XXXIV.—**The Geology of South-Eastern Kincardineshire.** By **Robert Campbell**,
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cated by Professor JAMES GEIKIE, D.C.L., LL.D., F.R.S.* (With Three Plates.)

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CONTENTS.

	PAGE		PAGE
I. Previous Literature	923	D. The Garvock Group	946
II. [?] Upper Cambrian	926	E. The Strathmore Group	948
III. Structural Relations of the [?] Upper Cambrian	928	IX. Palæontology of the Lower Old Red Sandstone	948
IV. The Unconformity between the Down- tonian and the [?] Upper Cambrian at Ruthery Head	929	X. Volcanic Activity during the Lower Old Red Sandstone Period	949
V. Upper Silurian (Downtonian)	930	XI. Hypabyssal Intrusions of Lower Old Red Sandstone Age	951
VI. Evidence regarding the Age of the "Stonehaven Beds"	933	XII. Physical Conditions during the Lower Old Red Sandstone Period	952
VII. Comparison of the Kincardineshire Downtonian with the Downtonian of the Southern Uplands	934	XIII. Upper Old Red Sandstone	955
VIII. Lower Old Red Sandstone	936	XIV. Intrusions of [?] Carboniferous Age	956
A. The Dunnottar Group	937	XV. Summary of the Chief Structural Features	957
B. The Crawton Group	939	XVI. Acknowledgments	958
C. The Arbuthnott Group	943	XVII. Bibliography	959
		XVIII. Explanation of Plates	960

I. PREVIOUS LITERATURE.

In 1804, Lieutenant-Colonel IMRIE* communicated to the Royal Society of Edinburgh a paper entitled "A Description of the Strata which occur in ascending order from the Plains of Kincardineshire to the Summit of Mount Battoc, one of the most elevated points in the Eastern District of the Grampian Mountains." He pointed out that, in a short stretch of six miles in the North Esk section, "we pass from the secondary horizontal strata of the newest formation to the vertical, contorted primary strata of the oldest date, and terminate with granite, the primitive rock in the conception of many geologists." The section, as subsequent research has shown, bristles with difficulties, but IMRIE, unlike so many of his fellow-geologists of the fighting days of the early part of last century, deliberately sets himself to give "a statement of the facts presented by nature, leaving to others to draw their conclusions in relation to their own speculations, which they imagine the facts to warrant." The alternation of sandstone, grits, and conglomerates among the "secondary" rocks and the steepening of their dip as they are traced towards the Highlands; the jaspers, grits, shales, and limestones of the "primary" rocks, and the "rather unusual manner in which the

* *Trans. Roy. Soc. Edin.*, vol. vi. p. 3, 1812.

secondary and older strata meet each other"; the numerous east-and-west dykes of whin and porphyry intruded into the secondary strata; and the porphyry dykes in the mica schist area trending in a direction at right angles to the strike of the schists, are in turn clearly described and their positions noted on the admirable sketch-map which accompanies the memoir. While the paper as a whole is a splendid record of close observation, the account given of the whin dyke near the House of the Burn may be singled out as a brilliant piece of descriptive geology. In a second paper,* read to the Wernerian Society in 1810, IMRIE described the thick conglomerates between Fowls Heugh and Stonehaven. He noted the occurrence of pebbles of jasper, porphyries, granites, gneiss, quartz, etc., and pointed out that "quartz" (quartzite) and porphyries predominate. He recorded also the presence of a vertical bed of "greenstone" at Stonehaven harbour and a "clay porphyry" at Cowie.

Of the many short sketches of local geology embodied in the *New Statistical Account of Scotland*, vol. xi.—Forfar and Kincardine—two, namely those on the parishes of Fordoun and St Cyrus, are of considerable historical interest. In his account of the geology of Fordoun, written in 1837, the eminent geologist Professor (afterwards Principal) JAMES DAVID FORBES† compared the "transition clay slate" series at the Clattering Bridge with the "primary" rocks of the North Esk section described by IMRIE. He noted the occurrence of a "clay porphyry" in the same relative position in each locality—in what we now know to be the line of the Highland Boundary fault; he suggested the correlation of the limestones in the North Esk, at Clattering Bridge, and at Mains of Drumtochty—a suggestion fully confirmed many years afterwards by the detailed mapping by Mr BARROW, who has designated them the Margie limestone; and further he recorded from the Clattering Bridge section a bed containing "red jasper in dots"—an observation which gives additional evidence of the occurrence of the Margie series of Mr BARROW at that locality. Professor FORBES's paper contains also an admirable account of the field relations of one of the east-and-west trap dykes, and he sees in the presence of this dyke "an adequate cause for the rapid rise of the sandstone strata" in the Ferdun burn.

The first record of fossils from Kincardineshire is given in the account of the geology of St Cyrus‡ written in 1841 by JAMES MURRAY, the local schoolmaster. In an interesting footnote it is stated that fossils were first discovered in Canterland Den in the "present year" by Mr JAMES PETER of Canterland. These consisted of "broad tapering leaves, fragments of the stems, branches, and leaves of fuci, called *fucoïdes*, and rounded masses of oval or circular dots, resembling the compressed seeds of the strawberry, and supposed by Mr MILLAR to be the roe of an extinct species of gigantic lobster." The fossil last mentioned is undoubtedly *Parka decipiens*.

If we may judge from the absence of published papers, the geology of Kincardineshire must have been rather neglected during the next twenty years—a fact which is rather

* *Mem. Wernerian Soc.*, vol. i. p. 453, 1811.

† *The New Statistical Account of Scotland*, vol. xi. *Kincardineshire*, p. 72, 1845.

‡ *Ibid.*, p. 274, 1845.

surprising when we consider the impetus given to the study of the Old Red Sandstone by the discoveries and writings of HUGH MILLER. The Forfarshire Old Red, on the other hand, was diligently exploited. Ultimately, however, the treasures of Canterland Den attracted the Forfarshire enthusiasts, and in 1861 the Rev. HUGH MITCHELL* of Craig published a list of the fossils obtained by him from that locality. Occasional references to the geology of Kincardineshire occur in POWRIE's papers on the Forfarshire Old Red, and in his account of the "Connection of the Lower, Middle, and Upper Old Red Sandstone of Scotland" he places all the Old Red Sandstone of Kincardineshire in the Lower division, including also the jasper, serpentine, and limestones of the "Highland Border rocks," which had been assigned more correctly by FORBES to the transition clay slate series.

A great advance was made in 1884 by the publication of the first edition of Sheets 66, 67, 57, and 57*a* of the one-inch-to-the-mile map by the Geological Survey. The maps embodied the results of detailed mapping by Messrs IRVINE and SKAE. The rocks on the foreshore between the North Esk and St Cyrus are mapped as Upper Old Red Sandstone; the contemporaneous character of most of the trap rocks is indicated and their boundaries on the whole accurately delineated. It is further shown that the Old Red Sandstone is separated from the metamorphic rocks of the Highlands by a great fault; and the mapping shows very clearly that the chief structural feature of the Old Red area is a continuation of the Strathmore syncline.

In his *Ancient Volcanoes of Great Britain*, published in 1897, Sir ARCHIBALD GEIKIE gives the first connected account of the volcanic history of the Kincardineshire Old Red Sandstone, and, in an interesting chapter dealing mainly with the coast section, describes admirably not only the volcanic rocks but also the remarkable conglomerates with which they are associated. He considers the Kincardineshire lavas as belonging to the "Montrose centre of eruption."

The revised edition of Sheets 57, 66, and 67, issued in the same year by the Geological Survey, contains valuable additions by Mr GEORGE BARROW, chief of which are the mapping of definite aureoles of contact minerals due to progressive metamorphism in the schistose rocks, and the recognition of a belt of Silurian [?] rocks intervening between the schists and the boundary fault of the Old Red Sandstone. Reference is made to the latter discovery in the *Ancient Volcanoes of Great Britain*† and in the *Silurian Rocks of Britain*,‡ published in 1899. A detailed account of the lithological characters and structural relations of the "Highland Border rocks" was communicated to the Geological Society of London by Mr BARROW§ in 1901. He has shown that between Cortachy and Stonehaven they appear as three lenticular strips. The lenticels between Cortachy and Clattering Bridge and to the north of Drumtochty Castle have been described in detail by Mr BARROW, who has shown that the rocks belong to two

* *Quart. Journ. Geol. Soc.*, vol. xvii. p. 147, 1861.

