XIII. *The Geology of the Oil Shalefields of the Lothians.* Anniversary Address by HENRY M. CADELL of Grange, B.Sc., F.R.S.E., F.G.S., President of the Edinburgh Geological Society.

(Read 15th November 1900.)

CONTENTS.

1. Introductory.
2. The Scottish Oil Industry.
3. Oil Shale: its physical characters.
4. Products of Oil Shale.
5. Extent of Shalefields.
6. Distinctive Zones.
7. General Geological Structure.
8. West Calder Shalefield.
9. Houston Marls.
10. General Section of the West Calder Shalefield.
11. Livingston District.
12. Pumpherston Shalefield.
13. Mid-Calder Basin.
14. Camps Limestone.
15. Broxburn Shalefield.
16. Binny Sandstone.
17. District north of Broxburn—Ash-necks.
18. Houston Coal.
19. Winchburgh District.
20. Philpstoun and Champfleurie Shalefield.
21. Hopetoun District—Shore Section.
22. South Queensferry.
23. Dalmeny Shalefield.
24. Burdiehouse and Straiton Shalefield.
25. Burntisland Shalefield.

ILLUSTRATIONS.

FIG. 1. General Horizontal Section of the West Calder Shalefield and Carboniferous Limestone Series to the west, 7 miles in length, drawn to a scale of 1 inch to a mile.
FIG. 2. Section from Dechmont Law through Pumpherston to Camps limestone basin, 5 miles.
FIG. 3. Section from Champfleurie through Ecclesmachan to Newliston (6 miles).
FIG. 4. Sketch Section along south side of Railway Cutting west of Priestinch.
FIG. 5. Sketch Section at bend of R. Almond above Illieston.
FIG. 6. Shore Section from Nethermill Burn along shore to Dalmeny (6 miles).
FIG. 7. Section of Burdiehouse and Straiton Shalefield, on a scale of 6 inches to a mile.
FIG. 8. Generalised Diagrammatic Vertical Sections of the Shalefields of West and Mid Calder, Broxburn and Burdiehouse.

THE GEOLOGY OF THE OIL SHALEFIELDS OF THE LOTHIANS.

1. *Introductory.*

IN quitting the Presidential chair of the Edinburgh Geological Society at the end of my term of office, which it has been a pleasure no less than an honour for me to have occupied during the last two years of the bright Nineteenth Century, it has occurred to me that this opportunity might be taken to speak of a subject that has engaged much of my time and attention during the last fifteen years, the first three of which were spent as an officer on the staff of H.M. Geological Survey.

The geology of the oil shalefields in the neighbourhood of Edinburgh is a branch of local geology well within the scope of this Society's work, and although the oil industry has existed in this part of Scotland for more than thirty years, no reliable general account has ever been published of the important section of the Lower Carboniferous formation which has so greatly conduced to the well-being of a large district and its people. Such a subject has many features of interest both to the scientific and the economic mind, and I now propose to speak in a popular way of some of the results of my geologisings, in the hope of being able to throw a little new light on the relationships and character of the rocks that have themselves been made, during this generation, to throw so much light over dark places in many a European country.

It is not my intention in these pages to treat the subject exhaustively after the style of a monograph such as we may hope the Geological Survey will publish before many years have passed. Nor do I wish to claim to have said the last words on many of the topics to be dealt with. Geology is, or ought to be regarded as, a progressive science in which new discoveries may overturn or greatly modify our present beliefs, so that it is impossible to claim finality in any department and particularly in that of the oil shalefields, our knowledge of which is being increased by fresh discoveries every year.

2. *The Scottish Oil Industry.*

The Scottish Mineral Oil Industry is to my mind one that bears conspicuous testimony to the *perfervidum ingenium Scotorum*—to the enterprise and inventive genius of our countrymen, to their perseverance and skill in meeting and surmounting formidable obstacles in the path of industrial progress, and to their courage in facing and ultimately overcoming the fierce foreign competition that was for many years directed against them and designed to crush them into subjection and extinguish the whole industry. It has been my lot to have wandered among the oil fields of Pennsylvania, Ohio, the Caspian and Burma, and to have seen the liquid fuel spouting high into the air or being pumped like water from the subterranean reservoirs. Many a time in these far off places have I turned my thoughts homewards to far other scenes where nature was less prodigal in her gifts, and refused thus to lavish away her wealth, without demanding in return some tribute of skill and science at the hand of man. While gazing at the oil fountains of the East and West, the foremost thought to rise in the mind of one accustomed only to see the crude yellow fluid trickling from the high retorts of the Lothians, is a feeling of despair at the apparent hopelessness of the unequal contest. The Scottish oil, in its dry matrix of black shale, has first to be laboriously won —blasted out of mines hundreds of feet deep, hauled or hoisted by machinery to the light of day and crunched into small pieces between strong iron teeth, then carried to the retorts where it is carefully distilled and separated from its earthly casing— before ever it reaches the condition of the crude petroleum that spouts up in other countries ready made. It is indeed with a feeling of no little pride that we can point not only to the continued existence but even to the comparative prosperity of the Scottish oil industry in the midst of such adverse conditions. If however our oil is hard to win, the winning of it has engendered a spirit of inventiveness, enterprise and scientific aptitude that might never have been developed under easier circumstances. Necessity—often dire necessity—has here been very conspicuously the mother of invention, and the lessons learned in her hard school are now returning their reward to those of her *alumni* who have studied well and have learned how many valuable things are contained in, and can be extracted from, a lump of oil shale.

3. *Oil Shale: Its Physical Characters.*

Oil-bearing shale as known in the Lothians is simply a fine black or brownish clay shale containing such a large proportion of organic ingredients as to give it certain special physical and chemical features which enable it to be easily distinguished in the field. Oil shale is known to Scottish miners simply as *shale*, and the stratified rock described by geologists as "carbonaceous shale" is distinguished as *blaes*, a term derived from the bluish colour it often assumes, especially when broken down into clay.[1] This distinction is a convenient one in several ways and will be followed without further explanation in this paper.

Oil shale or *shale* is easily distinguished in the field from *blaes*, but bituminous *blaes* may graduate into regular oil shale in such a way that it is impossible sometimes to draw the dividing line between them. Bituminous blaes if fairly rich in ammonia and volatile hydrocarbons may pass for shale if a practical test proves it to be workable for oil and ammonia on a commercially profitable scale. As a general rule good oil

[1] The word *blae* also appears in blaeberry, so named from its dark blue or slate colour.

shale can be distinguished by its brown streak, toughness, and resistance to disintegration by the weather. Ordinary black blaes is more or less brittle and often gritty, and when exposed to the air it cracks up and crumbles down into small fragments which ultimately sink into their original condition of clay or mud. Oil shale, on the other hand, resembles hard dark wood or dry leather, and its quality in the field is measured by the degree of facility with which it can be cut and curled up with the edge of a sharp knife. It is perfectly "mild" and free from grittiness, and is often flexible as well as tough. Some seams, such as those that crop out on the shore at Society near Hopetoun House, instead of breaking up like blaes, shed their fragments in slabs sometimes a couple of feet in length, that are washed about like heavy boards and rounded on the edges by the waves till they come to look like so many flat scones, substantial pancakes, or bannocks of black bread, capable of being bitten between good teeth without any injury to these organs.

Miners draw a distinction between "plain" and "curly" shale, the former variety being flat and smooth, and the latter contorted or "curled" and polished or glossy on the squeezed faces. The same seam may be partly plain and partly curly, and the curly beds are often richer in oil than the plain portions. Shale is probably curly because it is rich and not rich because it is curly, as the higher percentage of hydrocarbon in some beds may have rendered them more easily crumpled than the stronger but poorer bands alongside of them.

In thickness the shale seams vary greatly. At some places they run out altogether and pass into ordinary carbonaceous blaes, and at others they swell to six, ten, fifteen or more feet in thickness, with perhaps sub-divisions of barren blaes or ribs of hard calcareous or quartzose "kingle."

In internal structure oil shale is minutely laminated. This is apparent in the "spent shale" after distillation which is thrown out in fragments composed of extremely thin sheets like the leaves of a book or flakes in a piece of pastry.

4. *Products of Oil Shale.*

Oil shale is described by the practical oil man according to the quantity of oil a ton of the rock contains. Thus a "30-gallon shale" is one which yields 30 gallons of crude oil per ton when distilled on a practical scale. A seam such as the Broxburn shale producing this quantity is considered rich, but in addition to the oil a certain quantity of ammonia is produced as a bye product in the process of distillation. The ammonia, vapour is neutralised by strong sulphuric acid and converted into sulphate as it is produced, and as this salt is of high agricultural value as a source of nitrogen, the manufacture of sulphate of ammonia has come to be an important branch of the Scottish oil industry. Much attention has been given to the construction of retorts and plant designed to extract all the available ammoniacal vapour and produce the greatest possible quantity of the sulphate from the shale. This is one of the inventions of which necessity has been the mother, and on account of the ammonia it is now sometimes possible to work remuneratively what would formerly have been regarded as a worthless shale. It is therefore now usual to test a seam for its ammonia as well as its oil, and in describing its products to state the quantity of ammonia in its condition of sulphate. Many shales comparatively poor in oil are rich in ammonia and can be made to yield over 50 lbs. of the sulphate per ton. Roughly speaking the salt is worth 1d. per lb. and forms such an important factor in the value of the shale that without it few or none of the existing seams could be profitably worked.

It is a matter of common experience in the shalefields that the deeper we descend in the section the higher does the percentage of ammonia become in relation to the oil, the richest ammonia producers being the Pumpherston shales, to be described later on, which are situated, so far as our present knowledge goes, at the very bottom of the oil shale series.

The commercial products of the distillation of oil shale are numerous, and the chemistry of the subject is full of interest. Without digressing into the chemical field, a few lines may be devoted to the general composition of oil shale and its principal products. I am indebted to Mr D. R. Steuart, F.C.S., the chemist to the Broxburn Company for kindly supplying the following figures relating to the general composition of the Broxburn shale. On the average this seam has the following constitution—

	Per cent.
Carbon	5
Volatile matters	25
Ash	70
	100

The "spent shale" that is removed from the retorts and deposited in huge "bings" round the oilworks, consists of the fixed parts of the seam, viz., ash and carbon which makes up 75% of the whole. The volatile part distilled off in the retorts consists of—

	Per cent.
Crude oil	12
Ammonia water	8·5
Gas	4·5
	25

These are the theoretic figures obtained in the laboratory. The theoretical amount of nitrogen would produce about 60 lbs. of sulphate of ammonia per ton, but in actual practice with the best form of Henderson retort it is only possible to recover from 40 to 45 lbs. and from 15 to 30 gallons of crude oil per ton.

The crude oil is separated in the refinery into the following four classes of hydrocarbons of various degrees of density and volatility—

1. Naphtha or light spirit.
2. Light burning oils.
3. Heavy lubricating oils.
4. Solid wax or paraffin.

These refined products of shale oil can again be subdivided and combined with other substances in such ways as to minister in some form or other to the countless requirements of almost every department of civilized existence.

5. *Extent of Shalefields.*[1]

The Upper or Oil Shale-bearing division of the so-called Calciferous Sandstone Series of the Carboniferous system of the Lothians is bounded on the north by the Firth of Forth, on the west by the volcanic ridge of the Bathgate Hills and the basement beds of the Carboniferous Limestone Series, and on the south-east by a line sixteen miles long, extending from the south of Cobinshaw reservoir to Dalmeny. Outside this triangular area two small detached shalefields, are known at present, one of which is at Straiton and Burdiehouse, five miles south of Edinburgh on the eastern side of the Pentland ridge, and the other is at Burntisland, on the Fife Coast, on the same geological horizon. It must, however, not be forgotten that there are other tracts of country in Mid and West Lothian so deeply covered with drift that their geological structure is still wrapped in mystery. Quarter of a century ago, before mining operations disclosed the nature of the rocks beneath the unpromising surface, many of what have since proved to be most

[1] The shalefields are nearly all included in the western part of sheet 32 of the second edition of the 1-inch geological survey map of the Edinburgh district. I hope, however, in the autumn of 1901 to be able to complete a geological map on a smaller scale, to include the Carboniferous Limestone series to the W. of sheet 32, as well as the shalefields, which will be ready for publication in the next issue of the Society's "Transactions."

valuable shalefields were completely hidden, and it is quite possible that new tracts of good shale may yet be discovered in places where, from superficial appearances, no indication exists as to the presence or absence of subterranean wealth. It must also be remembered that while the principal and most productive seams of oil shale are contained in the Oil Shale group of rocks below the Carboniferous Limestone, oil-bearing shale is not by any means to be sought for exclusively in that position. It has been met with in the Coal Measures, and oil-bearing bituminous shales are found in the Carboniferous Limestone series, interbedded with coal seams and beds of ironstone, but none of these are at present believed to be workable at a profit.

The oil shale districts of the Lothians possess some peculiarities that greatly hinder the task of working out their correct geological structure. In the first place, the ground is more or less deeply covered with glacial drift or boulder clay, sometimes to a depth of over 100 feet, and in these places only hard knobs of eruptive rock appear at intervals. The more important strata being generally soft are often obscured, even if the soil be thin, and the outcrops of the shale seams are very seldom visible. In the next place, the structure is, unlike that of the Carboniferous Limestone areas to the east and west, most irregular and often very complex, the strata being bent and twisted about in various directions without much system, besides being cut up by faults and invaded by many irregular sheets and dykes of eruptive rock.

