matter, and 10·68 per cent. of ash, was encountered by the drill in November, 1893. The seam is considered to represent the Bulli Coal, and the site of the boring is supposed to be near the centre of the basin (Fig. 35, p. 309).

In Queensland, the chief coalfields of Permo-Carboniferous age occur in the Bowen River district, where the strata are separated into Upper, Middle, and Lower Bowen Series. The Upper Bowen Series is considered to represent the Newcastle Series. The Middle subdivision contains the Dempsey Seam of Pelican Creek. A composite seam, known as the Daintree Coal, occurs near the base of the Upper Series, and two more

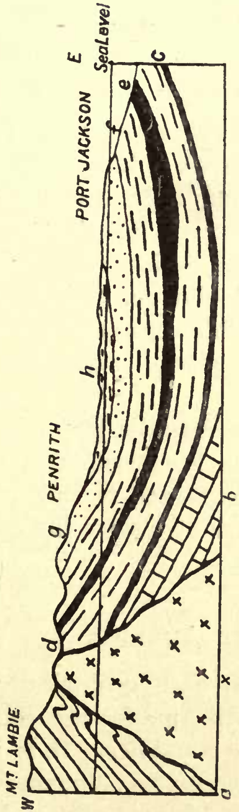


FIG. 35.—SECTION ACROSS THE COALFIELD OF NEW SOUTH WALES.
(*a*) Devonian; (*b*) Lower Marine Series; (*c*, *d*) Upper Marine Series, with Greta Series below; (*e*) Newcastle Series; (*f*) Narrabeen beds; (*g*) Hawkesbury sandstone; (*h*) Wianamatta shales.

Hor. scale, 1 inch = 33 miles. Vert. scale, 1 inch = 12,000 feet.

composite seams called the MacArthur and Havilah seams above this. All these seams give a very high percentage of ash, and are much intruded into by trap. The Settle River Coalfield, near Palmerville, contains numerous and thick seams, but they are of poor quality and mixed with dirt. An anthracite, 11 feet thick, has been found on the Dawson River. The Carboniferous and older rocks contain no coal. The former are marine formations, but are distinguished from the lower and upper marine beds of Permo-Carboniferous age by the absence of the corals *Trachypora* and *Stenopora* among animals, and by the absence of *Lepidodendron veltheimianum* among plants. Most characteristic of the Carboniferous marine beds are *Productus semi-reticulatus, Orthis crenistra, O. resupinata.* The lower part of the Lower Marine Series contains evidences of the existence of a cold climate, and in Victoria the Greta measures are possibly represented by part of the Bacchus Marsh beds of glacial origin, and containing no workable coals.

The output of coal for Australia in 1905 amounted to 7,495,956 tons, of which a considerable portion was shipped to the Pacific ports and to India, though less now goes to the latter country since the opening up of the Indian coalfields.

South America.

The most important, and geologically the most interesting, coals of South America are those found in the Brazil and Argentine republics. It is now beyond question that these coals can be compared in age with the chief coals of South Africa, India, and Australia—that is, they are of Permo-Carboniferous age. The flora, fauna, and nature of the Brazilian Coal-measures show, indeed, the closest parallelism to those of South Africa. In both countries the sediments were deposited in large continental lakes situated at high altitudes, and in striking contrast to the estuarine and maritime flats in which the Carboniferous Coal-measures of the northern hemisphere accumulated.

The South American succession of the Permo-Carboniferous rocks has been recently classified as follows:

THE GONDWANA SYSTEM OF SOUTH AMERICA.

Sao Bento Series	Serra Geral eruptives. Botacatu sandstones. Rio do Pasto red beds, with reptiles.
Passa Dois Series	Rocinha limestone. Estrada Nova grey and variegated shales. Inky-black shale. *Mesosaurus.*
Tubarâo Series	Palermo Shales. Rio Bonito shales and sandstone with coal. Orleans conglomerate. Yellow sandstone shales.