† Vol. i. p. 201.

‡ *Mem. Geol. Survey: The Silurian Rocks of Britain*, vol. i., *Scotland*, p. 73.

§ *Quart. Journ. Geol. Soc.*, vol. lvii. p. 328.

divisions: (1) "the Jasper and Green-rock series," probably of Arenig age, and (2) "the Margie series" resting unconformably in the former. They are always separated from the schists by a thrust plane and from the Old Red Sandstone by the Highland boundary fault. Further reference to Mr BARROW's paper will be made in connection with the description of another area of Highland Border rocks near Stonehaven.

The present paper deals with the stratigraphy of the palæozoic rocks of that part of Kincardineshire which lies south of the Highland fault. As has been shown in a preliminary note,* they include:

- (1) Upper Cambrian [?] (Highland border rocks).
- (2) Upper Silurian (Downtonian).
- (3) Lower and Upper Old Red Sandstone.

Evidence of contemporaneous volcanic activity is found in all the formations except the Upper Old Red Sandstone; and certain intrusive rocks are probably of Carboniferous age.

II. UPPER CAMBRIAN [?].

A narrow strip of Highland Border rocks occurs on the coast near Stonehaven, extending from a point on the foreshore opposite St Mary's Chapel, Cowie, to Garron Point. The predominating rock type is a crushed green igneous rock, which has undergone intense shearing and folding, and to a large extent has been converted into chlorite schist. Vesicular structure, however, can still be recognised in places, and "pillowy" structures are sufficiently well preserved to demonstrate the original igneous character of the rocks. The field evidence suggests that they are pillowy lavas or spilites, and this is borne out by microscopical examination of the least altered parts of the rock. All the slides examined are typical spilites, and several show characteristic variolitic structures.† The coarsely crystalline diabase types, presumably intrusive in character, described by Mr BARROW from the other lenticles, have not been found.

The Highland Border rocks at Stonehaven may be looked upon as consisting mainly of a succession of pillowy lavas, but here, as in nearly all described occurrences, they are accompanied by fine-grained siliceous sediments. In the present case these consist of cherts, jaspers, and black cherty shales rich in iron oxides. These occur chiefly as intercalations between successive flows, but to some extent they are found in lenticular masses, suggestive of their having originally filled spaces between adjacent pillows. The sediments in every case consist of silica and iron oxides with varying proportions of calcite. In none of the slides has any undoubtedly terrigenous material been detected. Some of the cherts resemble the radiolarian

* *Geol. Mag.*, dec. 5, vol. viii. p. 63.

† A detailed account of the petrography of these and other igneous rocks of South-Eastern Kincardineshire will be given in another paper.

cherts of the Southern Uplands, and the presence of rounded bodies suggestive of the remains of radiolaria probably indicates that they have had a similar origin.

In August 1909, on the occasion of a visit to the Garron Point section in company with Dr B. N. PEACH and Dr W. T. GORDON, we spent some time in searching for fossils in the above-mentioned sediments. The rocks on the whole seemed to be less intensely sheared than the similar rocks in the North Esk and Drumtochty sections, and the cleavage planes to coincide approximately with the bedding planes. Hence the conditions seemed favourable for the preservation of fossils. Nor were we disappointed. After a few hours' work we discovered in the black cherty shales on the north side of Craigeven Bay what were undoubtedly organic remains, namely, a linguloid shell, a bivalve phyllocarid crustacean, and a worm tube. Realising the importance of the discovery, we reported it to Dr HORNE, then Assistant Director of the Geological Survey, and the assistance of Mr D. TAIT was obtained in making a detailed search in the fossiliferous beds. Mr TAIT collected a remarkable suite of fossils, which have thrown important light on the age of the rocks. Dr PEACH, in whose hands the fossils were placed for determination, has very kindly supplied the following note :—

“The collection includes several specimens of hingeless brachiopods belonging to the genera *Lingulella*, *Obolella*, *Acrotreta*, *Linnarssonina*, and *Siphonotreta*; a few specimens of a bivalve phyllocarid allied to *Caryocaris* and *Lingulocaris*; cases of a tubicolar worm, the structure of the tubes being like that of the modern *Ditrupa*.

“Without further study it may be premature to express a definite opinion about the horizon of these fossils. The genera represented are most commonly found in the lowest division of the Lower Silurian (Ordovician) system and the Upper Cambrian. The absence of graptolites, however, suggests that they may belong to the latter rather than to the Lower Silurian.”

Dr WALCOTT, of the Smithsonian Institute, Washington, to whom a selection of the fossils was afterwards submitted, reports that he is inclined to agree with Dr PEACH's conclusion that the fauna is an Upper Cambrian one.

With the exception of radiolaria, which had been detected by Dr PEACH in the cherts at Gualin, near Loch Lomond, the other occurrences of these rocks along the Highland Border had not yielded any organic remains. Recently, however, Dr JEHU* has announced the discovery of fossils in the chert and black shale series at Aberfoyle. And in Dr JEHU's collection Dr PEACH has recognised *Lingulella*, *Obolus*, and the jaw of an annelid.

The chief interest in the discovery of fossils in the Highland Border rocks lies in the direct bearing which it has on the fascinating, if perplexing, problems presented by the tectonics of the Central and Eastern Highlands.

Are these rocks pre-Cambrian? Their correlation as Lower Silurian is suggested by the lithological and structural resemblances between the Jasper and Green-rock and

* *Nature*, vol. lxxxix. p. 347, 1912.

Margie series on the one side of the Central Valley and the rocks of Ordovician age on the other. The crushed spilitic lavas with their accompanying cherts and jaspers find their counterpart in the Arenig volcanic series of the Southern Uplands; the sediments of the Margie series, resting unconformably on the former group, and derived in part at least from it, may fairly be compared with certain higher horizons in the Ordovician of the South of Scotland. The palæontological evidence obtained at Stonehaven, on the other hand, favours the view that the Jasper and Green-rock series is Upper Cambrian. It is possible, however, as Dr PEACH* has pointed out, that the Highland Border rocks will ultimately be found to include representatives of both the Arenig and Upper Cambrian formations. But from our present point of view the distinction between Upper Cambrian and Ordovician as the position of the series as a whole is of minor importance. The vital question is: In the light of recent discoveries can they possibly be regarded as pre-Cambrian? Our lack of knowledge of the life of pre-Cambrian times may, it is true, forbid dogmatic assertion on this point; but it will be admitted, I think, by most geologists that the range of genera obtained at Stonehaven and Aberfoyle, taken together with the lithological resemblances cited above, affords very strong, if not conclusive, evidence against these rocks being pre-Cambrian.

III. THE STRUCTURAL RELATIONS OF THE [?] UPPER CAMBRIAN.

Along their northern boundary the Cambrian rocks are separated from the Dalradian Schists by an overthrust fault, which, during low tides, may readily be traced from the southern shore of Craigeven Bay to Garron Point. Its position is indicated by the occurrence of a dolomitic fault rock, creamy white on a fresh fracture, but weathering to a rusty brown colour. In Craigeven Bay the dolomite attains a maximum thickness of about 40 feet. Microscopic sections show that it is undoubtedly a fault rock, made up largely of carbonates, but containing here and there recognisable angular fragments of the spilitic lavas. Thin veins of similar rock are developed along some of the minor movement planes in the green rocks themselves. The overthrust character of the fault is well seen from the position of the dolomite bed on the cliff on the north side of Craigeven Bay, and again from the fault feature south of the Skatie Shore. The fault is not indicated in the first edition of the one-inch map of the Geological Survey, but has been inserted by Mr BARROW in the revised edition. It may be regarded as a continuation of the Highland Boundary fault.