For these and other reasons it is not surprising that geologists have hitherto entirely failed in correctly reading the structure of the ground by merely examining the natural sections. It is only by diligently studying the mining evidence and comparing the inadequate natural exposures with the results of thousands of borings and mineral surveys, that the general structure of the district has become apparent, and even yet, after many years of work and observation, places exist that seem to baffle our attempts at extracting their secret. Much has lately been done, but very much still remains, especially in the paleontological field, for the geologist of the future to accomplish, and surely it is well that this should be so—that there should still be a few unscaled heights to climb and unfathomed depths to sound, some unopened mines to descend and unexplored recesses to penetrate in this as well as in other provinces of Nature's inexhaustible realm.

6. *Distinctive Zones.*

The evidence that I have followed in working out the structure of the shalefields is, it may be mentioned, purely lithological and physical, and although many of the beds are known to be richly fossiliferous, paleontological evidence has been of no assistance here. It is left for future geologists to take up the interesting work of finding and following up fossil zones, and investigating the history of animal and plant life during that portion of the Carboniferous period.

In studying the stratigraphy of the shalefields, although there is considerable variation in the character of many parts of the series, certain well-marked zones occur with such regularity as to prove of great assistance in determining our whereabouts in a strange land. The lowest of these landmarks is the estuarine limestone of Burdiehouse, Camps, or Queensferry, and when once the position of this distinctive bed has been ascertained in reference to the strata in any district, we know whereabouts to look for oil shale. The Burdiehouse limestone lies below all the oil shales that have hitherto been discovered, except those of Pumpherston, and, roughly speaking, it occupies a position about 2400 feet below the marine or Carboniferous Limestone at the top of the Oil Shale series. While several calcareous bands are to be found in the shale districts, and are known to occur locally between the Burdiehouse and the marine or Mountain Limestone, none of these are to be regarded as geological horizons of general importance in the Oil Shale series.

The next important stratigraphical landmark is the Houston coal seam, which, although too poor to be of much commercial interest, is of great geological value in the field on account of its wide occurrence and the extremely characteristic deposit of so-called "marl" that everywhere covers it and marks its position. This bed indicates the top of tbe most valuable shale-bearing group of strata. Under it are situated the Fells, Broxburn, and Dunnet shales, the three principal seams above the limestone. The shales above the Houston coal, which will be referred to later on, although workable at places, are generally inferior to the deeper seams just named.

The Broxburn marls, a series of characteristic marly clays and limestones that always overlie the Broxburn shale, are also of stratigraphic importance; while the arenaceous beds under the Broxburn and above the Dunnet shale, known as the Binny Sandstones, form a well marked though variable zone over the whole of the oil shale districts.

7. *General Geological Structure.*

Although the structure of the West Lothian shalefield (and in this we may include, for geographical purposes, the shale-fields of Pumpherston, Mid and West Calder, which are within the borders of Midlothian) is far from regular when considered in detail, certain broad general features characterize the structure of the whole area. Subject to many local modifications, the strata are arranged in a series of undulations with a general northerly and southerly trend. These are cut from east to west or south-west by several large faults traceable for several miles across the district, which displace the beds more than 1000 feet at some places along their course.

The principal faults in the shalefield are four in number, while there are multitudes of minor dislocations. The most southerly of the great faults runs past Murieston, where it apparently brings the Burdiehouse beds down against the trap of Corston Hill, which seems to be an interbedded volcanic mass, probably on the horizon of the older lavas of Arthur's Seat. This fault appears to run south-westwards and cut off the upper shales in the Hartwood basin, bringing the Burdiehouse beds up against them on the south-east. The dislocation runs on into Lanarkshire, and no doubt crosses the moorland to Levenseat, where its course can be followed for several miles.

The next line of displacement, which may for want of a better name be called the Calder fault, runs nearly parallel to the other, and has a smaller downthrow in the same direction. This fault cuts off the Mid Calder basin on the south, and is probably the same dislocation as runs past Hermand and skirts the north-west side of the Hartwood basin, where it has a throw of between 700 and 800 feet.

The Middletonhall fault, which runs from the Almond north of West Calder to Uphall and Ratho, with a large downthrow to the north, will be referred to later on in connection with the Broxburn shalefield.

The fourth principal dislocation is the Ochiltree fault in the northern part of the shale area. This fault, unlike the others, has a downthrow to the south or south-east, and at Dalmeny the amount of displacement, as will be shown afterwards, is over 1000 feet. The effect of the two last-mentioned faults is to produce a trough about three miles broad, running from south-west to east across the centre of the shalefield. The Burdiehouse beds never reach the surface within most of this zone, and the Houston coal is, except at Philpstoun, not found outside of it.

The most conspicuous of the anticlinal arches is that of Pumpherston, in the centre of which crop up the lowest beds of the oil shale series in the form of a narrow ellipse whose major axis runs north and south for a couple of miles. On either side of the Pumpherston anticline the strata plunge steeply down into deep synclinal troughs. The eastern syncline which underlies the deep drift plain of Drumshoreland Muir, south of Broxburn, trends straight south for three miles to Mid Calder where it is clearly seen in the excellent sections of the Linhouse and Murieston Waters, and in the workings of the Oakbank Oil Company at the confluence of these streams. The eastern trough is straight and narrow, but the western, which extends from Pumpherston under Houston Wood to Dechmont, is broad and deep and is covered in the centre by a sheet of intrusive trap 200 feet in thickness. This basin, in the bottom of which the Burdiehouse limestone, whose outcrop can be seen at each side, is about 1000 feet deep, runs northwards, with a breadth of two miles, from the Almond at Livingstone to near Uphall. It is here cut by the great Middletonhall fault which at places has a downthrow to north of about 1500 feet. On the downthrow side the basin is still better defined, and is continued northwards for a mile and a quarter to Newbigging where it narrows to a point and disappears as a separate feature in the geological structure of the district. The beds in the centre of the basin at Middleton Hall are, in consequence of its great depth, the highest in this district and indeed had the depression been a very few fathoms deeper the interesting occurrence of a detached basin of Carboniferous Limestone would have been observed between Broxburn and Uphall in the midst of the oil shales, four miles away from the nearest place where its main outcrop is exposed.

Another well defined but low anticlinal extends northwards from Broxburn to Niddry a distance of about two miles, on each side of which the principal workings of the Broxburn shale have been made. The shales dip eastwards towards East Mains, then gradually rise at low angles and crop out in succession, the lowest or Dunnet seam being found rising to the surface along the course of the Brox Burn near Newliston House. North of Broxburn and Uphall the structure is much disturbed by intrusive trap, faulting and irregular dip. The undulations, however, are never great enough to bring up the Burdiehouse limestone, or to throw in the shales above the Houston marl.

To find the limestone again we must cross the Ochiltree fault which has been traced from Little Ochiltree past Threemiletown and Duntarvie to the shore at Dalmeny House. This important dislocation which runs across the district for about nine miles in a general E.N.E. direction brings the Burdiehouse limestone against the Broxburn shales to the south of Duddingston farm and at Dalmeny village. It has a downthrow at Dalmeny of over 1000 feet to the S.E. but splits into two faults near Woodend and the main dislocation diminishes to 400 feet and appears to run out in the vicinity of Binny Craig near Wester Ochiltree.

Hopetoun House stands in the centre of a short anticlinal fold on each side of which the Burdiehouse limestone dips to east and west respectively. The Eastern outcrop passes under a very distinct shallow basin occupied by beds including the Dunnet Shale and Binny section. These beds and the limestone rise again and form a second anticline to the east of Duddingston, the centre of which is occupied by a sheet of intrusive trap. The limestone again dips to the east at Echline and plunges under a second basin from which its representative emerges on the shore, east of the Forth Bridge. To the west of Hopetoun the limestone and overlying beds dip to the N.W. with a more regular strike, and trend S.W. to Philpstoun. Here they open out and form a low flat anticline on either flank of which there is a good outcrop of the Broxburn shale, mined at the Linlithgow and Philpstoun Oil Works. Between Philpstoun and the base of the Carboniferous Limestone, above which comes on the Bo'ness Coalfield, there is a tract of drift-covered land to the west not yet satisfactorily explored, in which shale may be discovered deeper down when the shallower fields become exhausted.

The West Calder shalefield in Midlothian is a district of much complication on account of the number of faults that intersect it and the irregularity in dip and strike of the beds within its area. In this district the entire section is traceable from the Burdiehouse to the Hurlet or lower marine limestone, so that by measuring across the outcrops we can describe the whole succession of strata and estimate the thickness with tolerable accuracy. Although the structure is complex, natural stream sections are fairly numerous, and the ground has been very extensively opened up in mines, quarries, and cuttings during the last thirty years, and it has thus become possible to work out the general structure and construct a geological map of the shalefield which, although still blank at places, may, so far as it goes, be considered fairly reliable. The principal tectonic features are two deep basins at Polbeth and Hartwood respectively, and a low anticlinal ridge at West Calder village to the west of and between these troughs. The shalefield is cut up by two large faults trending to N.E. with a downthrow to N.W., and by numerous smaller dislocations branching from or crossing these at various angles. Along the western edge of the shalefield the strike becomes more regular, and it is a curious circumstance that after we leave the shales and go westwards into the coalfield above the Mountain limestone the complications disappear and the strata maintain for about six miles a perfectly regular northerly strike and westerly dip, without any folding, and interrupted only by a few dip faults some of which are the western continuations of those in the West Calder shalefield. (See section fig. 1.)

As we go southwards to Cobinshaw natural sections become scarce under the drift- and peat-covered moorlands of that district. Mining operations show that the Houston coal and upper shales here extend southwards to the borders of Lanarkshire. A large and characteristic exposure of the Burdiehouse limestone has been laid bare in the quarries at Harburnhead. The limestone crops out under the peat and curves round beneath a shallow basin chiefly occupied by sandstones, the eastern side of which appears to be cut off by a large fault with a south-westerly downthrow which traverses the north end of the reservoir and brings the Fells shale and Houston coal down against these sandstone beds. The Hurlet coal and limestone have been mined at the southern end of the reservoir, but owing to faulting there is no continuous section from this horizon down to the shales. The two limestone outcrops approach within a couple of miles of one another, and this is the only place with the exception of the Straiton and Burdiehouse shalefield, where the zone of the Oil Shale series is compressed into such a narrow compass on the map.

After this brief outline of the general structure of the shale-

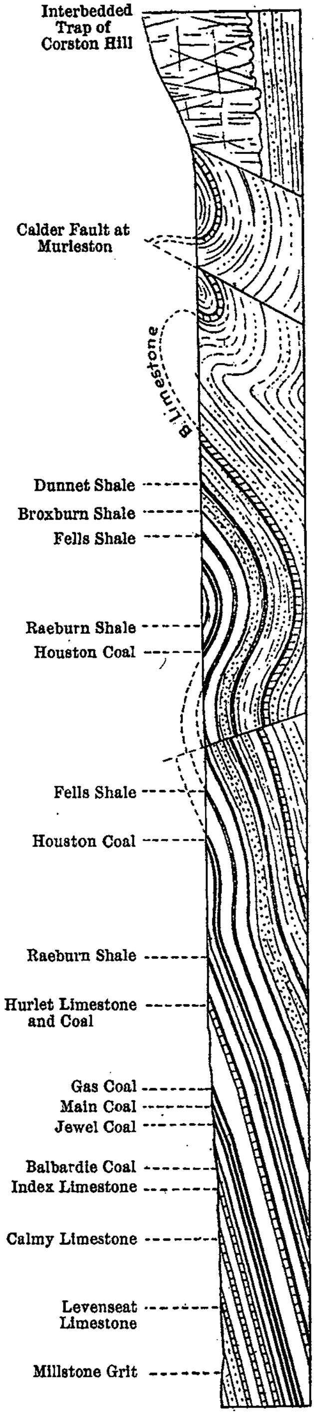


FIG. 1.—GENERAL SECTION OF THE WEST CALDER SHALEFIELD AND CARBONIFEROUS LIMESTONE SERIES TO THE WEST. (7 MILES)

fields, which can only be understood by reference to the geological map of the district, we may now turn to the stratigraphical details of a few distinct areas and compare the order of succession of the strata in these localities.

8. *West Calder Shalefield.*

Beginning with what I have called the West Calder district extending from Cobinshaw to the River Almond, a distance of six miles from N. to S. and about four from E. to W., we find, as has been said, all the section between the Burdiehouse and Hurlet limestones fairly well represented. The Burdiehouse is the lowest distinct horizon from which to work upwards, and no shales or seams of economic value appear to have as yet been found beneath it here. At Cobinshaw in the extreme southern part of the district the limestone which is about 20 feet thick is similar in all essential characteristics to the fossiliferous banded gray or cream-coloured estuarine bed at Camps and Burdiehouse. It is covered by greenish and yellowish gritty sandstones and marly beds dipping S.W. at 15 degrees. The thickness of these arenaceous strata must, judging by the dip, be not less than 900 feet, and although the ground has been well bored no shales of value have been found in the section. At Limefield, near West Calder, three miles further south, the same section is well exposed at more than one place. A good section of the limestone is seen in the railway cutting at Blackmire where the strata are tilted up at an angle of 60 degrees or more. The limestone is here 30 feet thick and is covered by beds of coarse felspathic, gritty sandstone with ashy conglomeratic beds. In all, about 430 feet of these strata are laid bare without any shaly intercalations. Unfortunately the section does not extend so far up as the position of the Dunnet shale. The beds below the Dunnet shale in the Hermand Burn at Limefield are likewise unfortunately not exposed continuously down to the limestone, but from all the evidence, and measuring across the strike it is clear there must be at least 600 feet of strata in this district, consisting chiefly of pebbly and gray or greenish marly or ashy sandstones between the limestone and the Dunnet shale.

As we go northwards into Livingston Parish a change begins, and we find the limestone at Barracks 2½ miles north of Limefield overlaid by a bed of blaes and with a seam of oil shale known as the Barracks shale, which, although not generally very productive, has been mined at some places on a small scale. As a rule this limestone has a shale or blaes roof, and except at West Calder there are generally several fathoms of blaes resting directly upon it in which a band of oil shale is often found.