Fossils are abundant in the Tubarâo Series. Among these, *Phyllotheca griesbachi*, *Sigillaria brardi*, *Glossopteris browniana*, *Glossopteris indica*, *Gangamopteris obovata*, and *Nœggerathiopsis hislopi* indicate that the Tubarâo Series represent the Ecca Beds of South Africa and the Karharbari Series of India. Like the Dwyka of South Africa, the Orleans conglomerate is of glacial origin.

In 1905 the output of Brazilian coal reached a total of 700,000 metric tons.

Peru possesses considerable coal areas in the Ancacho Santa valley, in the departments of Junin and Huanuco. In 1905 the output amounted to 75,338 metric tons. The principal coalfields of Chili, from which 789,229 tons were obtained in 1905, are of Tertiary age, and lie to the south of Concepcion.

In Trinidad, lignites of Tertiary age, but very variable in thickness and extent, have been found near Sangre, Williamsville, Caparo, Erin, Chatham, Rio Negro, Point Noir, and Cedros.

Bituminous coals occur in Guatemala, and several localities within a few miles of Port Livingstone.

CHAPTER XVI

COALFIELDS OF CHINA, CENTRAL ASIA, JAPAN, NEW ZEALAND, AND DUTCH EAST INDIES

FROM dealing with the well-defined coal-bearing regions of the northern and southern hemispheres, described in former chapters, we now pass to several eastern and southern coalfields which, though they geographically belong to one or other of the regions previously mentioned, are nevertheless geologically distinct. The important coals of northern China, for instance, belong to a different geological period to those of India; but the latter, as we have seen, are of the same age as those of Australia, though deposited under somewhat different conditions. The chief Australian coals, again, are distinct in age from those of New Zealand and other islands of the southern Pacific.

CHINA.

The total production of coal in China is altogether unknown, but that it exists in large quantities is an accredited fact, since it is extensively used throughout the country. Indeed, the use of coal as a fuel for manufacturing and metallurgical purposes, as well as a source of warmth, seems to have been known to the Chinese from remote antiquity.

The chief coals are of Carboniferous age, but whether they can be referred to the Uralian or Moscovian division remains uncertain.

In Manchuria, the most northerly coal-producing area of China, the coal—once thought to be of Westphalian age—is considered to belong either to the Stephanian Coal-measures or to the Permian. The chief outcrops of the coals lie to the east of the Port Arthur and Mukden Railway, the most important coal-field being at Tow Chouw, to the east of Mukden. The coal is mainly of a bituminous character, one seam attaining a thickness of about 96 feet. The estimated output for Manchuria is nearly 55,000 tons per annum.

Coal-measure strata occupy a considerable area in the province of Pe-chi-li, where the coal, as in Manchuria, though formerly placed in the Westphalian division, is now said to belong either to the Stephanian or to the Permian.

The basin of Kaiping, traversed lengthwise by the Chinese Imperial Railway from Pekin, is the chief coal-field of Pe-chi-li. This important coal area extends for over twenty-five miles from east to west along the main axis of the syncline, whose limits to the north are clearly defined by the outcrop of the Carboniferous limestone and Cambrian strata. Alluvial deposits conceal most of the southern outcrop west of Liushu. The Coal-measures dip at a high angle towards the centre, and are occasionally found to be reversed by over-folding.

At the Tongshan Colliery the coal-seams number seventeen, and yield about 75 feet of good coal to about 1,900 feet of barren strata. The present workings are confined to the upper seams, which vary in thickness