The southern boundary of the Jasper and Green-rock series at Ruthery Head has hitherto been mapped as a fault separating the schistose rocks from the Old Red Sandstone. During the present research, however, evidence has been obtained which proves that the junction is really an unconformable one, and that the overlying beds are of Downtonian age.

* Presidential Address to Section C, British Association, Dundee, 1912.

IV. THE UNCONFORMITY BETWEEN THE DOWNTONIAN AND [?] UPPER CAMBRIAN AT RUTHERY HEAD.

The nature of the junction between the Upper Cambrian and the Downtonian may be studied most satisfactorily in the cliff section at Ruthery Head and on the foreshore to the east of that headland. To the north extend the green Cambrian strata with their main structural planes, whether of cleavage or of bedding, in igneous and sedimentary rocks alike, dipping to the north-west; to the south lie the red Downtonian

TEXT-FIG. 1.—Sketch-map of Geology of the Coast of Kincardineshire from Cowie to Garron Point.* (R. Campbell.)

beds highly inclined towards the south-south-east. (See Sketch-map, and Plate I. figs. 1, 2, and 3.) It is not perhaps difficult to understand why the character of the boundary between the two sets of rocks should have been misunderstood, since there are many features in the section which suggest the presence of a powerful east-and-west fault. The Cambrian rocks for a considerable distance away from the junction have been stained red, and are in places very much shattered; the basement beds of the Downtonian consist of breccias made up to a large extent of reddened fragments of the underlying Jasper and Green-rock series; and the presence of numerous hitch faults tends still further to obscure the nature of the boundary. But, while it may be difficult, even after one has become familiar with the rock types, to distinguish the basement beds of the Downtonian from the reddened Cambrian rocks, it is always easy to recognise the character of the dominant structures in the respective types, and by means of these to trace the somewhat irregular course of the junction along the foreshore opposite Ruthery Head. The presence of intercalated beds of jasper in the

* Reproduced by permission from the *Geological Magazine*, dec. 5, vol. viii., 1911.

reddened spilites has also been found of great assistance in distinguishing these rocks from the overlying Downtonian.

Detailed examination of an exposure between two of the small hitch faults—such, for example, as that shown in Plate I. fig. 2—shows clearly that the junction is not a fault plane but an unconformity. It can be seen, moreover, that the younger rocks rest on a highly irregular eroded surface of the older.

An overthrust fault, which crosses Ruthery Head in north-easterly direction, shifts the outcrop of the lowest Downtonian breccias 160 yards to the south-west. From the fault the unconformity can be traced, although not so easily as in the section just described, along the foreshore in a westerly direction, until it is cut out again by the Highland fault near the mouth of the small stream which flows past St Mary's Chapel.

V. UPPER SILURIAN (DOWNTONIAN).

The rocks overlying the Upper Cambrian were formerly mapped as part of the Lower Old Red Sandstone formation. The palæontological evidence recently obtained, however, shows that the "Stonehaven Beds" must now be regarded as of Downtonian age. No marked discordance has been detected anywhere in the upward succession from Downtonian to Old Red Sandstone in this area; and since, in their lithological characters the former is of the nature of a transition series, it is not easy to fix the boundary between the two formations. In the description of the coast section given in my preliminary note, I took the massive conglomerate of Downie Point as the base of the Old Red Sandstone, but further study of the inland sections has led me to include with the basement conglomerates the brown micaceous pebbly sandstones at Stonehaven harbour along with the intervening tuffs and volcanic conglomerate. The sandstones contain numerous pebbles of quartzite, and herald the oncoming of the coarse "quartzite conglomerates" which form so characteristic a feature of the Lower Old Red Sandstone.

The succession of the Downtonian beds as seen in the coast section from the mouth of the Cowie Water to Ruthery Head is as follows (in descending order):—

	Feet.
7. Tuffs and tuffaceous sandstones	800
6. Grey sandstone and fossiliferous sandy shales and mudstones (with fish band)	600
5. Red sandstones	60
4. Volcanic conglomerate and tuffs	40
3. Grey and brown sandstones with thin red mudstones	1000
2. Purple sandstones	60
1. Basement breccias with intercalated sandy mudstones	200

The basement beds include a succession of breccias interstratified with finely bedded sandstones and sandy mudstones. The breccias consist in large part of angular and

subangular fragments of the underlying rocks, but they contain also rounded pebbles of weathered granite and schists. The purple sandstones overlying the basement beds appear to consist mainly of finely comminuted debris of the rocks of the Upper Cambrian series.

Next in the succession comes a thick series of grey and brown ochreous sandstones with intercalations of pale red mudstones. The sandstones often contain much volcanic debris in the form of fragments of andesitic and felsitic rocks; clay galls, indicating contemporaneous erosion of clay beds, are abundant; and false-bedding is everywhere of common occurrence. Beautiful examples of sun-cracks have been noted in the mudstones. On the south side of the entrance to Cowie harbour a dip fault with downthrow to the south shifts the above series to the west, and on the foreshore between Cowie and Stonehaven Bay the brown and grey ochreous sandstones are overlain by a coarse volcanic conglomerate associated with a belt of tuffs and tuffaceous sandstones.

The volcanic conglomerate has a maximum thickness of about 30 feet, and may be traced as a conspicuous ridge on the foreshore extending in a south-south-westerly direction from Cowie pier. As it approaches the Cowie harbour fault it is traversed by a large number of small dip faults, each of which shifts the outcrop slightly to the eastward as the conglomerate is followed towards Cowie. Made up almost entirely of rounded boulders of hornblende andesites and rhyolites, the conglomerate is overlain by a belt of soft red andesitic tuffs with a maximum thickness of 27 feet, to which succeeds a thin bed of fine conglomerate with green tuffaceous matrix.

The next member in the succession is a massive red sandstone with occasional thin mudstone intercalations. It presents no feature of particular interest.

The red sandstone is overlain by about 600 feet of grey sandstone and sandy shales with green and grey mudstones. This group (No. 6) is the most important in the series, since, alike in its lithological characters and in its fossil contents, it shows the Silurian rather than Old Red Sandstone affinity of the succession. The predominant sediments are grey sandstones, occasionally rich in clay galls, and in places containing bands of calcareous nodules. At intervals there occur intercalations of green and grey sandy mudstones and shales, in which *Dictyocaris* is found in great abundance. The most noteworthy of the mudstone and shale groups occurs about 20 yards east of Cowie harbour. On visiting this section in August 1909, in company with Dr PEACH and Dr W. T. GORDON, we found not only *Dictyocaris*, but also *Eurypterus* sp. and fragmentary plant remains, and in a thin bed of reddish sandy mudstone, overlying the red sandstone (No. 5), Dr GORDON discovered several fish plates. Some of the fish fragments were suggestive of *Birkenia*. Dr GORDON and Dr PEACH joined me again during the following summer in order that we might try to get material sufficient to establish the horizon of this fish fauna, and considerable additions were made to the finds of the previous year.

The fishes were submitted to the late Dr R. H. TRAQUAIR, who undertook the description of new species. In a preliminary note contributed to the *Geological*
TRANS. ROY. SOC. EDIN., VOL. XLVIII. PART IV. (NO. 34).

*Magazine** he concluded that the fish remains from Cowie consisted of: (1) Cephalaspidian scutes belonging to a species as yet unnamed and undescribed; (2) fragments of thin, minutely tuberculated plates, which might also be Cephalaspidian, though their nature was problematical; (3) two median plates of a beautiful new *Cyathaspis*. After examination of additional material Dr TRAQUAIR† communicated another short paper to the British Association meetings at Dundee, in which he gave the following brief diagnosis of the new *Cyathaspis*:—

“*Cyathaspis Campbelli* (Traquair).—Shield, ovoid, concave, shallow, broadest part situated behind the point of greatest expanse; covered with stout ridges running in a longitudinal direction, but also tending to converge a little anteriorly and posteriorly. These ridges are also constantly interrupted, so as to give almost a tubercular appearance, the tubercles being comparatively distantly placed, much compressed, and crenulated.”