The next important horizon in the West Calder district is that of the Dunnet shale, so named from its having been first mined by Mr Dunnet at Hermand. Whether this particular bed is continuous over all the shalefield cannot be definitely asserted, but it is certain that on or near this horizon a seam of good oil shale is well known to occur, and has been extensively worked in places as far apart as Burntisland, Burdiehouse, Newliston, West Calder, and Mid Calder, and proved by boring to exist in mostly every other shale mining district. The Dunnet shale is a large seam whose thickness reaches 10 or 12, or even 15 feet at places, yielding where good, 30 gallons of oil and 25 lbs. of sulphate of ammonia per ton, but the quality is variable and the yield of oil does not often reach this figure, although more ammonia may be obtained with the best retorts.

Above the Dunnet seam there are numerous beds of soft, greenish, marly blaes or fireclay in this district, sometimes known as the Dunnet marls which at Mid Calder swell out to 200 feet or more in thickness, but are here only a few feet in depth. The principal bed above the shale is the Hermand sandstone which has been extensively opened out in the quarry at Hermand a few feet above the Dunnet shale, and is here covered by a bed of the green marly blaes just referred to. This rock which is the representative in the West Calder district of the widely distributed Binny sandstone, is a first-class building stone. It contains nearly 95% of silica, and is very compact and not liable to be affected by the weather. It is gray in tint, and its architectural qualities can be studied from the following buildings in Edinburgh, all of which have been exposed to the weather for more than a dozen years, viz.:—The new part of Calton Jail; St Andrew's Free Church, Drumsheugh Gardens; West section of the Museum of Science and Art, Chambers Street; and the Bank of Scotland, George Street.

The beds above the sandstone are well exposed in the Hermand Burn, and consist of bands of green marly blaes with fine conglomeratic sandstones and fireclays, above which lies the Broxburn shale, a seam of prime importance in the oil-producing districts. The thickness of strata between the Dunnet and Broxburn shales, ascertained by measuring across the dip of the beds in the Hermand Burn, is about 420 feet or 70 fathoms. In this district the Broxburn shale is less than three feet thick and inferior in quality to the Fells seam, yielding less than 20 gallons of oil per ton. It was worked on Hermand estate for some years until that field was abandoned chiefly on account of the number of faults that were found to intersect the ground and the heavy pumping that was necessary to keep the workings dry, at a time, moreover, when the struggle for existence against the American oil had reached its acutest stage, and only the very best shalefields could hope to weather the storm.

The Broxburn shale is covered by a characteristic set of beds called the Broxburn marls, which are well exposed in the Hermand Burn above Murray's Pool Bridge. These strata are usually greenish, marly, or ashy clays, interbedded with carbonaceous shale and ribs of very hard, unfossiliferous cementstone or calcareous bands that vary in thickness from an inch to over a yard. The top of the series is, all over the West Calder district, characterised by a band of cream-coloured or gray limestone, three, four, or five feet thick, lying almost immediately under the Fells shale, and in boring for the shale this limestone is regarded as the infallible index of its position. No sandstone is found among the Broxburn marls as a rule, and this curious series of beds points to a period of tranquillity over a wide area, succeeding the time of swift flowing water that rolled along the pebbles and grains of sand before the period of the deposition of the Broxburn shale. The green so-called marls often appear to be beds of finely divided decomposed ash, wafted perhaps through the air from some far-off volcanic vent in a condition of intermittent activity, and deposited quietly and regularly in a deep and placid lake, with no strong currents to disturb its calm tranquillity and little animal life in its stagnant waters. The limestone bands may have been chemically precipitated from water charged with much calcareous matter in solution, or they may be of concretionary origin derived from the leaching out of the lime in the surrounding strata and its segregation and recrystallisation along certain planes without the aid of living organisms.

The principal oil-bearing seam in the West Calder district is the Fells shale, which rests directly on and marks the top of the Broxburn marls. The distance of the Fells above the Broxburn shale is here about 250 feet, and its thickness is generally from $2\frac{1}{2}$ to $3\frac{1}{2}$ feet in the Addiewell district, but it has at places proved workable for 6 or even 7 feet. It produces about 28 gallons of oil and 10 to 14 lbs. sulphate of ammonia in this district, but at Broxburn it becomes too poor to be workable, and passes into a band of ordinary blaes on the top of the marls. The Fells shale marks another change in the condition of the carboniferous sea. The water ceased for a time to be charged with marl-producing minerals, and a period of sedimentation of ordinary mud and sand set in. The beds of sandstone and fakes (or shaly sandstone), together 200 to 240 feet in thickness, that occupy the section from the Fells shale up to the Houston coal, tell of stronger currents and perhaps a gradually shallowing sea-bed nearer the shore from whence the sediments were derived. There is here no massive workable bed like the sandstone at Hermand indicating a continuous deposit of sand, but a succession of thin laminated beds mixed with blaes, showing frequent changes in the conditions of sedimentation.

The Houston coal is the lowest bed of workable coal known to exist in the Scottish Carboniferous System. It occupies a position of remarkable isolation from any other seam of the same sort, as with the exception of the insignificant 2 ft. coal above the Houston marl, the next bed of workable coal situated in the Carboniferous Limestone series is separated from it by about 2000 feet of sedimentary strata. The Houston coal is a pyritous seam of inferior quality, and on account of its bad roof and soft pavement, and of the quantity of blaes interbedded with it, has seldom in recent years proved remunerative to the miner. That it was formerly extensively worked near the outcrop the existence of numerous old crop pits testifies, but now it is only mined at one or two places, and there only during times of scarcity and high prices of all the better kinds of coal. The seam is about 6 feet thick at Baads, near West Calder, where it has been worked in connection with the shale. The pavement is here soft fireclay, and when mined in pillars it was found impossible to continue that system of working, as the pressure on the roof squeezed the pillars down into the pavement, while the roof was so bad that 1½ to 2 ft. of the seam had to be left in to support it, entailing the loss of nearly half of the available coal. The seam varies greatly in thickness from place to place. One section of it in an opening near West Calder is as follows:—

	Ft.	In.
Coal	1	4
Dirt	4	0
Coal	1	2
Faky Fireclay	0	7
Coal	2	6
Gas Coal	0	6
Oil Shale	1	2
Rough Coal on 5 ft. of White Fireclay	0	4
	11	7

About 50 or 60 ft. above the Houston coal a thin seam of oil shale known as the Gray shale is met with at many places, composed apparently almost entirely of entomostracan remains squeezed together like grains of linseed in a piece of oil cake.

In this connection it may be noted that entomostracans are exceedingly common in many of the shales, together with fish and plant remains, and it is probable that the large quantity of ammonia in some beds is due to the high percentage of nitrogenous animal matter that they originally contained. Other shales again are almost totally devoid of fossils, although rich in oil and ammonia, and this probably points to the presence of organisms with soft bodies and no shell or hard covering capable of preservation in the fossil state.

9. *Houston Marls.*

The Gray shale lies almost immediately under the Houston marls, to which I have already referred as being one of the most characteristic deposits in the oil shale districts.

The Houston marls (so called) are green or reddish massive amorphous, mudstone-like beds, which are hard when fresh, but crumble down on exposure to the weather. The individual beds are often a yard or two in thickness, and are separated by partings of hard kingle or cementstone a few inches wide, which resist the weather and project in ribs beyond the decaying matrix. The Houston marls appear to be unfossiliferous, and point to a complete change in the geological sequence of events over a wide area. These beds in the West Calder district reach a thickness of 150 to 200 feet or more, and their depth points to a long cessation of the conditions necessary for the deposition of oil shale in the carboniferous waters. The occurrence of regular well defined parallel beds and bands of different colour shows the rock to have been deposited in water, and the absence of shaly intercalations shows the process of deposition of this particular material to have been more or less continuous while it lasted. If the water contained carbonaceous matter, sand or mud, the precipitation of the marl appears to have been sufficiently rapid to prevent any of these extraneous substances from accumulating fast enough to produce separate beds within its limits.

This curious deposit, it is clear, must have been derived from some special source, and the subject deserves some consideration. Although locally called a "marl" for want of a better name, it is doubtful whether this is a correct description in the true acceptation of that term, as marl is a mixture of clay and lime, usually derived from finely divided organic remains, and the only external resemblance between the two rocks is their light colour, amorphous appearance, and the way they both crumble down under the influence of the weather.

Had the Houston marl been made up of finely divided volcanic material we should have had no difficulty in distinguishing it as a bed of ash such as is common in other parts of West Lothian, but being amorphous and structureless within the limits of each of its thick beds, and to all appearance as uniform in grain as a lump of putty, this explanation is not at first sight very satisfactory. There is much room still for controversy as to its origin, and I am not prepared to dogmatise either one way or the other in the matter. The following considerations would point from a physical standpoint to its volcanic origin:—

1st. The widespread uniformity of the deposit which extends over every part of the shalefield with greater regularity than any other single stratum in the district. This would lead us to infer a long continued period of unusual physical conditions, in which a material different from ordinary sand or clay was thrown down comparatively rapidly over an extensive region—so rapidly as to prevent beds of ordinary sediment from accumulating while these conditions lasted. The existence of a great volcano scattering extremely fine dust over the carboniferous sea—dust which fell continuously over the face of the waters in such a fine state of division as to be easily and thoroughly decomposed into impalpable mud—would seem to fulfil many of these requirements.

2nd. During a period when plant and animal life was so abundant on land and in water, the occurrence of an apparently perfectly unfossiliferous zone of such thickness as the Houston marl with a coal seam above and below it, shows some outside influence inimical to life to have been exerted in the area or near it, such as a volcano emitting clouds of dust that might choke the organisms in the sea and smother the plants on the adjacent land. The land might have been so devastated that while the vegetation was destroyed and buried under the ashy waste, the operation of the rivers was confined for a long period, perhaps long after the eruptions had ceased, to washing away and removing the thick covering of ashes, just as the streams of New Zealand are still doing on a smaller scale in the vicinity of Mount Tarawera, and in other regions where great eruptions of ashes have recently occurred.

3rd. At a few places the Houston marl actually contains volcanic fragments and becomes associated with beds of green basic tuff which would seem a clear enough argument for the volcanic theory.

4th. In order to test the matter in a different way I recently obtained samples of the marl from two different places, and at the same time I took a sample of green decomposed diabase from an intrusive sheet I had had occasion to bore into near

Carriden Church, on my estate of Grange. The decomposed whinstone looked superficially like the marl, and I resolved to see how both rocks behaved in the furnace. Accordingly a sample of each was put in a crucible and heated in my laboratory furnace to a temperature that melted malleable iron into globules. The marl which had been kindly supplied me by Mr A. H. Crichton from a bore at Waterston, near Philpstoun Oil Works, and the whinstone from my own boring, both melted down into a dense heavy black glass indistinguishable to the eye from obsidian, in a way that strongly suggested a volcanic origin for the one as much as for the other rock.

This test nearly satisfied me, but to clinch the argument so as to leave no room for doubt, I sent samples of marl from the Waterston bore and from the old railway cutting at Dalmeny to Mr Ivison Macadam for analysis, along with a sample of the decomposed diabase that had behaved so like the marl in the fire. The results, I am bound to admit, surprised me, as the analyses, which show a fair degree of uniformity of composition in the three samples of marl, give quite a different composition to the whinstone, and they show, moreover, that there is great room for doubt as to whether the marl is really a volcanic rock at all. The marls, it will be observed, contain much less silica than even the most basic of volcanic rocks, and a much greater percentage of carbonate of lime and magnesia. In the following table of results the sample No. 1 is of green "marl" taken from the bore at Waterston at a depth from the surface of the ground of 102 feet. Sample No. 3 is of reddish marl from the same bore at a depth of 135 feet. No. 2 is green marl, from the side of the old Queensferry railway cutting at Dalmeny, and No. 4 is the decomposed diabase from the bore at Carriden.

	No. 1.	No. 2.	No. 3.	No. 4.
Silica	40·09	34·92	36·90	47·75
Ferrous Oxide	3·42	2·33	0·42	7·66
Ferric Oxide	5·82	5·10	6·33	3·57
Aluminic Oxide	19·23	21·88	22·51	25·44
Calcic Oxide	10·87	11·82	10·84	4·11
Magnesic Oxide	4·97	3·56	3·93	1·89
Potassic Oxide	2·32	2·99	2·69	0·96
Sodic Oxide	3·02	3·56	2·99	0·89
Phosphoric Anhydride	0·21	0·11	0·16	0·08
Sulphuric Anhydride	0·32	0·36	0·26	0·39
Carbonic Anhydride	8·26	11·37	11·46	4·32
Titanic Oxide	1·16	1·64	0·96	2·26
Loss and Undetermined	0·31	0·36	0·55	0·68
	100·00	100·00	100·00	100·00

The "marl" is not a true marl or mixture of clay and lime, as the proportion of silica to alumina is too high for ordinary silicate of alumina which constitutes the basis of pure clay, and the percentage of lime seems too low to class it among true marls. It is evidently a peculiar rock the history of which will require further investigation. If it be volcanic it is unlike any other basic eruptive rock that we know of, either fresh or decomposed, and in the meantime it must remain the "Houston Marl" which does not commit us to any theory as to its origin. But for the analysis we should have, on physical grounds, concluded it to be distinctly volcanic, but geological is apparently not supported by chemical evidence in this case, and we cannot afford to dispense with any one class of evidence in our search after the true solution of such problems. Sedimentary rocks when strongly heated have, it must not be forgotten, been sometimes fused into a glass like obsidian, and microscopical research may disclose organic remains in the marl too small for the naked eye to discern.