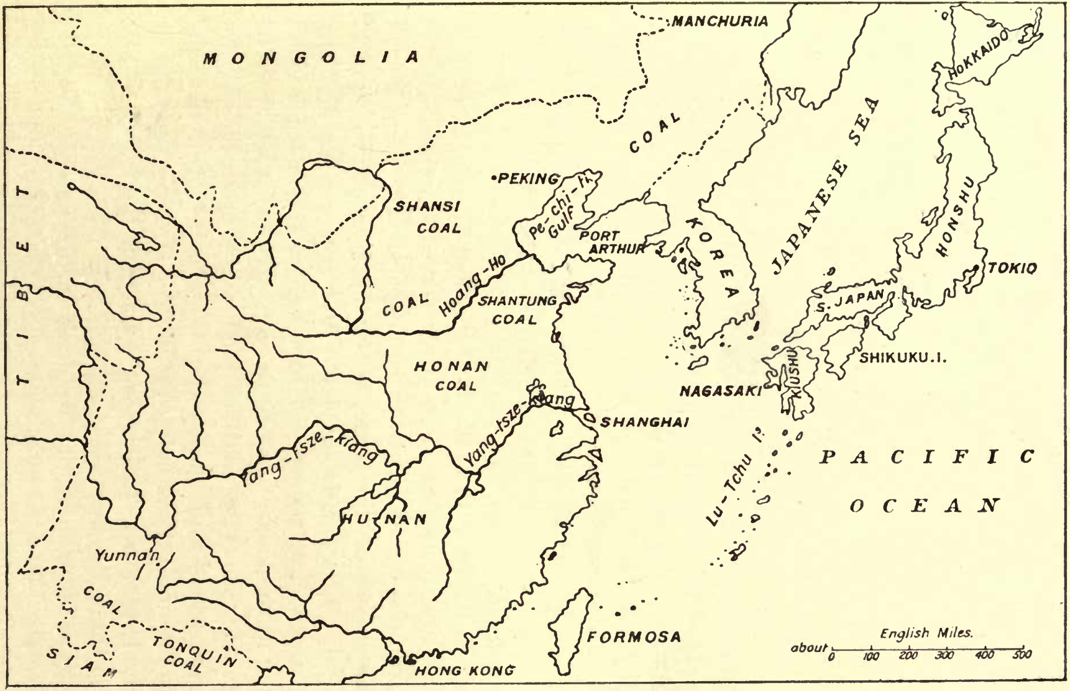


FIG. 36.—MAP SHOWING THE CHIEF COAL AREAS OF CHINA.

from 3 to 14 feet; but in the lower levels the coals show a tendency to unite. A considerable portion of No. 5 seam, one of the most worked, yields 'smalls,' giving a different analysis to the larger coal. The 'smalls' give fixed carbon, 55·27; volatile matter, 26·58; water, 0·30; ash, 17·85; while the large coal gives fixed carbon, 58·45; volatile matter, 33·50; water, 0·35; and ash, 7·70 per cent. This seam yields a good coke.

North of the Hoang-Ho River, in south-eastern Shan-Si, occurs one of the largest anthracite regions known, the area being roughly estimated at 13,500 square miles; and the amount of anthracitic coal, taking an average of 40 feet in thickness over the district, is calculated at over 630,000,000,000 tons. The bituminous coalfields of western Shan-Si are considered to be nearly as large, and coal is also said to occur in thick and extensive deposits in northern Shan-Si.

On the plateau of Shan-Si the coal-bearing formation is said to consist of a lower limestone (Kohlenkalk) overlain by a series of shales and sandstones, with some beds of limestone, containing the chief seams of coal. The deeply dissected and scarped faces of the plateau show several outcrops of coals, one seam varying in thickness from 10 to 40 feet being everywhere in evidence. The coal-bearing strata are overlain by sandstones and shales (Bantgefärthen) of a reddish-brown or yellow colour, affording striking features in the landscape. Loess covers many of the hills and fills up the valleys.

The fossils of the Kohlenkalk, at present known, are *Phillipsia*, *Spirifer mosquensis*, *Orthotetes*, and *Orthis michelini;* although the coal-bearing strata rest in places on Carboniferous Limestone, it appears that they often unconformably repose on limestones of Ordovician age, which have been mistaken for those of the later Palæozoic formation.

From our knowledge of the character of the strata in other regions where anthracites occur, the presence of these would suggest a folded and highly disturbed area, or one in which igneous activity had been developed on a considerable scale. Reports of Shan-Si state, on the contrary, that the coal-bearing strata lie almost horizontal, and are not intruded into by igneous material. The anthracites from Shan-Si give a carbon percentage between 84·67 and 89·24, with that of the ash between 6·19 and 12·20, and a calorific power of 5,727 and 7,166. The coal is very hard in character, with little impurity; it burns with scarcely any flame, emits no smoke, and leaves little ash.