Dictyocaris, unfortunately, must still be labelled “*incertæ sedis*.” From its resemblance to the living *Marchantia* it was thought it might possibly be a plant; but Dr D. H. SCOTT, to whom specimens were sent for determination, replied that in his opinion they were not vegetable. Dr SMITH WOODWARD thought they were unsatisfactory fragments of the dermal armour of Cephalaspidian and Pteraspidian fishes, and a larger collection of specimens was made and submitted to Dr TRAQUAIR along with the undoubted fish remains. Dr TRAQUAIR was of opinion that it was not likely that the fossil could represent the median layer of the Pteraspidian shield, although the resemblance was a suggestive one. There can be no doubt, however, that the Cowie specimens are identical with the *Dictyocaris* of SALTER, which occurs in the Upper Silurian of the Southern Uplands and in the Downtonian of England.

Apart from plant fragments and worm-tracks the remaining fossils in my collection belong to the Arthropoda. They include *Ceratiocaris* sp. (carapace, rostrum, and cercopod); *Archidesmus* sp., and a new genus of Myriapod; (?) larval form of insect; *Eurypterus*, sp. nov.; and fragments of scorpion. The arthropoda will be described by Dr PEACH, to whom I am indebted for the above provisional determination.

As long ago as 1881 Mr MACCONOCHIE collected for the Geological Survey from the “Stonehaven Beds” *Dictyocaris*, fragments of *Pterygotus*, *Eurypterus*, and (?) *Kampecaris*, and Dr HORNE has told me that in discussing these fossils at that time Dr PEACH expressed the opinion that they might be of Silurian age.

The highest beds in the Downtonian series (No. 7) consist of green and red tuffs and brown tuffaceous sandstone with occasional intercalations of pebbly bands and thin sandy mudstones. They are exposed in the foreshore at Stonehaven Bay, but can be examined only when the tides are low.

Inland, on account of the drift-covered character of the country, the succession cannot, of course, be studied in the same detail. In sections in the Carron Water and its tributaries, however, in railway cuttings, and in occasional quarries, evidence has

* *Geol. Mag.*, dec. 5, vol. viii. p. 66, 1911.

† *Ibid.*, vol. ix. p. 511, 1912.

been obtained which has enabled me to map the Downtonian series for about seven miles to the west. The general strike of the series is parallel to the Highland fault, while the strata are highly inclined with dip to the south-south-east. Locally, as may be seen in the coast section, there is inversion, and the beds dip towards the fault. It is quite clear, however, that from the mouth of the Cowie Water to the basement breccia we are dealing with a descending succession. From the coast to the neighbourhood of Elfhill the Downtonian rocks form the lowest strata in the steeply inclined northern limb of the Strathmore syncline. Westwards from Elfhill there is a tendency to set up a steep-limbed anticline pitching out to the south-west against the Highland fault, and from Elfhill to the Carron Water just west of the farm of Waters the Downtonian series occupies the core of the anticline.

No very useful purpose would be served by describing in detail the various inland sections. The volcanic conglomerate with its associated tuffs (No. 4), and the fossiliferous green and grey mudstones of No. 5, have been traced at intervals for about six miles to the west of Stonehaven. They keep the same relative position, their lithological characters are constant, and *Dictyocaris* continues to be the characteristic fossil. Both zones may be recognised in the Carron Water between Carron Lodge and the bend of the river opposite Dunnottar church. Just west of the church the series is traversed by an important fault, which extends from Thornyhive Bay to the Highland fault near Fetteresso sawmill. The outcrop of the fossiliferous beds is shifted to the north-west. Reappearing in the Cheyne Burn near the sawmill, they may be traced westwards, and are found in the Burn of Graham a short distance below Bridge of Graham, on the Carron Water about half a mile west of Tewel, and again on the Carron Water at its junction with the Elfhill Burn. The volcanic conglomerates and tuffs are best seen in a splendid strike section in the Elfhill Burn. They are also exposed in the Burn of Graham.

From the section in the Carron west of Tewel Mr D. TAIT obtained a fish spine, and, since there the green mudstones are associated with a reddish sandy mudstone, which, lithologically, is identical with the band which yielded the fishes at Cowie, it is hoped that careful search in this locality will yield further specimens belonging to the Cowie fish fauna. In a quarry near the schoolhouse of Tewel a curious mottled sandstone is in places richly charged with plant remains, none of which unfortunately are determinable.

VI. EVIDENCE REGARDING THE AGE OF THE "STONEHAVEN BEDS."

At an early stage in this research one of the points which appealed to me most strongly was the marked dissimilarity between the "Stonehaven Beds" and the usual facies of the Caledonian Old Red of Kincardineshire and Forfarshire. And when, afterwards, under the guidance of Dr PEACH, I had visited typical sections of the Downtonian of Lanarkshire and the Pentland Hills, it became clear at once that, so far as lithological evidence went, the above series bore the impress of a Downtonian rather

than a normal Old Red Sandstone type of sedimentation. In Kincardineshire, just as in the Southern Uplands, the Downtonian rocks form what is truly a transition series, in some respects exhibiting the characters of a typical Upper Silurian group of sediments, in others those of the Lower Old Red Sandstone. To the former belong the green and grey mudstones and the greywacké-like sandstones; to the latter, the coarse conglomerates and the false-bedded ochreous sandstones.

Consideration of the palæontological evidence cited above leads to a similar conclusion. Neither *Dictyocaris* nor *Ceratiocaris* has hitherto been met with in rocks younger than Upper Silurian, while both are common forms in the Downtonian elsewhere in Britain. The unique fishes of the Downtonian of the South of Scotland, it is true, have not so far been found; but, since the nature of the invertebrate fossils favours the reference of the "Stonehaven Beds" to that horizon, the occurrence of *Cyathaspis*, as Dr TRAQUAIR has pointed out, may be regarded as corroborative evidence.

Professor KIÆR* has recently announced the discovery of a Downtonian fauna in the sandstone series of the Kristiania area—a series described as Old Red Sandstone by MURCHISON in 1844, and so regarded by most Norwegian geologists since his time. The list of fossils given by Professor KIÆR in his preliminary report includes *Dictyocaris* (very abundant), *Ceratiocaris* sp., at least two new species of *Eurypterus*, *Pterygotus* sp., two new Cephalaspidomorph fishes, and three new genera of Anaspid fishes.

There is undoubtedly a striking similarity between the above assemblage of fossils and those found at Stonehaven. It is impossible, of course, to compare the eurypterids and fishes of the two areas until fuller descriptions are available, but in both cases there is a noteworthy abundance of the problematical *Dictyocaris* along with fragments of *Ceratiocaris*.

In short, the palæontological evidence and the character of the sedimentation together show conclusively that the "Stonehaven Beds" must be regarded as Downtonian, although not necessarily on the same horizon as that of the fossiliferous zones of the Downtonian rocks of the South of Scotland.

VII. COMPARISON OF THE KINCARDINESHIRE DOWNTONIAN WITH THE DOWNTONIAN OF THE SOUTHERN UPLANDS.

The palæontological evidence† obtained in the Southern Uplands indicates that the green and grey mudstones, the greywackés, and the fish band are marine. They have yielded species of eurypterids, which in the Wenlock series are associated with graptolites, in the Ludlow series with a *Lingula*; they contain, moreover, *Glauconome*, *Spirorbis*, crinoid stems, and sponges. The rock types resembling the Old Red Sandstone sediments, on the other hand, have been supposed to indicate fresh- or brackish-water

* *Videnskapselskapets Skrifter*, i. Mat.-Naturv. Klasse, 1911, No. 7.