Whatever may have been the physical conditions under which the Houston marl was laid down, these conditions seem to have ceased as suddenly as they began. The marl is covered by a few feet of fine fireclay on the top of which rests the Two-feet Coal or Wee Houston, a seam too thin to be workable, but interesting as a geological landmark, and as proving that vegetation was waiting to spring up as soon as the conditions for plant life permitted. No more marls are found in the shalefields above this horizon, but at Drumcross near Dechmont the coal is covered by an extensive bed of green tuff showing that local volcanic action was not extinct in the district.

The Two-feet Coal has a fireclay roof, and the superincumbent strata are chiefly soft sandstones, blaes and fireclay beds. A small oil-bearing seam about two feet thick known as the Mungals shale occurs about 130 feet above the coal, and 100 to 120 feet higher up we reach the Raeburn shale, the highest workable seam of oil shale in the series. The Raeburn shale which is about 5 or 6 feet thick including bands of blaes, has been worked at West Calder and Tarbrax south of Cobinshaw. It is covered by beds of blaes with ironstone ribs and fakes, with but little sandstone. Higher up there are a few thin coal seams with more sandstone, and a seam of ironstone that has been worked on a small scale about 15 fathoms below the Hurlet limestone. The whole thickness of strata from the Raeburn shale to the Hurlet limestone which marks the top of the oil-shale group and the base of the Carboniferous Limestone series is from 450 to 500 feet. The West Calder area is, with the exception of the Burdiehouse district, the only shalefield in which the whole succession can be followed from the Burdiehouse limestone upwards to the top of the series, and this must form an apology for describing it at such length.

10. *General Section of the West Calder Shalefield.*

The following section tabulated from mining information and from measurements across the beds in natural exposures, may be taken as a fairly reliable general summary of the West Calder strata :—

	Feet
Hurlet limestone and coal.	
Strata including thin coals and ironstone .	450
Raeburn shale 3 to 5 feet.	
Strata	100 to 120
Mungals shale 2 feet.	
Strata	130
Two-feet coal (not worked) 1½ to 2 feet.	
Houston marls	150 to 180
Gray shale (not worked).	
Strata, fire-clay and blaes . .	50
Houston coal in bands 4 to 6 feet.	
Strata, chiefly shaly sandstone . . .	200
Fells shale 3 to 5 feet.	
Strata, Broxburn marls	250
Broxburn shale 4 to 6 feet.	
Strata including the Hermand or Binny sandstone	420
Dunnet shale 6 to 10 feet.	
Strata, gritty conglomeratic sandstones with bands of blaes and lime ribs	600
Thickness of beds below Hurlet limestone . .	2400
Barracks shale resting on the Burdiehouse limestone 20 to 40 feet thick.	
Strata to Pumpherston shales	800
Apparent total thickness of oil shale series .	3200

The West Calder section corresponds generally with that at Broxburn, and a generalised view of the principal seams in the different shalefields is given in the accompanying diagram (Fig. 8).

11. *Livingston District.*

As we go northwards and cross the Almond to Deans and Seafield, the principal shales are found striking northwards towards Dechmont with a general dip first to W. and then to

N.W. The beds are crossed by numerous faults most of which have a downthrow to the south and cut up the shalefield into a series of blocks much to the disadvantage of the miners.

The Burdiehouse limestone has been worked in numerous old quarries between Barracks and Knightsridge, but its connection with the shales worked to the west is concealed by the southern prolongation of the Middletonhall fault. A fairly continuous section of the overlying sandstones, etc., is exposed in the burn half a mile N.W. of Livingston village, and after crossing about 420 feet of these beds we come to a shale seam, corresponding to the Dunnet, dipping S.E. under beds representing the sandstones of Hermand and Binny.

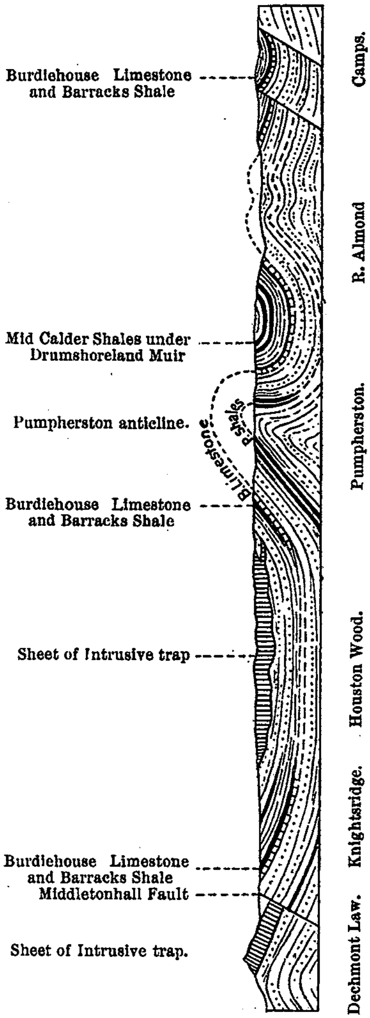


FIG. 2.—SECTION FROM DECHMONT TO CAMPS. (5 MILES)

12. *Pumpherston Shalefield.*

This outcrop apparently trends north past Knightsridge along the western side of the great trough between Houston Wood and Pumpherston. The shale dips eastwards into the basin under the sandstones, but does not emerge in workable condition on the opposite side, probably because its place is occupied by the great sheet of intrusive trap that has been irregularly injected among the strata occupying the centre of the syncline.

This brings us to the Pumpherston arch, the most conspicuous example of a perfect anticlinal fold in the whole shale-bearing area. The surface of the ground is quite flat, and but for occasional low knobs of basalt rock and a few shale outcrops in the burn half a mile north of Pumpherston Mains, there is nothing to indicate the presence of a valuable shalefield here characterised by such a pronounced but simple geological structure.

The Burdiehouse limestone has been proved by boring to crop out along the eastern side of the syncline and to dip westwards towards the farm of Milkhouses at an angle of about 45 degrees. About 450 yards east of this outcrop we reach the line of the Pumpherston shales which also dip west at high angles and are separated from the limestone by 800 feet of strata. This group of shales is on the lowest oil bearing horizon that has been discovered, and therefore so far as our present knowledge goes we must take the Pumpherston beds as the base of the Upper or Oil Shale division of the Calciferous Sandstone series. The Pumpherston Oil Company have worked one of the shale seams to a depth of 1050 feet below the surface, and through their courtesy I have been enabled to draw an accurate section across the shalefield and calculate the depth of the shale below the limestone, which, as has just been stated, is almost exactly 800 feet. The outcrop of the shales forms on the map a narrow elliptical or pear-shaped figure a mile long from north to south, and 560 yards from east to west in the direction of greatest breadth. No faults of any importance cross the strike to interrupt the regular continuity of the beds.

The Pumpherston shales are noted for their richness in ammonia, the yield, with the best form of retorts, being from 50 to 60 lbs. of the sulphate with 20 gallons of oil per ton. There are in the group five workable seams included in a vertical thickness of 92 feet of strata.

The following is a section of the Pumpherston group of shales. The "Curly" part of No. 3 shale near the top of the section is interesting paleontologically on account of the quantity of well preserved fossil fish it contains which belong chiefly to the following species: *Elonichthys Robisoni, Eurynotus crenatus, Rhadinichthys carinatus, Mesopoma macrocephalum, Acanthoda sp.* The richness of the shales in ammonia may quite possibly be due to the unusual abundance of animal remains embedded in them.

ROOF OF SEAM HARD CALCAREOUS BAND OR LIMY RIB 4 INS. THICK.

	Ft.	In.	Ft.	In.	
Shale			7	0	No. 1 or "Jubilee" seam
Blaes			14	0	
Shale Curly .	2	9	5	3	No. 2 or "Maybrick" seam
Do. Plain with rib	2	6			
Blaes and thin ribs . .			13	7	
Carry forward			39	10	

	Ft.	In.	Ft.	In.	
Brought forward			39	10	
Shale Plain .	1	1			No. 3 "Curly" seam, fish bed on top of the curly band
Do. Curly .	1	2	7	5	
Do. Plain with rib	5	2			
Flakes			16	7	
Blaes			5	5	
Shale			7	8	No. 4 or "Plain" seam
Faky blaes, rib on top .			2	8	
Shale			1	5	
Blaes			0	4	
Rib			0	2	
Blaes with rib in centre			6	4	
Shale			4	2	No. 5 Wee or Under Shale worked with 2 ft. of blaes above it
			92	0	

The beds above the Pumpherston shales are for the first 500 feet chiefly blaes with thin bands of sandstone and very hard quartzose or calcareous ribs known as "kingle stone" or "kingle." Higher up, towards the limestone, sandstones predominate, with bands of fakes and sandy blaes all more or less calcareous, but containing no beds of workable oil shale here.

The limestone which is about 20 feet thick on the western outcrop at Pumpherston, is covered by shaly blaes containing a seam of inferior shale the equivalent of what is known as the Barracks shale on the western side of the Houston basin. Bores have been made at various times to prove the section in the basin under the trap, but nothing of economic value has been found in them. The depth of the limestone in the centre of the trough where it is, as at Hopetoun, split up into numerous thin beds, appears to be about 1000 feet, and that of the Pumpherston shales 1800 feet.

The beds between the limestone and the trap are chiefly blaes and fakes with beds of sandstone and thin conglomerate, and there are also several beds of limestone a few feet thick and many calcareous ribs through the whole section. The Dunnet shale may be represented by some of the beds of blaes which are occasionally shaly, but it has not been distinctly traced on this side of the anticline.

On the eastern limb of the arch the beds are highly inclined and even quite vertical towards the southern end of the shalefield. Curiously enough the trap has not been found here, but happily for the miners the whole succession of beds from the limestone up to and including the Dunnet shale has recently been revealed in the Pumpherston Co.'s new openings under Drumshoreland Muir.

It is now quite clear, as both the dip of the beds exposed in the Almond and the adjacent boring and mining operations prove, that the eastern as well as the western haunch of the Pumpherston arch springs from the edge of a district synclinal basin. The eastern trough is not more than a mile broad, and its axis runs straight south across the Almond valley to Mid Calder where it is prominently seen in the glen and in mining sections. At Mid Calder the shale basin is less than half a mile broad and is abruptly truncated on the south by a large upthrow, already referred to as the Calder fault, which brings up sandstones of lower position on its southern side and cuts off all the shalefields in that direction.

The Pumpherston shales plunge steeply down under the drift of Drumshoreland Muir which here covers parts of the ground to a depth of over 100 feet. In the bottom of the basin they are probably about 1000 feet deep, but they soon begin to rise and apparently come near the surface at Almondell where the sharp ridge of a second anticline is exposed in the river and a thin seam of oil shale crops up in the midst of a thick bed of black blaes.

So far as we know with certainty these shales have not hitherto been worked anywhere else in this locality. In the grounds of Dalmahoy, N.E. of the house, and at Burnwynd on the south side of the Gogar Burn, a thick shale outcrop is traceable for some distance which may prove to be the re-appearance of the Pumpherston beds to the east of the Camps limestone, but as yet the position of the shale is uncertain. It may be mentioned that at Broomhill, near Burdiehouse, a thick shale seam crops up close to the great Pentland fault which seems to represent the Pumpherston section, and on the shore east of the Forth Bridge a seam of good curly shale can be seen some distance below the limestone position. It is interesting economically, if not scientifically, to note these outcrops, as one day when the upper shales become exhausted, mining engineers will have to look about for new seams, and it is well to be able to indicate on what geological horizons new seams may with confidence be sought for.

13. *Mid Calder Basin.*

In the Mid Calder basin the whole section from the limestone up to the Broxburn marl has been revealed in the course of mining operations. The vertical section in the centre of the basin near the mouth of the Linhouse Water begins with the Broxburn marls which are well exposed in the glen above Mid Calder, where they are much more calcareous in character than elsewhere in the shalefields to the west. The basin, though small, is peculiarly rich in oil shale, no less than eight seams of which have been sunk through in the Oakbank Oil Company's shaft. In order to ascertain definitely the position of the section, a diamond bore was drilled by the Company in 1892 in the bottom of the basin from the Dunnet shale level to the limestone, and I am indebted to the Company for supplying me with the general results of the boring. The limestone was reached at 98 fathoms, and a continuous vertical section of over 1000 feet has thus been disclosed, of great geological and mining importance.

The Mid Calder section disclosed in the pit and deep bore of the Oakbank Oil Company differs considerably from that of West Calder and Broxburn. It is, generally speaking, as follows—

	Ft.	In.
Surface, Broxburn marls	46	6
Wee shale	1	0
Strata, blaes and lime ribs	13	0
Big shale	4	6
Strata, various	12	0
Lower big shale	16	0
Strata, shaly blaes	10	0
Curly shale	6	0
Strata, blaes	5	0
Broxburn or M'Lean shale	4	0
Strata, chiefly blaes	16	0
Wild shale	4	0
Strata, blaes, Binny sandstones and marly beds	288	0
Dunnet shale	6	0
Strata, marly blaes	45	0
New shale (bottom of shaft)	8	0
Strata, blaes	65	9
Shale	2	0
Strata, blaes and shale, with ribs	22	0
Shale with fireclay rib 1 inch	6	3
Strata, blaes and hard ribs	5	1
Sandstone	7	10
Very hard white whinstone or kingle	18	3
Hard faky sandstone	5	0
Limestone, hard	3	0
Sandstone very hard, with hard blae ribs	190	2
Conglomerate, fine	16	0
Sandstone, faky, blaes and hard ribs	222	8
Burdiehouse limestone	24	0
Fakes and sandstone	12	0
Total depth	1075	0

The relation between the limestone in the Mid Calder basin and that in the neighbouring basin of Raw Camps, nearly a mile further east, is not clear. At Camps there are two distinct limestone basins, and therefore there must be either another outcrop between the westmost of these at the edge of the Mid Calder shale basin, or else a fault must run north and south between the latter two basins to interrupt the continuity of the beds and bury the outcrop of the limestone. The relation of the Mid Calder section to that of West Calder and Broxburn is shown diagrammatically in Fig. 8.