The annual output of coal can only be approximately guessed at by calculating the amount that must be consumed for domestic purposes and in the iron furnaces. The population of Shan-Si is estimated at from fifteen to twenty millions, and as coal appears to be extensively used for fuel, the annual output, it is reckoned, cannot be less than 5,000,000 tons for domestic purposes alone.

In Shen-Si, west of Shan-Si, the Kiu-Chou series of red shales and sandstones, with marine limestones and local coal-seams, are of Permo-Triassic age. They rest on the Wu-Shan limestone of Carboniferous age which locally contains coal.

In northern Ssï-ch-uan folding took place at the close of the Carboniferous period, but not till early or late Triassic times in the middle Yang-tsi region.

In Shan-Tung the coal-bearing series, of Moscovian age, consists at the base of shales and sandstones, and of lavas, tuffs, and intrusive rocks near the summit. Red and grey sandstones, shales and conglomerates, succeed. The Lower Carboniferous rocks, forming the Po-Shan Series, contain *Chonetes*, *Squamularia*, and *Marginifera*, and rest on the Tsi-nan limestones of Ordovician age.

In Honan the coal-bearing measures contain the fossil plant *Pecopteris cyathea*, a Uralian species.

Coal also occurs in Hunan, where most of the seams are considered to belong to the Moscovian development of the Westphalian Coal-measures. The coal is an anthracite of good quality.

In Yunnan and Tonkin the coal-bearing strata belong to the Rhætic formation. The coals, of a semi-bituminous character, contain about 30 per cent. of volatile matter.

Central Asia. — Carboniferous shales containing workable coals rest on Dinantian Limestone at Ekibas-Touz in the steppes of Kirghis. Coal-bearing Jurassic strata cover a large area in the basin of Kouznetsk. The coals are irregular, but occasionally attain a thickness of over 150 feet. Coke obtained from these coals is extensively used in the metallurgical works of the Altai district.

JAPAN.

Japan, in the distribution of her coalfields, displays an arrangement resulting from earth-movements on a great scale. The islands of the empire are but the summits of a partially submerged range girdling the Asiatic continent on the east.

In Formosa (Taiwan) the watershed follows the longer axis of the island. The lofty peaks of the Lu-tchu (Ryūkū) islands continue the girdle as far as the island of Kiushu (Kyūshū), with the north-easterly trend of the central mountain range dominating the physical outline, though the nearly meridional coast-line south of Hyūgo conforms to the strike of the Tertiary formations. The Kyūshū range continues into the island of Shikuku. Honshū, or the main island, is divided by an east-and-west tectonic line into a northern and a southern part. Hokkaido, again, is traversed in the middle by the Ezo range trending north-north-west and south-south-east.

The framework of the Japanese Islands had been outlined before the deposition of the Mesozoic strata, which contains the oldest of the coal-bearing formations. Great earth-movements followed the Mesozoic period in Japan, and resulted in the partition of northern and southern Japan in Tertiary times, the formation of the general north and south structural lines, and in the determination of the shape and distribution of the coalfields as they are now seen.

At the end of the Tertiary and during the Quaternary period Japan was the seat of volcanic manifestation of great magnitude, comprising the eruption of liparites, dacites, andesites, and basalts met with in the Tertiary or most important coal-bearing formation in Japan. Besides these newer igneous rocks there are also intrusions of granites, quartz diorites, diorites, gabbros, periodotites, and porphyrites, of which the age is very uncertain, some being of early Tertiary and some of much older date.

The sedimentary strata of Japan may be chronologically tabulated as follows:

THE GEOLOGICAL FORMATIONS OF JAPAN.

Recent and Quaternary	Alluvium. Diluvium.
Tertiary -	Pliocene. Miocene. Coalfields of Kyūshū and Hokkaido. Eocene. (?) Nummulite beds of Ogasawara-jima.
Cretaceous -	Mikura and Misaka Series. Shinzi Series. Ammonite beds of Hokkaido. Coal. Izumi Sandstones. Ryoseki and Torinosu Series.
Jurassic -	Tetori Series. Shizugawa Series. Inkstone Series (Nagato). Anthracite.
Triassic -	Plant bed of Yamanoi (Rhætic). Anthracite. Pseudomonotis beds. Ceratites beds.
Palæozoic	Upper Chichibu Series (Carboniferous). No coal. Lower Chichibu Series.
Archæan : Schists and Gneiss.	