† *Mem. Geol. Survey: Silurian Rocks of Britain*, vol. i. pp. 69, 603.

conditions. In Kincardineshire no evidence has been obtained so far which would point to marine sedimentation. No undoubtedly marine organism has been found, and the association of the eurypterids with plant remains, scorpion fragments, galley-worms, and a larval form of insect appears to show that the green and grey mudstones were laid down in close proximity to a land area, and, at the most, can imply only estuarine conditions; the interbedded ochreous sandstones with their characteristic false-bedding, and the development of sun-cracks in the red mudstones, point conclusively to deposition in shallow water. The coarse volcanic conglomerate, like those of the Old Red Sandstone, is in all likelihood a torrential flood gravel.

No contemporaneous volcanic rocks have been found in the Downtonian series of the Southern Uplands; the earliest lavas and tuffs invariably overlie the basement greywacké conglomerate of the Lower Old Red Sandstone. Sir ARCHIBALD GEIKIE* has correlated the initial outbreak of volcanic activity in "Lake Caledonia" with the coming on of the conditions which gave rise to the lowest of the massive quartzite conglomerates at Stonehaven. That volcanoes were active in this region at a much earlier period is seen from the development of tuff and volcanic conglomerates in the Downtonian sequence. The lowest volcanic conglomerate is about 2500 feet below the above-mentioned quartzite conglomerate. As we have already seen, the lowest zone of volcanic conglomerates and tuffs can be traced inland until it is lost against the Highland fault. There is abundant evidence also to show that the materials of all the associated sediments were derived from the Highland area. One must conclude, therefore, that early in Downtonian times (or perhaps in pre-Downtonian, but subsequent to the movements which folded the eastern schists) volcanic activity had already begun in the schist country to the north of the Highland fault.

In the Southern Uplands the Downtonian series passes down conformably into the Ludlow. The presence of quartzite conglomerates shows that the sediment, in part at least, was derived from the Highland area. At Stonehaven the Downtonian rests unconformably on rocks of a much lower horizon (probably Upper Cambrian), and there is in all probability a marked overlap as the Lower Old Red Sandstone formation is traced over the Highland area to the west. In Kincardineshire the Downtonian series passes up conformably into the Lower Old Red Sandstone; in the Southern Uplands it has been found that the two series are separated by an unconformity in the Pentland Hills and Ayrshire; while in Lanarkshire there is an "apparent conformability," the basal conglomerate of the Lower Old Red Sandstone series being made up everywhere mainly of boulders of greywacké derived from the rocks of the Silurian tableland to the south.

Consideration of the chief points in the above comparison leads to the following conclusions:—

(1) During early Downtonian times there was continuous subsidence of the southern part of the central valley and the area now occupied by the Southern

* *Ancient Volcanoes of Great Britain*, vol. i. p. 303.

Uplands, while along the Highland Border and further northwards there was a movement of compression and elevation and consequent denudation. Such a theory affords a satisfactory explanation of the occurrence of boulders of Highland rocks in the Downtonian conglomerates of the Southern Uplands.

(2) The above movements of subsidence reached the Highland Border during late Downtonian times. This is shown by the fact that the Downtonian rocks of Kincardineshire, which include the highest beds in that group, rest unconformably on the Highland Border series.

(3) While this movement of subsidence went on continuously in the central valley, about the end of the Downtonian period movement of compression set in towards the south, resulting in the production of the land area of the Southern Uplands, of which the southern Downtonian rocks form a part.

(4) At the beginning of Lower Old Red Sandstone times the central valley was flanked to north and south by mountain ranges and itself formed a subsiding area on which the coarse sediments derived from the rapid denudation of these mountain masses were deposited.

(5) Finally, the earlier beginning of volcanic activity in the northern side of the midland valley may be correlated with the earlier development of movements of compression and elevation in that region.

VIII. LOWER OLD RED SANDSTONE.

The rocks of Lower Old Red Sandstone age, which occupy the greater part of south-eastern Kincardineshire, include coarse conglomerates, sandstones, and marls interbedded with lavas, tuffs, and volcanic conglomerates. The enormous thickness of the groups of contemporaneous volcanic rocks points to a prolonged period of volcanic activity, which, as we have seen above, had been initiated at least as far back as Downtonian times. Resting conformably on the Downtonian series, the Lower Old Red Sandstone is in turn overlain by rocks of Upper Old Red Sandstone age. The latter are found in Kincardineshire in a small area along the coast between East Mathers and the mouth of the North Esk, and the junction between the two series is everywhere a line of faulting. Near Arbroath, however, the Upper Old Red Sandstone rests unconformably on the Lower; and, as Dr HICKLING* has clearly shown, the latter series had undergone extensive folding and denudation before the deposition of the former.

In Kincardineshire, as elsewhere, one notable characteristic of this formation is the paucity of organic remains. A few additions to our knowledge of the fossiliferous localities have been made in the course of the present research, but the palæontological evidence is so meagre that it has been found of little value for stratigraphical purposes. Lithological evidence, on the other hand, obtained from conglomerates,

* *Geol. Mag.*, dec. 5, vol. v. p. 396, 1908.

lavas, and tuffs, and, in particular, the recognition of a well-marked succession in the lavas, has aided materially in elucidating the structure of the area occupied by the Lower Old Red Sandstone.

The rapid variation in the character of the rocks in any given horizon makes it almost impossible to draw a sharp line of demarcation between one zone and another. For convenience in description, however, I have divided the Lower Old Red Sandstone series into five groups, arranged as under in descending order :—

- E. The Strathmore Group.
- D. The Garvock „
- C. The Arbuthnott „
- B. The Crawton „
- A. The Dunnottar „

The approximate thickness of each group is as follows :—

	Maximum feet.	Minimum feet.
Dunnottar Group	6900 }	7500
Crawton „	1600 }	
Arbuthnott „	5000	3000
Garvock „	4000	3800
Strathmore „	1500 +	

The marked variation in the thickness of the three lowest groups is due in large measure to the varying development of the intercalated lava zones, and to the rapid lateral variation of the associated volcanic conglomerates.

The above figures confirm Sir ARCHIBALD GEIKIE's* estimate of 20,000 feet as the maximum thickness of the Lower Old Red Sandstone of Lake Caledonia, included in which are the "Stonehaven Beds" (2760 feet), regarded in this paper as Downtonian.

A. *The Dunnottar Group.*

The Dunnottar group includes the part of the Lower Old Red Sandstone which lies between the base of the series and the top of the Tremuda Bay lavas. A brief description of the coast section from Stonehaven to Thornyhive Bay will perhaps serve to indicate the general aspect of this portion of the Old Red succession. Its chief characteristic is a magnificent development of coarse conglomerates with intercalated thin brown sandstones. In the conglomerates well-rounded quartzites are always the most conspicuous constituent. They are accompanied by other "Highland" rocks and by a varying proportion of granites of "newer granite" type, quartz porphyries, rhyolites, and acid andesites. Boulders derived from the Jasper and Green-rock series are present, as a rule,

* *Text-book of Geology*, vol. ii. p. 1008, 1903.

in great abundance, but in the conglomerates underlying the Tremuda Bay lavas they are almost entirely wanting, their place being taken by an abnormally large number of rhyolites and acid andesites. Locally, too, and particularly in the conglomerate just south of Strathlethan Bay, boulders of a coarse grit resembling the "Haggis rock" of Caradoc age of the Southern Uplands are fairly numerous.

At four horizons the conglomerates are interbedded with contemporaneous volcanic rocks.

(a) At Stonehaven harbour the basement members of the group, brown micaceous pebbly sandstones, are separated from the coarse quartzite conglomerate of Downie Point by a considerable thickness of acid tuffs, with a few bands of coarse volcanic conglomerate.

Three lavas are indicated in the Geological Survey map as occurring in the vicinity of Stonehaven harbour, but I have been able to find only one crystalline igneous rock, and that an intrusive quartz dolerite.