14. *Camps Limestone.*

At Camps and Raw Camps the limestone which lies in deep basins is covered with thick blaes full of fossils containing a seam of shale 8 feet thick, yielding 22 gallons of oil, which is the local representative of the Barracks seam. The Camps or eastern quarry, now abandoned and full of water, is in a complete basin originally 1300 feet long by 1100 feet broad, and 140 feet deep. The limestone, which reaches the unusual thickness of 42 feet, was used entirely as a flux for ironmaking, and is now all wrought out. The huge quarry hole has lately been acquired by the Edinburgh Corporation as a dumping place for police refuse, and the limestone will therefore in course of time be found replaced by a deposit of a very different and very miscellaneous character.. The Raw Camp quarries are likewise deserted and full of water, but the rock, which is 42 feet thick, is at one place mined for ironmaking by a pit 240 ft. in depth.

It may here be mentioned that between Mid and West Calder the limestone crops out in a very small basin at Crofthead, and on a larger scale at Newpark Station, where it has been extensively quarried for iron making at Murieston and at Bellsquarry. The basins, which at these places lie close together, are separated by a large fault nearly parallel to the railway—the continuation of the Calder Fault that crosses the Hermand Burn at Dykefoot. On the south side of the railway at Newpark the limestone, which is 33 feet thick, forms a complete basin over 250 feet deep with vertical sides. The northern outcrop runs along the edge of a sharp synclinal fold, on the north limb of which the beds are quite vertical, and even a little inverted at Brucefield quarry.[1] The geology of this little bit of ground is very complex, and the exposures are not sufficiently numerous to let the structure be completely determined.

In the Mid-Calder section there is no trace of the intrusive sheet to the west of Pumpherston, but in the Raw Camps

[1] These basins are indicated at the right side of Fig. 1.

quarry and at different places round East Calder village numerous dykes of trap with apophyses branching into and dolomitizing or otherwise altering the adjacent strata are very common.

15. *Broxburn Shalefield.*

The Mid Calder and Pumpherston shalefields are separated from that of Broxburn and Uphall by the great structural feature already referred to as the Middletonhall fault. Beginning as a small dislocation on the Almond near Seafield, this fracture runs from south to north, then turns north eastward at Dechmont, then runs due east at Uphall past Middletonhall, Ryal, and Kilpunt, where it apparently again crosses the Almond under the railway viaduct, being traceable for a total distance of over 9 miles. Beyond this point it has not been traced in mining, but as the line runs straight for the end of the great eruptive sheet between Bonnington and Ratho, which seems abruptly cut off at its northern extremity, there is every probability that the square ending at Ratho Station of the stocking-shaped patch on the map is due to this fault. Its downthrow is to north, and future researches may result in our being able to continue the line eastwards to Gogar, Corstorphine and Edinburgh, where we have evidence in the Princes Street valley of a powerful fault running in the same direction, with a northerly throw between the Calton Hill and Arthur's Seat. The effect of the fault is perhaps best displayed at Middletonhall, where on the southern or upthrow side the Broxburn shale has been worked at Stankards directly opposite a seam of ironstone a short distance below the carboniferous limestone on the downthrow side, the two horizons thus placed in juxtaposition being no less than 1500 feet or 250 fathoms apart.

The Broxburn shalefield, in which may be included the districts of Newliston, Ecclesmachan, and Uphall, consists structurally of a series of undulations from east to west. Beginning at Newliston, the Dunnet shale dips gently northwestwards under a shallow trough, whose deepest point lies under the farm of East Mains. The beds then rise over a well-marked anticlinal at Stewartfield, on either flank of which the extensive mines of the Broxburn Oil Co. run into the celebrated Broxburn shale seam, the outcrop of which forms an elliptical figure about a mile in length. The western limb of this flexure sinks steadily to a great depth under the strata in the basin at Fivestanks, a short distance east of Uphall village. At Uphall the western side of the basin is sharply defined by the reappearance of the lower beds at high angles. Among these beds a ridge of basalt resembling a thick trap dyke forms a marked feature in the landscape running northwards along the edge of the basin from Uphall and Uphall Church to Newbigging Craig. This is clearly the northern prolongation of the flat eruptive sheet already described as covering the centre of the basin west of Pumpherston. In this case it plunges down into the deep trough north of the fault, and is found cropping up at each side. The occurrence of the eruptive rock, with two narrow outcrops at one side, and lying in a single flat cake on the other side of the fault, shows that although it is not quite conformable, it was nevertheless originally a single sheet which was bent and broken by the same movements that affected the surrounding strata, and is therefore, although younger than the sedimentary beds, older than the period of these movements.

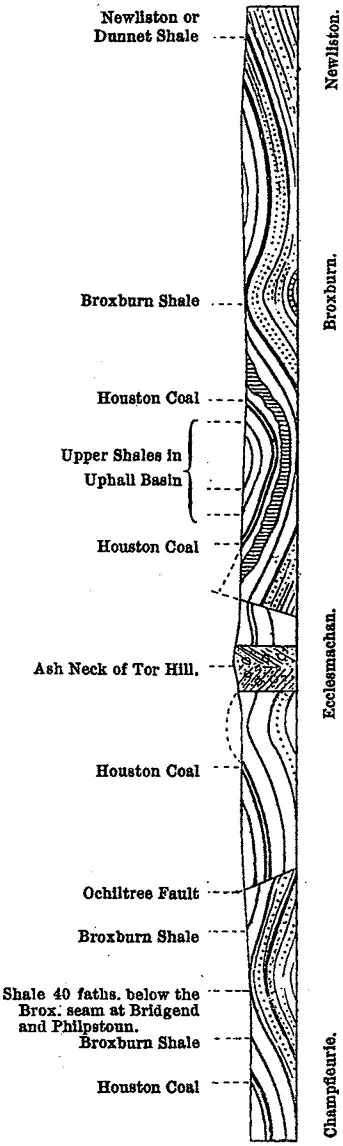


FIG. 3.—SECTION FROM CHAMPFLEURIE TO NEWLISTON. (6 MILES)

This same intrusive sill apparently produces the striking escarpment of Binny Craig and the irregular patches of trap at Niddry and Winchburgh. The heated mass has been injected among shales and beds of bituminous blaes, and has raised the temperature of these strata so as to distil their hydrocarbons and drive them into any available cavity, where they have cooled in the liquid or solid form. This is a characteristic feature of the Broxburn district, and deserves special notice. In 1890 a diamond bore was made near Little Ochiltree, about a mile north of Binny Craig, which after passing through the Houston marl, Houston coal, and Fells shale, struck a thick sheet of intrusive dolerite situated near the position of the Broxburn shale. It was noticed that the whinstone core brought up from a depth of over 600 feet was cracked at places, and the fissures were full of a soft yellow substance like vaseline or wax, which melted in the sun and spread in an oily film over the stone. This was, I believe, nothing but the result of distillation by the trap of the hydrocarbon in the shale, and, as was therefore to be expected, when the seam or its representative was penetrated, it was found to be quite worthless as an oil producer.

In the Broxburn district the section extends from the Dunnet shale up to the highest members of the oil shale group. The Raeburn shale only occupies a small area over the deepest part of the Uphall basin between Middleton Hall and Fivestanks, and the Mungals shale, or a seam corresponding to it in position, has been proved to crop out round the edge of a larger field at a greater distance from the centre of the trough. Beyond this line there is a ring of Houston marl above the coal, the outcrop of which can be traced from the old crop pits, bores, and workings, at shallow depths round the basin. Under the Houston coal the east and west sides of the basin are defined by the outcrop of the intrusive trap bed already described, which seems to be fairly conformable to the strata on the east side, but to cut obliquely across the beds and to rise into the position of the Fells shale at Old Uphall on the western side, or else to be faulted against the overlying beds in that locality.

The Fells shale, whose position is defined by the top of the Broxburn marl group, is not workable in this district. The Broxburn shale is, undoubtedly, the best and most important oil producing seam in this part of West Lothian, and wherever it is found over all the country between Broxburn and the Forth, its productive character is never wanting.

The Broxburn shale, as I have already stated, is situated between the Binny sandstones and the Broxburn marls. In this position we find beds of blaes, with one or more seams of shale, sometimes close together and sometimes several fathoms apart.

The section at Broxburn Oil Works is as follows—

Gray shale		5½ to 6 ft.
Hard rib		1 to 2 in.
Blaes		9 ft.
Wee or curly shale	2 ft. 6 in.	5½ ft.
Dirt	1 ft. 2 in.	
Shale	1 ft. 6 in. to 1 ft. 8 in.	
Blaes		5 ft.
Broxburn shale		5½ ft.

A generalized vertical section of the Broxburn shalefield is shown in Fig. 8, and a generalized horizontal section on a scale of 1 inch to the mile, of the rocks to the north and east of Broxburn is given above in Fig. 3.

16. *Binny Sandstone.*

The famous sandstone formerly extensively quarried at Binny, a mile north of Uphall, crops out along the crest of a low anticlinal dome, the centre of which crosses Binny Burn at Binny Bridge, near Wyndford. The Broxburn shale crops out at Wyndford, in the bed of the burn, a short distance above the sandstone, so that there can be no question as to its exact position in the section. The sandstone has been reached in numerous bores between the Broxburn and Dunnet shales, and has been opened out in the quarries of Humbie, Whitequarries near Philpstoun, Dalmeny, and other places, as well as in the long railway cutting west of Winchburgh. The great viaduct of the N.B. Railway across the Almond at Newliston was built from the Humbie quarry stone. The Binny quarries, which supplied the freestone for many of the finest buildings in Edinburgh during the first half of the century, such as the Scott monument, are now totally abandoned and full of water. The rock, which lies in thick beds separated by bands of blaes, is gray in hue and very strong and durable. It is hard and well adapted for lasting monumental work; but its hardness, like that of the celebrated Craigleith freestone, makes it costly to hew, and the quantity of unproductive blaes between the beds, together with the increasing depth of "tirr" or overburden to remove, have rendered the quarrying of it too expensive to be longer payable at Binny. The rock, as has been already said, is to be found under the Broxburn position all over the shalefields from West Calder to Dalmeny and Burdiehouse, and there are still many other places where it will no doubt be worked with much advantage at some future date.

Fifty years ago, when the Binny quarries were in full operation, it was quite common for the workmen to find considerable quantities of ozokerite or natural pitch in joints or cavities in the higher beds of the rock. This was made into black candles which burned with a smoky flame, and specimens may still be seen in the Museum of Science and Art of these uncivilised attempts at the art of candle-making. This ozokerite has no doubt a similar origin to the solid hydro-carbon already described as produced by the intrusion of the basalt of Binny Craig into the oil shales. In this case the products of distillation must have percolated downwards, as the intrusive rock was injected into beds considerably above the level of the sandstone. It is certainly curious to reflect how the vast paraffin candle industry of Broxburn, in which tons of snow-white candles are produced every week from the shale oil, should have been preceded by rude attempts on the part of the old quarrymen to light their humble dwellings with black candles made from the products of distillation of the same shales long before the modern industry was so much as dreamt of.

Last summer (1900) an intrusive sheet of yellow trap about 3 or 4 feet thick was cut while driving through the shale at the mouth of the Albyn mine on the eastern outcrop of the Broxburn shale anticline. The trap was full of cavities coated with calcite, filled in the heart with mineral wax, yellowish-gray when fresh, and brown in tint after exposure to the air. On analysing the hydrocarbon it was found by Mr Steuart to consist of—

Carbon	84·35	98·86
Hydrogen . . .	12·83	
Nitrogen . . .	1·68	

with traces of sulphur in some specimens.

The shale was worthless near this rock, and the hydrocarbon is clearly derived from its distillation and subsequent accumulation in the cavities of the trap.

It may here be mentioned that in a few places liquid petroleum has been struck in the mines and borings at Broxburn and Pumpherston from which a few hundred barrels, perhaps, of oil have been obtained. Some of the bores have struck natural gas also, and one bore tapped what proved an intermittent gas spring, that when lit blazed up once a month with great regularity for some years, and burned for a whole day, lighting up the country-side with much brilliancy during the eruption.

The Dunnet shale has been reached in bores about 80 fathoms below the Broxburn seam. It has not yet been worked at Broxburn, but is mined at Newliston where it crops out along the line of the Brox burn below the Almond viaduct. The workable part of the seam is about 7 feet thick, and it dips north-west at 5 degrees, but its outcrop is hidden under about 100 feet of drift and alluvium of the old bed of the river.

What seems to be the same shale has more recently been proved to crop out along the south side of the Almond near Ingliston and crosses it at Carlowrie. It here lies comparatively flatly under the alluvium which fills up the old valley to a depth of over 200 feet. The shale dips gently to the south and east, proving the existence of a low anticline in the beds between Kirkliston and Ratho station.