The chief anthracite fields are those of Moriyosho (Tertiary), Higashi-Muro-gōri (Mesozoic), Nagato (Trias-Jura), and Amakusa (Cretaceous). Andesite dykes cross a seven-foot seam in the Moriyosho field. In the Higashi field the seams vary from 1 to 4 feet thick, giving from 84·11 to 90·09 per cent. of coke and 2·03 to 5·16 per cent. of ash, and yielding annually about 30,000 tons. The Amakusa anthracite field, considered to be of Cretaceous age, contains, in the northern half, three seams, the highest being 8 feet thick. Many dykes of liparite cut across the northern and southern fields, and in their passage convert the anthracite into a natural coke (*senseki*).

Out of an output, exceeding 11,000,000 tons in 1905, coals classed as anthracite yielded less than 100,000 tons, the major quantity of coal raised belonging to the bituminous class.

The main supplies of bituminous coals come from the islands of Kinshin, which yield 82 per cent. of the total output, the northern island of Hokkaido (Yezo) giving about 10 per cent., the rest coming from the provinces of Hitachi and Nagato, in the main island (Honshu).

Kinshin contains five coalfields, comprising those of Chikuhu, Karatsu, and Miike, and of the three islets Takashima, Hashijima, and Yokoshima, and the anthracite field on Amakusa Island. The axes of the synclines are directed north-north-west and south-south-east. Excepting that of Amakusa, all these coalfields are referred to the Tertiary System.

In Chikuhu the available quantity of coal is estimated at 87,000,000 tons, and in Miike 100,005 tons, within 1,500 feet below sea-level. The Miike Coalfield, one of the most productive, contains eight seams of coal, enclosed in a thick-bedded Tertiary sandstone. The lowest or Eight Feet seam, which often reaches 20 feet in thickness, is the best. It is a bituminous coking coal containing much sulphur, and possessing a calorific power of 2,100 calories. An average of analyses gives volatile matter, 40·1; coke, 53; water, 0·65; ash, 6·84; sulphur, 3·14 per cent.

On the main island the chief coalfields are those of

Nagato, probably of Rhætic age, and of Iwaki, in the province of Hitachi. The output is 250,000 and 450,000 tons respectively per annum.

The Island of Hokkaido produces annually about 1,000,000 tons. The total amount of available coal is estimated at 600,000,000 tons. In the Yutari Mine the coal is pure, dry, and very hard, giving an analysis of volatile matter, 42·89; coke, 57·11; ash, 4·57; water, 1·46; sulphur, 0·31 per cent.

Formosa contains several thin seams of Tertiary coal seldom exceeding 4 feet in thickness. Tertiary coal of good quality, but of limited extent, occurs on Isiomoteshima, one of the Lu-tchu islands. In 1900 the production was 18,640 tons. The exports from Tamsui and Kilang amounted to 39,072 tons.

New Zealand.

Crystalline rocks of Archæan age cover extensive areas, and the coal-bearing strata of Cretaceo-Tertiary age are for the most part restricted to Auckland in the North Island, and to the west and south-east in the South Island. Tertiary lignites of inferior quality occur in several localities.

The Cretaceo-Tertiary formation consists in its upper part of marls, greensands, and limestone containing marine fossils. At the base the greensands pass down into the coal-bearing mudstones and brown sandstones with dicotyledonous and coniferous trees.

New Zealand coals chiefly belong to the brown coal group, but vary very much in quality. Some seams are good pitch coal, others bituminous and coking, while a few seams of anthracite are met with in the vicinity of igneous intrusions. The bituminous coals give an average analysis of: fixed carbon, 61·75; volatile matter, 34·20; water, 2·53; ash, 1·54 per cent. The anthracitic varieties have the following composition: fixed carbon, 89·01; volatile matter, 2·60; water, 3·21; ash, 5·18 per cent.

In 1905 the total output of coal amounted to 1,585,756 tons.