(b) In Strathlethan Bay the Downie Point conglomerate underlies a series of soft tuffs and tuffaceous sandstone, with which again are associated volcanic conglomerates. Here, too, we find the lowest lava flow of Old Red Sandstone age in Kincardineshire—an augite andesite. It forms the small island of Carlin Crag, but is truncated by a fault and does not appear in the cliff section.

(c) After a long interval, represented by a great thickness of conglomerates, another zone of acid tuffs is found in Old Hall Bay, just south of Dunnottar Castle.

(d) At Tremuda Bay the highest members of the Dunnottar group include a series of at least six flows of olivine basalt of a coarsely crystalline, doleritic type, each of which consists of a massive central portion with well-marked scoriaceous upper and under surfaces. The second shows good columnar structure. The slaggy upper surfaces occasionally enclose "veins" of sandstone. The bottom lava has flowed over a bed of soft mud, portions of which have been caught up in the lower scoriaceous surface. At the north side of Thornyhive Bay the lavas are truncated by the important fault already alluded to, and the top of the series is not seen.

The lava near the lighthouse at Todhead Point is a doleritic basalt of the same type as the above, and, along with the underlying conglomerates, may perhaps be considered as belonging to the Dunnottar group. It shows a very slaggy upper surface with the characteristic sandstone veinings, and has been described and figured by Sir ARCHIBALD GEIKIE.*

Inland sections are sufficiently numerous to show that, along the steeply inclined northern limb of the Strathmore syncline, the Dunnottar group maintains the same general characters which it exhibits in the coast section. Quartzite conglomerates predominate, but at intervals there occur acid tuffs and volcanic conglomerates. On the south-eastern slope of Carmont Hill, near Square's Knap, a vesicular augite andesite is associated with a coarse volcanic conglomerate, and, although the lava is not quite of

* *Ancient Volcanoes of Great Britain*, vol. i. p. 303.

the same type as the andesite of Carlin Crag, it seems fairly certain that it is on the same volcanic horizon as the Strathlethan Bay zone.

The only fossils obtained from the Dunnottar group are specimens of *Parka* sp., collected from a grey sandstone associated with the tuffs at Strathlethan Bay.

From Stonehaven harbour to the middle of Old Hall Bay the general direction of strike is east-north-east and west-south-west, while the strata are vertical or very highly inclined. In the section on the foreshore in the southern half of Old Hall Bay the angle of dip falls very rapidly, until at the extreme south corner it averages about 35° . South of the next important headland, Maiden Kaim, the beds swing round the great synclinal fold of Strathmore, the strike changing to north-west and south-east, and the average angle of dip falling to 25° .

B. *The Crawton Group.*

The Crawton group is characterised by a marked increase in the proportion of volcanic rocks, quartzite conglomerates no longer predominating as in the underlying series. Detailed mapping has shown that it presents markedly different suites of lavas on the two sides of the Strathmore syncline. The area occupied by the northern limb of the fold contains a fine development of acid andesites; along the southern limb there occurs a remarkable group of porphyritic basalts.

(a) *The Crawton Basalts and Associated Rocks.*—The predominating type of lava in this series is a basalt with large tabular phenocrysts of plagioclase, which closely resembles the well-known Carnethy "porphyry" of the Pentland Hills.* We shall refer to it as the Crawton type of basalt. The most southerly exposure of the Crawton basalts is seen on the shore about a mile south of Gourdon, where they are striking seawards in a north-west and south-east direction. Swinging round somewhat abruptly near Nether Knox, they return to the north-north-east and south-south-west direction of strike—the general strike of the synclinal fold. They may be followed along the higher slopes of Gourdon Hill, and ultimately crop out in the Water of Bervie near Pitcarry Mills. There they are truncated by a fault, the line of which is marked by a thick fault breccia forming a prominent wall-like feature on the left bank of the river. Reappearing on the north side of the above fault near Mill of Bervie, the Crawton basalts form the lower of the two prominent rock features of Bervie Brow. As they are followed northwards it is found that, just west of Grange and again a short distance east of Wardend, the continuity of their outcrop is interrupted by two faults, which have the effect of shifting it successively further to the east. Good exposures of the basalts are seen in the old quarries in Whistleberry Wood, and the group may be followed in a northerly direction for about a mile and a half until it is again traversed by a dislocation—the Braidon Bay fault—which shifts the outcrop out to sea on the downthrow side. The direction of strike, however, again changes as the beds begin to

* *Mem. Geol. Survey*, "The Neighbourhood of Edinburgh," p. 32, 1910.

swing round the synclinal fold, and the characteristic Crawton basalts reappear on the coast section at the village of Crawton, where they attain their maximum thickness. From Crawton their outcrop may be followed in a north-north-westerly direction parallel to the coast to Gallowton, when, interrupted by a fault, it bends abruptly round to the east, and the group comes back to the coast at Thornyhive Bay. On the northern limb of the syncline the Crawton basalts appear in the Glaslaw Burn, and may be traced towards the south-south-west in bare rocky knolls in the fields almost as far as Upper Criggie.

On the shore section near the village of Crawton it can be seen that the Crawton type of basalt occurs in three successive flows, each with a slaggy upper and under surface, and a massive, columnar central portion. The parallel arrangement of the tabular feldspars imparts to the rock a marked platy structure. The lowest flow shows a somewhat unusual type of weathering. On a gently sloping rock platform, which has been carved out in the massive portion of the flow between low- and high-water marks, the sea has worked out a regular series of pot-holes, each of which coincides in position with the centre of one of the hexagonal basalt columns. Apparently some agency acting along the joints has hardened the margins of the columns, while the centres have been left an easy prey to the eroding action of the sea. In many places the vesicular surfaces of the Crawton lavas show the characteristic sandstone-veinings. But perhaps the most striking feature of the group is the evidence which it everywhere gives of contemporaneous erosion. This is particularly well seen at the top of the highest flow at Crawton. The overlying conglomerates are seen to rest on an irregular eroded surface of the lava (Plate I. fig. 4). Sometimes the slaggy top of the latter has been entirely removed, and the pockets of conglomerate rest directly on the massive central portion. The eroded hollows coincide in position with prominent joint fissures, which are seen to narrow as they are traced downwards, and to be occupied by successively finer and finer pebbly sandstones, until they end off in minute cracks filled with very fine silt. Obviously the lavas had cooled and consolidated before the advent of the currents which carried out the work of erosion. Although the overlying conglomerates contain occasional large slaggy boulders of the Crawton basalt, still the proportion of such boulders is remarkably small, and certainly does not suggest that the conglomerates have been derived by wave action from an old shore cliff of Crawton lava. To this point we shall return later. Meanwhile, it may be noted that the restriction of the Crawton basalts to one definite horizon, coupled with their occurrence as boulders in the overlying conglomerates, has been of great service in mapping the latter.

Associated with the basalts of the Crawton type are other basalts which will be described in detail in another paper. The most widespread is a type, sparingly porphyritic with olivine and augite, which overlies the normal group from Crowhillock, Kinneff, to Gallowton. Occasionally, too, there are small intercalations of coarsely crystalline non-porphyritic basalts—for example, at Bervie Brow and Whistleberry; and in the Glaslaw Burn section the highest flow is a basalt with porphyritic plagioclase,

olivine, and augite. These associated lavas also exhibit evidence of having undergone contemporaneous erosion.

Between the porphyritic basalts and the base of the Crawton group there intervenes a series of volcanic conglomerates, tuffs, and "Highland" conglomerates,* with one small intercalation of basic andesites or basalts near Whistleberry Castle.