17. *District North of Broxburn—Ash Necks*

At Ecclesmachan village, a mile north of Uphall, the strata are interrupted by one of the ash necks whose occurrence is common in the district between Broxburn and the Forth. The Tor Hill is an oval-shaped, smooth-backed knoll of yellowish tuff, containing baked fragments of the surrounding rocks, projecting like a knot in a well-worn floor, and shaped like an old hill fort, flanked on the north, west, and south sides by a broad hollow, but sloping gently to the east like other hills of the crag and tail pattern. A spring of sulphuretted hydrogen water, known as the Bullion Well, bubbles up at its southern edge and probably rises from the fissure between the volcanic plug and the surrounding sedimentary beds. The Houston coal has been worked in old pits up to its edge on the eastern side, and the neck cuts through the Fells shale on the north and west. Among the other ash necks in the shalefield may be mentioned (1) the neck in the railway at Niddry Castle, (2) Binns Hill, (3) the neck south of Binny Craig, (4) Parkly Place neck, (5) neck at the Canal Bridge east of Linlithgow, (6) a small neck cut through in the Broxburn shale workings at Gallowscrook, near Philpstoun.[1] Besides these, a few other smaller ash necks have been observed in the shalefields, and also in the Carboniferous Limestone series north of Linlithgow, while the basalt of Craigtonhill may mark the site of a volcanic pipe from which solid lava instead of ashes has been thrown up. In this case, however, it is to be noted that the surrounding beds are on the horizon of the Dunnet shale, which is lower than that of the strata surrounding the other necks, so that it is possible the Craigton rock may represent the solid lava in the bottom of a volcanic vent, the upper contents of which may have been of ash now all denuded away. Sections through the Tor Hill and a small neck on the shore near Society are given in Figs. 3 and 6 respectively.

Interbedded crystalline volcanic rocks are not known among the oil shale strata or the coal measures to the west, and these necks, therefore, probably belong to the volcanic series of the Carboniferous Limestone period so well developed between Bathgate and the Bo'ness coalfield. If we measure the depth of strata, from say the Broxburn shale up to the lowest of the interbedded basalt rocks of the Bathgate hills, we find that the parts of the necks now visible must have been originally buried at least 1500 or 2000 feet below the surface. The quantity of quartz sand in the ash as well as the presence of small pebbles of non-volcanic origin proves that the orifices of many of these

[1] Described in the "Transactions," Geol. Soc., Edin., vol. vii. p. 477.

vents were under water, but the water was not that of the oil shale period, which was on the whole a time of calm and comparatively undisturbed tranquillity.

18. *Houston Coal.*

To the north of the village of Ecclesmachan the Houston coal outcrop has been well proved by many old workings, and although most of the pits have been abandoned long ago the present high price of the better qualities of coal have led to the re-opening of the seam at one or two places by the oil companies. A complete basin of Houston coal occurs at Hillend, half a mile north-east of the Tor Hill. The section of the seam in the Hillend pit is as follows—

		Ft.	Ins.
Soft Coal		0	3
Parrot or Cannel Coal		0	4
Soft Coal		1	0
Fireclay with ironstone nodules		2	0
Fireclay holing		0	2
Soft Coal	1 ft. 6 ins. to	2	9
	Total thickness of seam	5	9

The roof of the seam is generally weak and the coal itself so full of pyrites and ribs or bands of stone as to be unprofitable except during times of scarcity and high prices.

To the north of Hillend basin the coal begins to turn over and dip northwards, but is abruptly cut off by a fault running through Glendevon Farm with a downthrow to south, and a hade rapidly diminishing towards the west. This fault runs out near Waterstone, but at Glendevon and Winchburgh it increases so quickly as to throw the Houston coal against beds considerably under the Broxburn shale position. The Broxburn shale on the north side dips north-west at a low angle towards Auldcathie, and is here extensively mined by Young's Oil Company. It crosses the railway at Priestinch, but has not been traced continuously beyond the cutting. At this point the section, although well exposed in the deep cutting, becomes obscure, and the shales seem to have been thrust together by two reversed faults whose effect is to make certain beds appear much thicker than is really the case. The section (fig. 4) in the cutting resembles an unconformability, but there is no other evidence for such a phenomenon in the district, and the line of break is too sharp and clean to suggest a plane of erosion such as an unconformable junction demands.

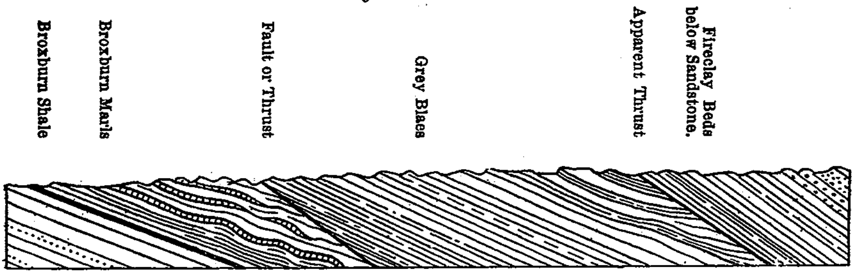


FIG. 4.—SKETCH SECTION IN RAILWAY CUTTING WEST OF PRIESTINCH.

Another section (fig. 5) is seen in the cliff at the north side of the bend of the Almond just above Illieston. The beds above the break dip to east and those below to west in such a way as to suggest a small thrust plane.

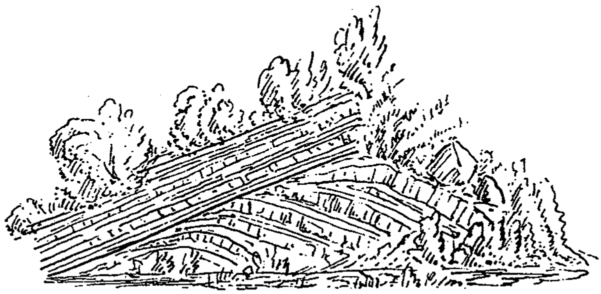


FIG. 5.—SECTION AT BEND OF RIVER ALMOND ABOVE ILLIESTON.

Thrust planes are known to occur in the Kelty coalfield in Fife, and have within recent years been found in many countries to be much commoner than was formerly supposed, and in a district such as this, which has been so much folded and squeezed, it would not surprise us if the cause of the apparently inexplicable structures of some areas were found to be traceable to the repetition of the beds by thrusts or revised faulting at low angles.

19. *Winchburgh District.*

At Winchburgh station we find a thick series of carbonaceous shales which are largely quarried for brickmaking. These beds seem to occupy the position of the Dunnet seam, but no good oil-bearing shale has as yet been discovered here. In the summer of 1890 the arched roof of the tunnel at Winchburgh (which is 1100 feet in length), gave way, and I had an opportunity while the building was being repaired, of examining the overlying rock. I found no oil shale or limestone, but there was near the south end, some gray freestone under beds of blaes dipping to north-west at 10 to 20 degrees at some places, and flat at others. At the north end there was a good deal of white trap and white shaly marly beds apparently altered by the intrusive rock. When the tunnel was originally made, a thick bed of limestone was cut below thick shale dipping to west at the south end of the opening. The limestone rested on sandstone beds, and had a crystallised burnt appearance, probably due to the proximity of the trap of Winchburgh Hill. It is quite possible that this may have been the Burdiehouse rock, which should be near the surface here, but has not been laid bare in any recent excavations. As we pass westwards towards Philpstoun the railway section discloses the Houston coal and marls at Craigton and then the cutting runs through a series of very thick sandstone beds with few shaly intercalations. This local development of the Binny rock is thrown up against the Houston marls by the Ochiltree fault which must have at this point a throw of over 800 feet down to the south-east. The sandstones are seen continuously for about 500 yards in the side of the cutting, dipping westwards at 15 degrees, so that these beds under the shale must be here no less than 370 feet thick, far thicker than in the Binny and Broxburn section, where the actual thickness of sandstone is comparatively small. The thick sandstone was quarried for some years on the north side of the cutting near Craigton, and on the south side of the railway many years earlier, but both quarries are now full of water. The rock is traceable northwards past Craigton House to Whitequarries, and is here used by Lord Hopetoun for estate purposes. It lies in strong massive beds with thinner bands dipping north-west at 45 degrees, and striking north-eastwards to Hopetoun Wood. A large fault which branches from the Ochiltree line of dislocation near Duntarvie, and runs north-westwards through the north side of the wood, cuts off the sandstones and brings up the Burdiehouse horizon against them, interrupting the continuity of the outcrop between the railway and the shore.

20. *Philpstoun and Champfleurie Shalefield.*

Continuing to follow the railway section westwards, the sandstones are seen to dip under the Broxburn series, but the actual junction is hidden from view. That we are on the Broxburn horizon, or near it, is quite clear as we come to an exposure of the typical Broxburn marls, and in the neighbouring shale mines at the Philpstoun Oil Works where it is extensively developed, the whole section is traceable up to the Houston coal.

There is, however, in this shale field one problem the solution of which is not yet by any means clear. Under the Broxburn seam and separated from it by 40 fathoms of chiefly argillaceous strata, there occurs another seam about 10 feet thick, of oil shale rich in ammonia which is called locally the Dunnet seam. Now as has been said there is ample proof that the real Dunnet seam is under the Binny sandstone, which is, as we have seen, unusually thick and well developed in this district. As yet the sandstone near Philpstoun has not been pierced by boring, but on the shore two miles to the north a couple of thick seams of shale are exposed beneath large sandstone beds, one of which no doubt corresponds to the Dunnet shale. I am inclined to think that this so-called Dunnet shale which can be seen in the Haugh Burn a short distance above Bridgend, and is worked by the Linlithgow Oil Company from the outcrop westwards, is a new seam between the Broxburn shale and the Binny sandstone, and that the strata above the sandstone must be much thicker locally than they have been found anywhere else. There is no doubt a little sandstone above this seam, but nothing to represent the great beds in the cutting only 1½ miles off. It is possible that the shale may represent some of the thin blaes beds intercalated with the upper parts of the sandstone, and that in the interval the sandstone above it may have become much thinner and may have given place to argillaceous beds, but this is one of the questions that will require further mining evidence to clear up.

The Philpstoun shalefield lies in a flat anticline extending south-west from Philpstoun station to Gateside and Ochiltree. The south-eastern side of the field is abruptly cut off by the Ochiltree fault, which, as has already been said begins among highly inclined and folded beds to the south-west of Little Ochiltree and increases in dimensions as it runs north-eastwards to Craigton, Duntarvie and Dalmeny. It has a downthrow to the south-east or south of over 100 fathoms at places, and produces a well marked break in the geological succession for a distance of ten miles, no beds so deep as the Burdiehouse limestone being found at any place on its downthrow side, and nothing above the Broxburn shale for nearly all the way along its upthrow side.

The Broxburn shale, which is about six feet thick in the Philpstoun and Champfleurie shalefield, dips westwards under the marls and the beds representing the Fells shale.. The latter seam is not workable here, and so far nothing of economic value has been hitherto found above the Broxburn position in this corner of the West Lothian shalefield. There is still however an area of three or four square miles to the north of Champfleurie, between the Houston coal and the base of the Carboniferous Limestone, apparently undisturbed by eruptive rocks which has been little explored, but which may yet be found to contain shales as good as those in the corresponding upper section of the West Calder district.

The only economic mineral that is known to occur to the west of the Houston coal outcrop in workable quantity is sandstone of which one large bed was formerly quarried at Kingscavil, while another thick bed is being extensively quarried at Pardovan half a mile north of Champfleurie House. This bed dips to the N.W. at 25 degrees and thus appears to lie above the Houston marls, but if so this is the only place where thick sandstone has been found in such a position in the shale fields. The Pardovan rock is on the other hand certainly not like that in the Binny section, and in some bores in the vicinity the Raeburn shale is said to have been found. If this is so the upper part of the Oil Shale series must be here much more arenaceous than it is either at West Calder or Broxburn.

The Broxburn shale outcrop on the western limb of the Philpstoun arch has been traced continuously in the workings of the Linlithgow Oil Company from Wester Ochiltree to Bridgend, where it is shifted eastwards by a cross fault running through Bridgend and westwards past the south of Champfleurie House towards Kingscavil. From Bridgend the outcrop as proved by Messrs James Ross & Company at the Philpstoun Oil Works, runs northwards to Philpstoun Station and bends round the northern end of the anticline where it rolls over into a shallow basin on the south side of the line and spreads out over the surface so that it could be worked opencast over several acres. The Wee and Curly shales of the Broxburn series are also worked at Philpstoun in a seam 7 feet thick, known as the Upper Broxburn. The outcrop of the whole section rises up on the east side of this local trough and resumes its north-easterly trend to the north side of Hopetoun Wood where it is cut off by the large fault mentioned already as bringing it nearly against the Burdiehouse limestone outcrop.

21. *Hopetoun District—Shore Section.* (*Fig.* 6.)

As we cross over this fault towards Abercorn, good sections of the beds are seen in the Nethermill Burn and along the shore all the way to Queensferry, a distance of four miles. As I have already mentioned the beds seen in the shore section on the north side of the Ochiltree fault are situated deeper down in the series than those on the southern or downthrow side of the dislocation, and while it is highly important to have a fairly complete disclosure of the Burdiehouse series and the shales and strata for several hundred feet above the limestone, it is unfortunate that the section just ends at the mouth of the Nethermill Burn without bringing us up to the undoubted position of the Broxburn shale. It is clear from the shore section that we have on this horizon not one distinct bed but two or more beds of limestone between 200 and 300 feet apart with numerous thin flaggy calcareous beds between them. These limestones have the banded structure and fossiliferous zones characteristic of the Burdiehouse section, but the fact of the limestone being split up into different beds, with shaly intercalations makes the definite mapping of the ground unsatisfactory, as it is a matter of some difficulty to decide which bed should be regarded as the datum from which to reckon the thickness and position of the overlying strata. For practical purposes the highest of the thick limestones may be adopted as the Burdiehouse horizon, since all the shales hitherto worked lie above it, and although some workable shale undoubtedly exists at a lower level, it is not yet possible to speak with certainty of the shales near the Pumpherston position in the Hopetoun district.

The shalefield which is principally on Hopetoun estate will in time probably prove a good oil and ammonia producer, as the shore section discloses several thick and rich-looking seams, one at least, and perhaps two of which are apparently new to the section, and have neither been worked, named, or even tested by boring.