Buller Coalfield.—The flat coastal belt at Westport rises abruptly inland into a high plateau intersected by numerous ravines and deep gorges. At the foot of the hills the coals are faulted and shattered, but are undisturbed on the plateau above. The coalfield has a length of about forty miles, with a maximum width of seven miles. The seams vary greatly in thickness, and are hard and of good quality.

Brunner Coalfield.—This coalfield is favourably situated on the Grey River. The coal is in places nearly 18 feet in thickness, being a bituminous coking coal of good quality, yielding a large quantity of gas.

Kaitangata Coalfield.—The strata of this coalfield consist chiefly of conglomerates, sandstones, and shales, and cover an area of about forty square miles in the hilly country between Kaitangata Lake and the sea-coast, along which the measures and coals can be seen in the cliffs. There are several seams; one of them, being as much as 30 feet thick in places, is seen in open section at Coal Point. The coal contains 3 per cent. of ash and about 10 per cent. of water. It is free-burning, furnishes a good house coal, and is also used on locomotives.

Shag Point Coalfield.—This field lies to the north of Dunedin. The measures resemble those of the Kaitangata Coalfield. A seam of pitch coal 7 feet thick was followed in undersea workings.

Green Island Coalfield.—Though the seams are very inferior brown coals, the close proximity of this coal area to Dunedin has resulted in the establishment of several collieries.

Malvern Hills Coalfield.—This coalfield is situated about 30 miles to the west of Christchurch. The measures consist of sandstones and shales containing several seams of coal, the thickest seam being about 7 feet. Numerous dykes of basalt intersect the seams, converting them locally into 'glance' coal or anthracite.

Waikato Coalfield.—This coal area lies in South Auckland. The coal-bearing rocks are supposed to be of Lower Greensand age. There are several workable seams ranging from 18 to 30 feet in thickness. Some of the mines have proved very successful.

Dutch East Indies.

Lower Carboniferous rocks are found in the Islands of Sumatra and Timor, but are unproductive. The upper Carboniferous strata, if they were ever deposited, must have been denuded away during the long time—embracing nearly the entire Mesozoic period—that the islands of the Archipelago were above water. The coals belong to the Tertiary period, the best being of Eocene age, the next those of Miocene age, while the Pliocene coals are inferior lignites. The output from the islands in 1905 was nearly 390,000 tons.

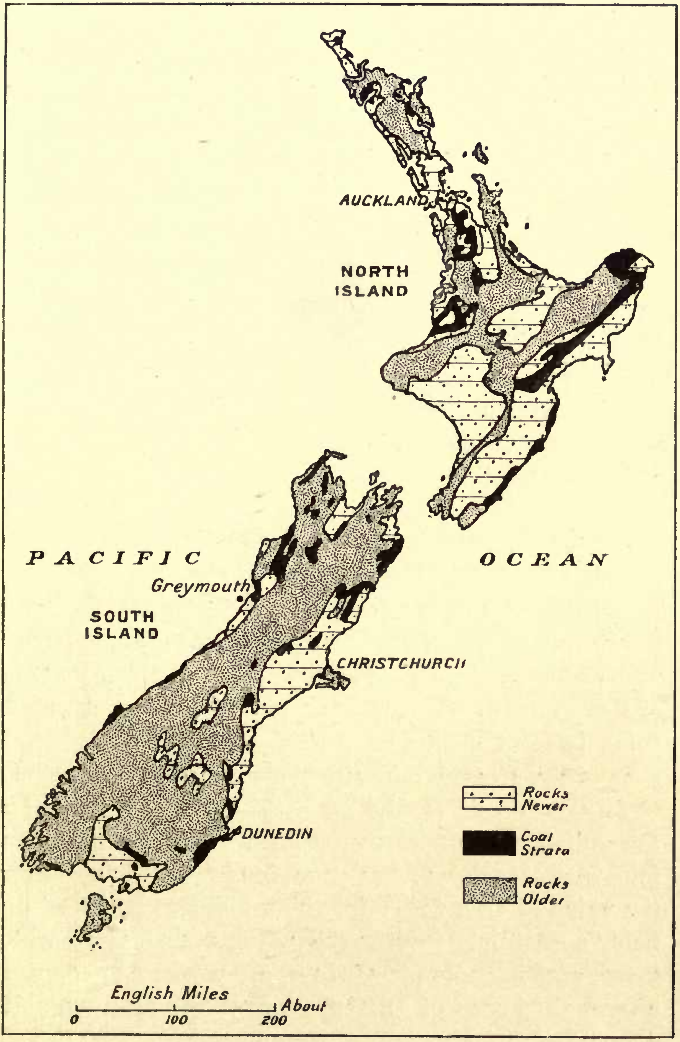


FIG. 37.—THE COALFIELDS OF NEW ZEALAND.