The tuffs and volcanic conglomerates attain their maximum development between Bervie Bay and Whistleberry. In that tract, indeed, the "Highland" conglomerates play quite a minor part. The tuffs are built up essentially of angular and subangular fragments of hornblende and biotite andesites and felsites, the andesites always predominating. Locally they contain in abundance angular pieces of a green rock which resembles the spilitic lavas of the Upper Cambrian series. They are frequently calcareous, and weather with characteristic honeycombed and furrowed surfaces. Like the tuffs, the volcanic conglomerates consist mainly of the debris of hornblende and biotite andesites. A noteworthy feature is the large size of the well-rounded boulders of hornblende andesite—a section across one in a conglomerate near Shieldhill measured 9 feet $\times$ 10 feet. The relative proportion of boulders and matrix is variable, but the latter, which has much the same composition as the associated tuffs, is always more abundant than in the "Highland" conglomerates. The latter are characterised as usual by the almost bewildering variation in their composition as any one particular bed is traced from point to point. As a rule they contain a fair proportion of volcanic rocks belonging to Old Red Sandstone types. But the feature which, despite the extraordinary variety of the constituents, always arrests attention, and which serves to distinguish the "Highland" conglomerates of this group from all the others, is the abundance of boulders derived from the Upper Cambrian series. The green spilitic lavas are often so numerous as to impart a general greenish hue to whole belts of the conglomerate. The occurrence of "Haggis rock" boulders is also noteworthy. At many points, and particularly in the vicinity of Shieldhill, excellent examples of contemporaneous erosion can be seen where these conglomerates rest on an uneven surface of tuffs and volcanic conglomerates.

To the north and south of the Bervie-Whistleberry tract there is a marked change in the character of the sediments between the Crawton basalts and the base of the group. The tuffs and volcanic conglomerates play a smaller and smaller part in the succession as they are traced in either direction from the above centre, and their place is taken by conglomerates in which "Highland" rocks predominate and by brown tuffaceous sandstones. The lowest conglomerates in the neighbourhood of Todhead Point contain a big proportion of basic lavas, derived perhaps from the contemporaneous erosion of the underlying Tremuda Bay series of basalts. At a higher horizon, and separated from the above by a bed of acid tuff, a somewhat remarkable conglomerate

* Throughout this paper the term "Highland conglomerate" is used to designate a conglomerate in which the majority of the boulders belong to rock types occurring in the Highland area. Similarly, quartzite conglomerate and volcanic conglomerate denote conglomerates whose predominating pebbles are respectively quartzites and volcanic rocks.

forms the cliffs below Hallhill. It contains large scattered boulders in a tuffaceous matrix. One rounded boulder of acid andesite measures in section 14 feet $\times$ 9 feet; quite near it is another of green schistose grit measuring 7 feet $\times$ 5 feet $\times$ 3 feet. Two points are noteworthy—the exceptionally large amount of matrix, and the occurrence together of unusually big boulders of “Highland” rocks and acid andesites. Detailed descriptions of this and other conglomerates must be reserved for another paper. The following general results, however, have been arrived at from a preliminary study of the conglomerates of this group:—(1) the predominance of volcanic conglomerates in the Bervie-Whistleberry tract, with a gradual transition northwards and southwards to non-volcanic conglomerates; (2) the abundance in all the “Highland” conglomerates of boulders derived from the “green rocks” and jaspers of Upper Cambrian age; (3) the maximum development of “newer granites” in the neighbourhood of Bervie Bay.

The lava flow near Whistleberry Castle is of particular interest, since it shows, better perhaps than can be seen elsewhere in Kincardineshire, very characteristic “sandstone veining.” Through practically its whole thickness it is traversed by sandstone veins and by large irregular patches of finely bedded sediments (see Pl. I. fig. 5). It recalls the examples from the Turnberry shore described by Sir ARCHIBALD GEIKIE.*

In the sediments underlying the Crawton lavas there is also a noteworthy development of minor intrusions in the form of decomposed lamprophyres, which occur sometimes in thin sills, sometimes in narrow dykes, too small to be shown on the $\frac{1}{2}$ -inch map. They are restricted to this horizon.

(b) *The Burn of Guinea Andesites and Associated Rocks.*—We have seen above that the Crawton basalts may be traced along the northern limb of the syncline as far as Upper Criggie. Further to the west is found another volcanic group occupying approximately the same horizon, but showing an altogether different assemblage of lavas. Basalts are represented by two, or at most three, small flows, and these markedly different from the Crawton type. The predominating types are acid andesites.

Appearing first near Temple of Fiddes—about a mile west of Upper Criggie—this volcanic zone may be followed a short distance beyond Collieston. Then for about two miles the solid geology is completely obscured by a great thickness of drift. Just west of Drumlithie similar lavas again begin to make their appearance, and, continuing with an east-and-west strike, they cross the Bervie Water beyond Hawkhill. Again for a short distance they are concealed under a thick deposit of boulder clay, but, swinging round the Elfhill anticline, they return to the Bervie Water at the Horse Pot. Then for about a mile they are hidden under drift. They reappear, however, on the northern limb of the anticline, in the Burn of Guinea, and again circling round a synclinal fold which succeeds the anticline, they are finally lost against the Highland fault. North of the fault, however, in the extreme west of the area, a series of lavas, exposed in the Kirkton Burn and other stream sections, and mapped as intrusive porphyrites on the

* *Ancient Volcanoes of Great Britain*, vol. i. p. 333.

Geological Survey map, belong to types which are identical with the Burn of Guinea hornblende andesites. It is extremely likely that these belong also to this horizon.

At the bottom of this volcanic zone occurs a group of dacites extending from East Kinmonth to the Water of Bervie, and forming for a considerable distance the northern bank of a remarkable dry valley. I was unable to find any exposure showing the nature of their contact with the adjacent strata, and I had doubts as to whether they might not be intrusive. But since they show everywhere very fine fluxion structure, and since dacite boulders almost identical in character make their appearance in the overlying conglomerates, they are in all probability lavas.

The lavas coloured on the map as hornblende and augite andesites include normal hornblende-biotite andesites with phenocrysts of plagioclase, hornblende, and biotite, and compact non-porphyrific types which are somewhat more basic in character, but which, on microscopic examination, are seen to contain occasional patches of magnetite, which may represent resorbed hornblende and biotite.

The basalts which are found intercalated with the above series between the Bervie Water and Drumlithie include a doleritic type, and a black compact hypocrySTALLINE type with porphyritic olivine.

The widespread occurrence of boulders of the hornblende-biotite andesites in the overlying conglomerate shows that this volcanic group underwent extensive contemporaneous denudation, and a very fine example of an eroded lava surface with the overlying conglomerate is seen in a small quarry at Harlingtongue.

Owing to the paucity of exposures, but little can be made out regarding the sediments associated with the above lavas. On the Bervie Water at Burn of Guinea farm there is a fine section of a coarse "Highland" conglomerate with boulders of quartzite, granite, granophyre, quartz porphyry, and schists. Conglomerates of the same type occur in the Pilketty Burn and in Kinmonth Den. At Whitehill Quarry, near Bogincabers, the lavas overlie a tuffaceous sandstone.

C. *The Arbuthnott Group.*

In the Arbuthnott group, as in the last, we find a markedly different assemblage of rocks on the two sides of the Strathmore syncline. In the south-eastern part of the area it includes the thickest and most widespread of the lava belts; in the north and west its chief member is a remarkable volcanic conglomerate.

(a) *The Hypersthene Andesite and Hypersthene Basalt Series, with their Associated Sediments.*—As will be seen from the accompanying map, the hypersthene andesites and hypersthene basalts, with occasional intercalations of sandstone and conglomerate, may be followed continuously along the southern limb of the syncline from the North Esk to Bruxie Hill, where they swing round and continue along the steeply inclined northern limb as far as the Stonehaven-Laurencekirk road. Then, like the hornblende andesites of the Crawton group, they are lost sight of for nearly two miles, concealed

doubtless under the thick mantle of drift which here completely obscures the solid geology. Reappearing again at the Knock Hill, they may be followed as occasional flows intercalated in the volcanic conglomerates along the slopes of the Haerscha Hill to Paldy Fair Den. Then, circling round the Elfhill anticline, they cross the Bervie Water between Dillavaired Ford and Tippetty. Between that stream and the Highland fault they are again concealed under the drift. This group of lavas undoubtedly thickens towards the south and east.