Near Society on the shore below Hopetoun House an excellent section of the limestone is laid bare, dipping eastwards at 45 degrees. The highest, and apparently the main bed which is about 9 feet thick, is covered by black shaly blaes, and rests on black and blue blaes with calcareous ribs, all dipping at the same high inclination. These underlying beds are traversed by a dyke of white or yellowish trap, with cavities full of bitumen such as have been noted in the Broxburn district. Farther west, a few yards beyond the dyke, the lower limestone crops up, 3 or 4 feet of which are exposed. The distance between the outcrops is about 400 feet, and at an average dip of 45 degrees this would indicate about 280 feet as the thickness of the limestone series. Whether or not the lower limestone is at the very base of the calcareous zone the section does not indicate. In a boring for water made in 1887 near North Newton farm above the old lime quarry, the following section was passed through—

	Ft.	Ins.
Light limy fakes .	10	6
Blaes	8	6
Dark blaes and limy ribs	66	6
Limestone, very hard .	4	9
Hard marly blaes .	119	6
Limestone, hard . .	11	9
Blaes, soft	1	6
Limestone in harder and softer bands .	25	9

The beds above the limestone are distinctly exposed at Society with but few interruptions. After we cross the thin band of black blaes, resting immediately on the limestone, and passing under a thick series of brown calcareous sandstone beds, we come on a thick seam of excellent oil shale about 340 feet above the calcareous zone which may be fairly regarded as the local representative of the Dunnet seam. Boring operations have quite recently established the truth of my prediction fifteen years ago that the outcrop of this shale runs southward past Crawstane to Duddingston, parallel to that of the limestone at Newton, and that the shale is likely to prove of great commercial value.

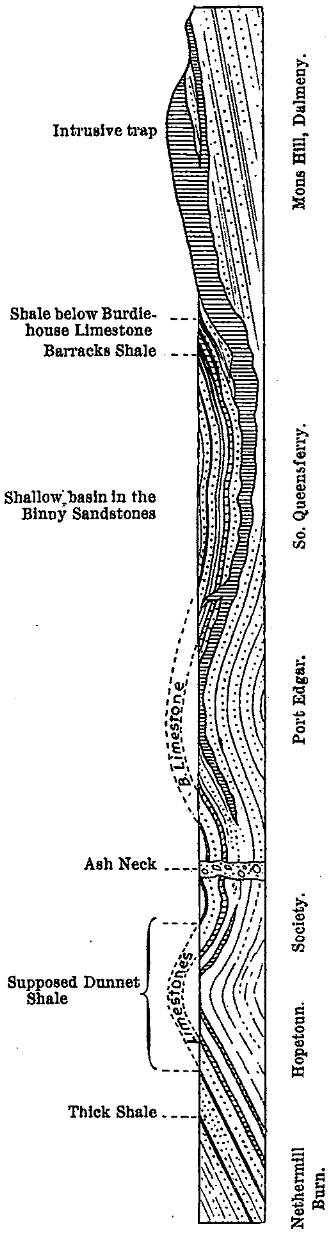


FIG. 6.—SHORE SECTION FROM HOPETOUN TO DALMENY. (6 MILES.)

Unfortunately the section is not quite regular to the east of Society as the dip changes and the symmetry of the basin between Society and Duddingston is interrupted for some distance. Towards the west the beds arch steeply over below Hopetoun House which lies on the crest of a well-marked anticline, and dip continuously west-north-westwards as far as the mouth of the Nethermill Burn, a distance of three-quarters of a mile. The continuity of the section is unfortunately interrupted on this side also, and a local change of dip prevents the whole sequence being followed out. It is, however, pretty clear that on or near the position of the Society shale bed there is a fine seam of good oil shale 10 feet thick, with a sandstone pavement with hard ribs of kingle running through it. Immediately above this seam there is a gap, as there is at Society, due no doubt to soft strata, easily removed by the waves. Farther on, the beach shows an almost uninterrupted succession of yellow sandstones, dipping to the W.N.W. at 20 to 25 degrees for a distance of 300 yards. Then comes another massive bed of what is apparently good oil shale full of entomostraca whose thickness is not less than 16 feet. Measuring across the strike of the beds we find that the thickness of strata, chiefly sandstones, between these two shales is about 400 feet. This shale has a thick bed of sandstone both above and below it, and judging by its sandstone roof, its entomostracan and fish remains, and the absence of the Broxburn marls above it, I am inclined to believe it to be quite a new seam, and the shale below the Broxburn seam at Bridgend to be a second new seam in this part of the county, which may, when opened up, add many years to the life of the local oil industry.

The shales on the shore strike south-westwards past Abercorn, and are cut off by the fault at Hopetoun Wood. The highest of the two seams—the supposed new shale—or a seam not far above it, crops out for half a mile in the bed of the Nethermill Burn, where it is seen to be full of entomostracan and fish remains, and if the theory I have already propounded be correct, it should, on account of its preponderance of animal remains, prove particularly rich in ammonia. Indeed the same observation is also applicable to the lower shale of Society, but we must wait some years until mining developments in this area shall afford an opportunity of testing the validity of the hypothesis on a practical scale.

There is almost no exposure of stratified rock along the shore to the west between Midhope Glen and the Bo'ness Coalfield, and the inference may perhaps be drawn from this circumstance that among the higher members of the oil shale group soft beds have a predominating place. There must be several undulations to enable these beds to spread over so much ground, and the few outcrops that do exist point to this being the case.

22. *South Queensferry.*

Proceeding eastwards from Society towards South Queensferry a set of thin limestone beds, with some oil shale (the Barracks seam), can be seen cropping out with a westerly dip above a thick series of false-bedded sandstones. These sandstones form the top of a second low anticlinal, whose axis is at Butlaw, near Port Edgar. To the east of Butlaw the dip changes to N.E., and a thick bed of intrusive trap crops up among these sandstones and spreads out southwards and westwards for about a mile to Lawflat. At Port Edgar we come on to the outcrop of the Queensferry limestone, which was formerly mined between the shore and Echline, half a mile to the south. The limestone seam in the old workings at Port Edgar was from 6 to 9 feet thick; it was dark in colour, and contained some iron. It was in three beds, and was traversed by a "dyke" of so-called sandstone conglomerate divided in the centre by a vein of spar containing galena and running in a N.W. and S.E. direction. The limestone outcrop is no longer visible, but the course of the workings can be traced by "sits" or subsidences into the "waste" close to the railway at the head of the pier, and in the field north of Echline farm.

The succession of beds above the Burdiehouse horizon is somewhat different here from that noted at Hopetoun. The deep railway cutting at Port Edgar discloses a thick mass of black blaes, with few or no oil shale intercalations, resting on some hard dark calcareous sandstone ribs that lie almost immediately above the workings. The upper part of this argillaceous series contains beds of marly fireclay, with hard calcareous ribs and occasional sandy partings. The thickness of the series, which dips to the N.E. at 10 to 12 degrees, must be nearly 200 feet, and in all this section there is not a single bed of sandstone. The railway cutting here runs into boulder clay, but on the shore between Port Edgar and Queensferry a series of massive white and yellow false-bedded sandstone comes on apparently just above the marly beds in the lower parts of the cutting, and it is probable that the shale which crops out at Society, although not exposed at the outcrop here, will be found represented at or near the base of these sandstones when the ground comes to be systematically explored by boring.

The town of South Queensferry is situated on a flat syncline, with a low anticlinal arch in the middle. The sandstones which dip eastwards into the basin emerge on the west at New Halls under the Forth Bridge, and continue to dip continuously westwards all the way along the remainder of the shore section. Just east of the piers of the Forth Bridge a seam of oil shale crops up under the sandstone beds, and farther east a thick series of black bituminous shales, with some good oil shale, are very well exposed on the beach. These beds contain thin limestones near the base, which are apparently the local representatives of the

Burdiehouse section, but the strata on this side of the syncline do not reappear with enough regularity to enable us to correlate the beds and shale seams quite satisfactorily with those to the west. We have no evidence of two such distinct beds of limestone as occur at Hopetoun, but in plotting the section from the dips accurately mapped, it is clear the limestone should crop up where the calcareous beds and shales appear, and therefore there can be little hesitation in placing its outcrop here (fig 6). The shales associated with the limestone appear fairly rich in oil and no doubt represent the Barracks seam which has lately been proved in the boring operations at Duddingston to be far thicker and far better in quality in this district than it is anywhere else in West Lothian.

As we move still further eastward we cross lower and lower beds, and finally reach the great eruptive sheet of Mons Hill, which dips west at 20 degrees, and must here occupy a position about 800 feet below that of the limestone. This basalt intrusion is no doubt part of the sheet already referred to that crops up close under the limestone at Port Edgar, but here it is farther down, and much thicker and more extensive. The beds immediately above the trap are, so far as exposed at the Long Craig pier, chiefly sandstones or fakes (argillaceous bedded sandstones), but above the sandy beds a good seam of curly shale crops out at high water mark a couple of hundred feet or more below the limestone. The limestone rests on marly blaes with some oil shale, several bands of which appear of good quality. The shales and calcareous beds are inclined at angles of 45 to 50 degrees, but this high dip only prevails for a short distance. Good fish and plant remains are found in abundance on this horizon similar to the fossils belonging to the Burdiehouse section all over the oil shale districts, and in this case the paleontological evidence is of assistance in working out the stratigraphy of the ground.

The shore section does not run far inland at Dalmeny and Queensferry, as all the rocks we have been considering are abruptly cut off by the eastern extension of the great Ochiltree Fault at a distance of half a mile from the coast. The Limestone is thrown against the Houston coal, whose characteristic green marl has been well laid open near Wester Dalmeny in the cutting of the old railway to Port Edgar. The vertical distance between these horizons is over 1500 feet at Broxburn, and is probably a good deal more here, so we cannot be far wrong in estimating the downthrow of the fault at 250 fathoms or 1500 feet in the Dalmeny shalefield.

23. *Dalmeny Shalefield.*

The structure of this shalefield is quite simple, and were the beds completely exposed they would be seen to form a basin about two miles broad, the centre line of which nearly coincides with that of the road running northwards from Kirkliston to Queensferry. The basin is bisected from east to west by the line of fault which brings the sandstones near the Dunnet position on the upthrow or northern side against the beds in the Mungals shale position above the Houston marls, which occupy the centre of the syncline on the southern side of the dislocation.

The Houston coal which can be seen in the railway cuttings, although recognisable, is so thin and disturbed as to be quite unworkable here, and the Fells shale, whose place in the section is also quite distinct, is not of commercial value. Under the Fells position there are here several thick beds of sandstone overlying the Broxburn marls which are well developed but not seen in any natural exposure. The thickness of these strata between the Fells and Broxburn shales is about 300 feet. The Broxburn shale is the oil producer here, and the long continued prosperity of the Dalmeny Oil Company is due both to the excellence of the seam and to the ability with which the Company's operations on it have been conducted during the last thirty years. The shale as at present mined is in two seams, the "Curly" and the "Broxburn." The former, which is the higher of the two, is 6 feet thick, and is separated from the latter by 7 feet of shaly blaes forming the roof of the "Broxburn" seam. The Broxburn section, whose workable thickness is 7 feet, is a little richer in oil than the overlying Curly seam, and produces 30 gallons of crude oil, with 35 lbs. of sulphate of ammonia per ton.

The workings at Dalmeny are confined to the south-eastern part of the basin, and although the beds are known to strike south-westwards and then to double round and strike northwards past Dundas Castle the shale has not yet been found workable in that direction. The shale has been mined to a depth of nearly 600 feet under the Forth Bridge Railway where it dips steeply to the north, and at this level one section of the workings has recently become truncated by the fault running approximately on the line I indicated on the map many years ago. The strata were cut off by a wall of whinstone, and as is often the case when a fault is struck, a considerable flow of water had for some time to be faced causing much expense and anxiety to those in charge of the mining operations.

The Broxburn shale rests on a few fathoms of blaes, under which we find the Binny sandstone well developed in thick beds. The sandstone is to be seen in a line of old quarries east of Dalmeny village and oil works, dipping to the west at angles of from 30 to 40 degrees. These quarries once yielded much valuable building and monumental stone said to be superior in quality to that of Binny. Among the Edinburgh buildings of Dalmeny stone are the Palace Hotel; Union Bank, George Street; the east side of Palmerston Place and nearly all of the east side of Coates Gardens. The sandstone is in thick massive beds with partings of blaes, and the upper part of the section shows much gray bituminous shale full of entomostraca such as is also met with at Binny. Under the sandstones the Dunnet Shale should be found, but at what depth is still uncertain. There is no reason to suppose that the shales, which are so plentiful at Hopetoun, should be without representatives on this side of the basin, and after the Broxburn shale has been all exhausted the lower seams may prove the means of giving a new lease of life to the Dalmeny shalefield.

In this district there is much intrusive rock, and close to the shale pit at the Dalmeny Oil Works a small knob of whinstone rises through the strata to the surface. Dundas Hill appears to be a sheet of trap bending over an anticline in beds under the horizon of the Dunnet shale, and may be the southern extension of the eruptive rock already mentioned as occurring at Port Edgar, and to the west of Duddingston on the other side of the fault. It is quite possible, and not at all improbable, that all the patches of trap on the map from Houston to Uphall, Binny Craig, Ratho, Winchburgh, Dundas, and Dalmeny Park may ultimately prove to be part of the same sheet, or "sill" wandering about between certain geological horizons from the Fells shale to the beds below the Burdiehouse limestone, conforming locally to the general structure and affected by all the dislocations of the region, but every now and then changing position in such a way as to improve the scenery and reprove the geologist for forming theories too hastily, and seeking to pry into too many of Nature's secret places.