Sumatra.

After crossing the long chain of mountains known as the Brissan range, composed of crystalline rocks, and extending along the entire length of the island, the Padang Lowlands are entered. The basin of the Ombilen River, which crosses the Lowlands, contains the chief coalfields of Sumatra. It yielded an output of 207,280 metric tons in 1904-1905, and is estimated to contain over 200,000,000 tons of available coal. Volcanic activity commenced in the Cretaceous period, and attained its maximum development in post-Tertiary times, when the long line of volcanoes along the western coast was formed.

In the Ombilen Coalfield the Tertiary formation rests directly on Lower Carboniferous or older rocks. The Eocene formation is divided into a lower series composed of breccias, conglomerates, shales, and limestones, a middle series of sandstones and shales containing the important seams of coal, and an upper series of marls and sandstones with a few thin seams of coal. These are overlain in the southern part of the coalfield by thick beds of orbitoidal limestone. The entire thickness of the Eocene deposits is estimated at 5,600 feet.

The coal-basin is divided into: (1) The northern or Parambahan Coalfield, containing several thin seams and four workable coals; but numerous faults detract from the value of this field; (2) the middle or Ligalet Coalfield, containing seven very regular seams, of which three, and in some places four, are workable and give a united thickness of 18 feet of coal, the total available supply being estimated at over 70,000,000 tons; (3) the Soengi Doerian Coalfield, proper, containing three workable seams—a lower seam from 21 to 24 feet thick, and two higher seams averaging 6 feet in thickness.

Ombilen coals are stated to be very free from ash, and to contain 77 per cent. of carbon, 6 per cent. of hydrogen, 13 per cent. of oxygen and nitrogen, and 4 per cent. of moisture. The sulphur varies from 0·35 to 0·60 per cent.

Java.—The chief coalfields of Java are of Eocene age, deposits of which are found over the whole island. The coals are friable, but stated to be of good quality.

Borneo.

Carboniferous strata consisting mainly of limestones and sandstones, but not so far found to be coal-bearing, are met with in several parts of the island, and form a broad zone in Sarawak.

In British North Borneo the chief coalfield—doubtfully referred to the Oolitic period—occurs on the island of Labuan, from which the yield in 1905 amounted to 58,768 metric tons. The output is chiefly derived from a seam averaging over 9 feet in thickness and mined at Coal Point.

In Dutch Borneo the coals are of Tertiary age, and chiefly occur in the south and east. The best seams belong to the lower quartz-sandstone series of Eocene age. The next in quality are of Miocene age; and the poorest, consisting of inferior Brown coal and lignite, and containing over 20 per cent. of moisture as compared with 12 per cent. for the Eocene coals, belong to the Pliocene period.

The seams over the large Barite basin in southern Borneo number from six to eleven, but usually only two or three are of sufficient thickness to be worked. These are of Eocene age and mined chiefly at Pengaron, inland from Banjermassin. Most of the seams contain thin bands of clay difficult to separate from the coal, and therefore forming a large quantity of ash. These Eocene coals are hard, of a greasy appearance, and contain much resin. Excluding the ash resulting from the intercalated bands of clay and shale, an average analysis shows: carbon, 74; hydrogen, 5·6; oxygen and nitrogen, 15; and ash, 8 per cent.

Immense deposits of coal of Miocene age are met with in East Borneo in seams from 1 to 9 feet in thickness, but, like those belonging to the Eocene formation, possess the disadvantage of containing interstratified bands of clay. The chief coal districts are those of Sanga-Sanga, Pelarang, Salili-Prangat, and Berouw.

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THE END

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