24. *Burdiehouse and Straiton.*

In the Burdiehouse and Straiton shalefield the same general order of succession is observable, but the thickness of beds from the limestone up to the so-called Raeburn shale is very much less than in the district to the west. In this section only one workable seam—the Pentland shale—corresponding to the Dunnet and Burntisland seam of oil shale has been found. It is about 6 feet thick and is situated only 120 feet above the limestone. The limestone is typically developed, and, as need hardly be said, has been well known for many years since its wealth of fossil remains was first revealed by Dr Hibbert and other old Edinburgh geologists a couple of generations ago. The Burdiehouse limestone is still extensively quarried near Straiton where it is about 30 feet thick, and dips at an angle of from 30 to 40 degrees under the thin strip of oil shale bearing beds below the edge coals of the Dalkeith basin (Fig. 7).

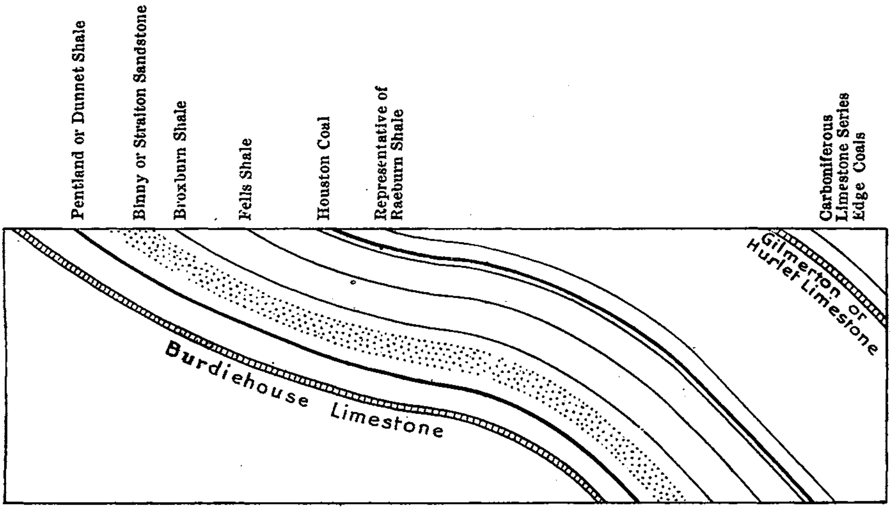


FIG. 7.—SECTION OF BURDIEHOUSE AND STRAITON SHALEFIELD.

The Pentland shale has been mined by the Clippens Oil Company to a depth of over 1000 feet, and in the workings the angle of dip increases to 45 degrees at the lower levels, while to the south the beds become very steep, and are bent into several sharp folds. The accompanying section (Fig. 7) shows the general structure of the shalefield at Straiton. Above the Pentland shale there is a thick bed of sandstone corresponding to the Binny rock, which has been quarried at Straiton, and above this the Broxburn shale is represented by a seam 2½ to 3 feet thick, but not sufficiently valuable to work. The Fells shale and Houston coal are also represented, and at the top of the series there is a thin seam of finely laminated shale supposed to be the equivalent of the Raeburn shale. These beds are shown diagrammatically on the accompanying vertical section (Fig. 8), in which the whole thickness of strata from the Burdiehouse to the Hurlet or Gilmerton limestone is seen to be only about 1500 feet. The actual thickness of the shale-bearing or lower group of strata is only 850 feet as compared with nearly 2000 feet at West Calder, showing a marked diminution in the amount of sedimentation on the east side of the Pentland axis during the whole of the oil shale period. After the deposition of the highest shale seam, however, the thickness of strata between it and the marine limestone of Gilmerton shows that sedimentation in the two areas proceeded at a fairly uniform pace.

The Oil Shale series of Mid Lothian extends in a narrow strip northwards from Burdiehouse to the sea, between the Edge Coals on the east and the great Pentland Fault on the west. Although no mining operations have as yet been carried out in this shalefield north of Straiton, oil shale of workable quality has been proved to occur here, and will no doubt receive attention from mining men, when other areas begin to give out or the industry becomes more profitable.

25. *Burntisland Shalefield.*

The Burntisland shale, as has already been mentioned, corresponds in position with the Pentland seam, and is situated about 150 feet above the Burntisland or Burdiehouse limestone. It is not now worked; but was mined from its outcrop on the face of the Binn Hill northwards for 900 yards under the interbedded traps that here occupy the upper part of the oil shale group. The dip was about 10 degrees a little to the west of north, and two faults were crossed at distances from the mine mouth of 350 and 680 yards, running nearly east and west, with a downthrow to the south of 10 and 8½ fathoms respectively. The shale to the west became bad as the seam approached the great tuff neck or volcanic plug filling up the old vent of the Binn. This ash neck pierces lower strata than the smaller necks in West Lothian, to which reference has already been made, and the fact that it is full of volcanic agglomerate of a very coarse variety shows that the part now visible was probably originally near the surface, and, as Sir Arch. Geikie has pointed out, the top of the volcano was very likely above water during the latter part of the oil shale period. It is quite possible that some of the ashy looking beds in the marls of the Lothians may have been derived from dust from this or some neighbouring vent; but this is by no means certain as yet, and the analyses of the Houston marl given above warn us not to accept any theory, however neatly it seems to fit, unless it can be proved to fit everywhere, be free from holes and water-tight in all directions.

The generalized sections (Fig. 8) on the opposite page, show the stratigraphical relationships of the principal shalefields of the Lothians.

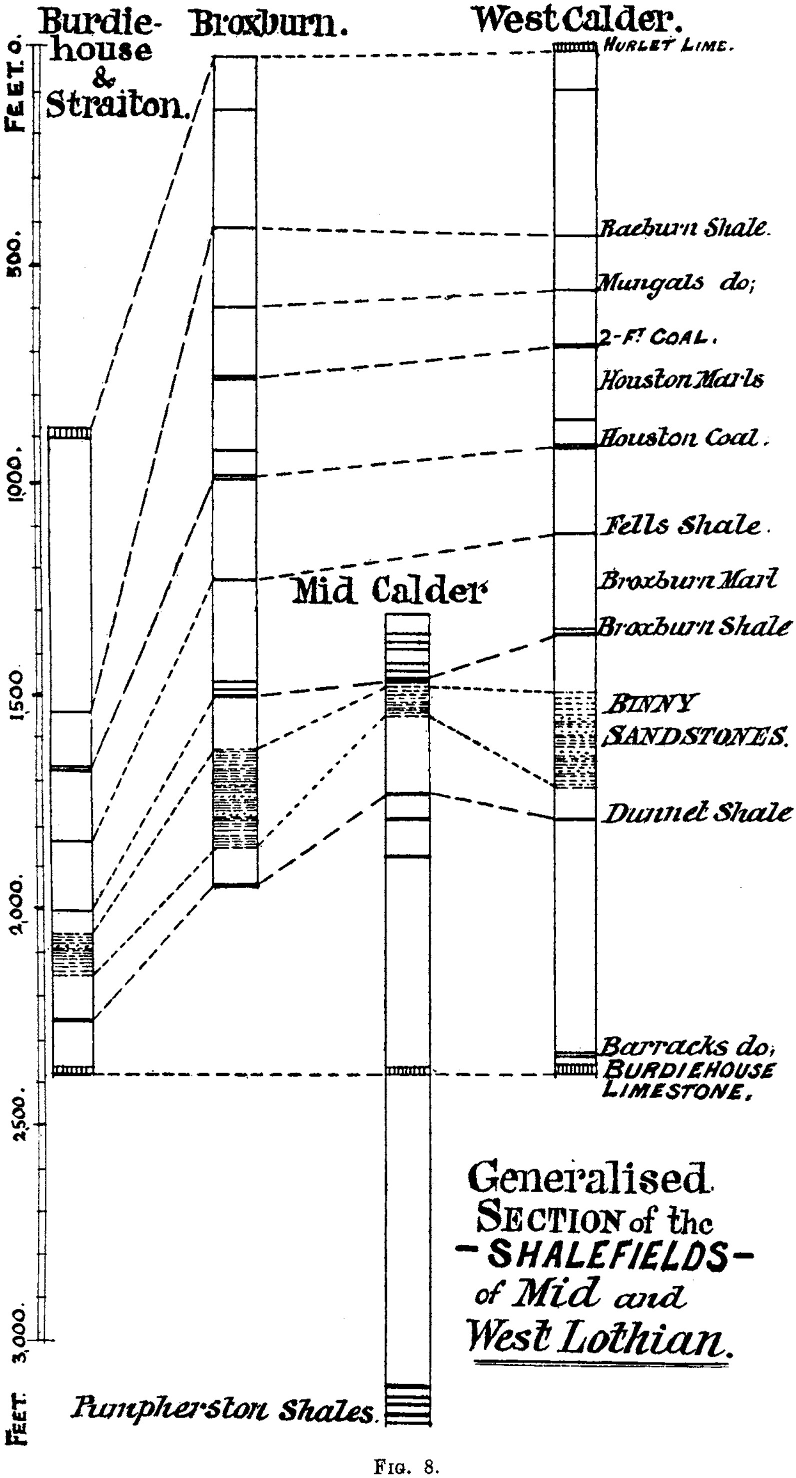
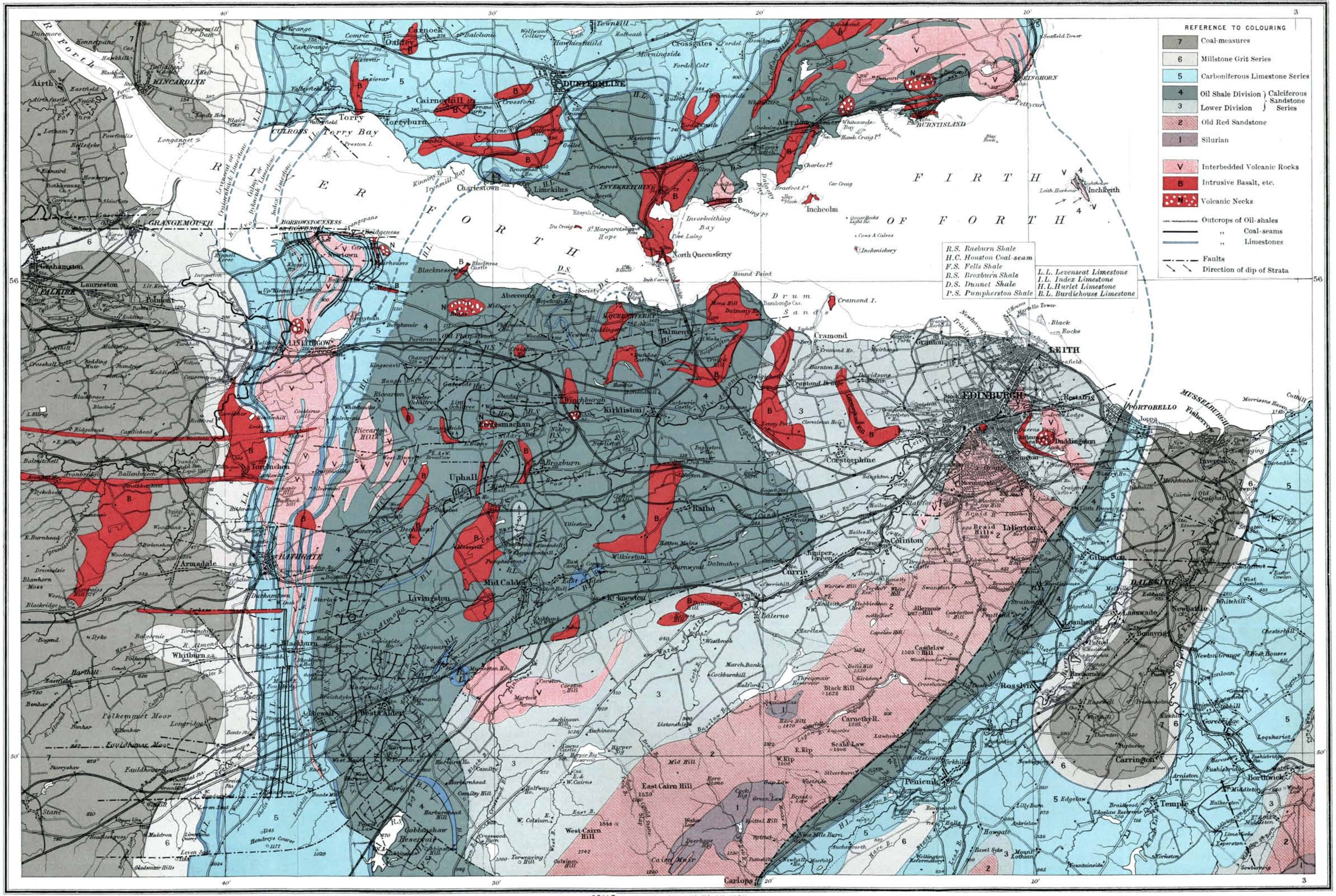

Burdie-house & Straiton.
Broxburn.
West Calder.
Mid Calder
FEET. 0.
500.
1000.
1500.
2,000.
2,500.
3,000.
FEET.
HURLET LIME.
Raeburn Shale.
Mungals do;
2-FT COAL.
Houston Marls
Houston Coal.
Fells Shale.
Broxburn Marl
Broxburn Shale
BINNY SANDSTONES.
Dunnet Shale
Barracks do;
BURDIEHOUSE LIMESTONE.
Pumpherston Shales.
Generalised SECTION of the -SHALEFIELDS- of Mid and West Lothian.

FIG. 8.

Trans. Edinr. Geol. Soc., Vol. VIII, Plate IV, 1902.

Geological Map of the Oil Shalefields of the Lothians and Coalfields of Linlithgowshire &c.

by Henry M. Cadell, B.Sc., F.R.S.E., F.G.S.



SCALE 1 : 126,720 = 2 MILES TO AN INCH

0 1 2 3 4 5 Miles

The Edinburgh Geographical Institute — J. G. Bartholomew