If we exclude a few intercalated flows of doleritic basalt which occur chiefly at or near the base of the series, the lavas of the Arbuthnott group form an assemblage of types altogether different from those found in any other part of the Lower Old Red succession in Kincardineshire. Detailed descriptions of these will be given in another paper, but meanwhile it may be noted that they are mainly hypersthene-bearing andesites and basalts. At one extreme we find normal hypersthene andesites without olivine; at the other, hypersthene basalts containing much olivine and very little hypersthene. Numerous transition types are characterised by varying proportions of the above two constituents.

Like the similar types in the Ochils and Cheviots, these hypersthene-bearing basic lavas are remarkably rich in chalcedony, fine red veinlets of which are usually to be found ramifying through the rock in every direction, while the vesicular portions of the flows yield beautiful examples of agates in great variety and abundance. It is on this horizon, at Usan on the Forfarshire side of the Montrose anticline, that the vesicular lavas occur which yielded many of the finest specimens in the Heddle collection.

That the lavas of this group underwent contemporaneous erosion, although not on the same extensive scale as those of the Crawton and Dunnottar groups, is seen at more than one locality, but particularly well in a stream section about 200 yards below the bridge near Biddrie. There between two of the flows occurs a bed of volcanic conglomerate containing numerous boulders derived from the slaggy portions of the underlying lava. The general assemblage of the pebbles in this conglomerate, together with a typical intercalation of tuffs, recalls, however, the conglomerates of the Clattering Bridge section, which are believed to represent the Arbuthnott group on the north side of the Howe of the Mearns.

"Sandstone-veinings" are of frequent occurrence in the slaggy upper portions of the lavas, the material of the veins consisting usually of hardened, red or green, fine-grained micaceous sediment. The green veins in one of the flows near St Cyrus show curiously contorted bedding, and they exhibit also vesicular structure. The vesicles are filled with agate material similar to that found in the adjacent lava.

In Paldy Fair Den I have mapped a flow which possesses somewhat unusual characters. It is, or at least it had been originally, a very vesicular vitrophyric type, with abundant phenocrysts of plagioclase and scattered phenocrysts of hypersthene and augite. But its most striking feature is the abundance of xenoliths of rounded boulders, mainly of hornblende andesites; in places the xenoliths are so numerous that

the rock might be mistaken for a volcanic conglomerate. The enclosed blocks are similar to the boulders in the underlying conglomerate. Probably the xenoliths were collected by the lava as it flowed over an unconsolidated gravel.

At the base of the group everywhere along the southern limb of the syncline we find a very coarse "Highland" conglomerate whose chief constituents are well-rounded quartzites. Locally it contains boulders of the underlying basalts. Comparing it with the "Highland" conglomerates of the Crawton group, we notice at once a marked decrease in the proportion of boulders derived from the Jasper and Green-rock series. This zone of coarse conglomerate is succeeded by a belt made up of finer conglomerates, associated with sandstones and flaggy beds; sometimes the sandstones, sometimes the fine conglomerates predominate. This belt may be traced along the strike by a line of quarries mostly now disused. Three Wells quarry, near Bervie, is still worked, and there I was fortunate enough to find a good specimen of *Cephalaspis Lyelli*. As the base of the lavas is approached we begin to find, particularly in the north-eastern part of the area, intercalations of the volcanic conglomerates and tuffs which occupy almost the whole thickness of this group along the northern limb of the syncline.

(b) *The Volcanic Conglomerates and Tuffs.*—The volcanic conglomerates and tuffs, which occur at intervals interbedded with the ordinary conglomerates and sandstones along the southern limb of the syncline, attain a considerable thickness in the vicinity of Law of Lumgair. It should be noted, however, that the width of the outcrop there is in great part accounted for by the low angle of dip. From Mid Fiddes westwards they form almost the whole thickness of the Arbuthnott group, taking the place which is occupied by the hypersthene andesites and basalts and the ordinary sediments in the south-eastern part of the area. Their base rests on the hornblende andesite of Harlingtongue, and their upper limit is found a short distance above the top of the Knock Hill lavas. Westwards from the Knock Hill the top of the series may be traced in an east-and-west direction as far as Glensaugh, while the basal members swing round the Elfhill anticline, and, as we have seen, along with the accompanying andesite cross the Bervie Water near the Horse Pot, Dillavaired. In the drift-covered country to the east of the Bervie the only satisfactory exposures of these beds are found in a stream section a short distance west of the Bridge of Bogincabers. Near the ford of Dillavaired the beds strike north and south and dip towards the west at an angle of 30°. In the neighbourhood of Drumtochty Castle the direction of strike is almost east and west, and, consequently, at Glensaugh the series is almost entirely cut out by the Highland fault. The direction of strike changes again to south-west and north-east, and a very fine section of the volcanic conglomerates and their associated tuffs is seen in the Ferdun burn at the Clattering Bridge. There, although the base of the series is not seen, it attains a thickness of about 2000 feet. From the Clattering Bridge westwards these rocks may be hammered in almost every stream section, until, the direction of strike changing gradually to west-south-west and east-north-east, they are eventually lost against the Highland fault about half a mile from the river North Esk.

Representative collections of boulders from these conglomerates at various horizons show that the boulders consist almost entirely of acid andesites and rhyolites. A big percentage of the former belongs to types found in the acid andesite zone of the Crawton group. None of the basic andesites or basalts are represented in the collections made from these conglomerates along the Highland Border. Sometimes the volcanic conglomerates are built up entirely of the debris of volcanic rocks, but more frequently they contain a small percentage of boulders derived from the Highland schist series—a point which is of interest in showing that the material was being derived from the area to the north of the Highland fault. Locally, too, there occur thin conglomerates of the “Highland” type, but such form an insignificant part of the succession. The volcanic conglomerates are associated invariably with interbedded “tuffs.” While some of the latter may have been derived from an already consolidated series of lavas by the ordinary agents of denudation, numerous occurrences have been noted in which the sharply angular nature of the constituent fragments clearly shows that they are true pyroclastic tuffs. These tuffs are rhyolitic rather than andesitic, and in this way differ from the tuffs associated with the Crawton group. Excellent examples occur in the Bervie Water near the ford of Dillavaire, and in the Shag Burn opposite Honeybank. The tuffs are not separated from the volcanic conglomerates on the accompanying map, but they make up no inconsiderable part of the whole series.

Indeterminable plant fragments, found in a thin intercalation of grey micaceous shales near the ford of Dillavaire, are the only fossils which have been noted in this part of the Arbuthnott group.

D. *The Garvock Group.*

This group consists for the most part of coarse “Highland” conglomerates, with intercalated grits, sandstones, flagstones, shales, and limestone. It includes also the highest of the lava zones.

The main belt of lavas extends from the North Esk near Marykirk to Cairn of Shiels. A minor group at a somewhat lower horizon occurs on either side of the Bervie Water near Whitefield, and a small development of lavas is found also to the north of Canterland Den, almost at the base of the Garvock series. The lavas are all basalts, occasionally with phenocrysts of olivine, but more usually coarsely crystalline, non-porphyrific doleritic types. The slaggy surfaces show the usual “sandstone-veining,” but the material of the veins in the highest flow at Balmakelly is a sandy limestone. The basalts give no evidence of having undergone contemporaneous erosion. This lava series does not appear in the northern limb of the Strathmore syncline, and, like the hypersthene-bearing series in the Arbuthnott group, thickens towards the south and east.

In the coarse quartzite conglomerates of the group the boulders which occur in greatest numbers are flaggy gneisses. Quartzites and vein quartz also play an

important part. Jasper and "green rocks" are much less numerous than in the lower conglomerates, although locally, on the Garvock side of the syncline, they are fairly abundant. The presence of many boulders of rhyolites and acid andesites shows that the acid volcanic rocks had not yet been entirely removed from the Highland area. It may be noted in this connection that the finer sediments of this group often contain a remarkable amount of felsitic debris. The chief characteristic of the conglomerates, however, is undoubtedly the great abundance of boulders of flaggy gneisses. The flat boulders of the gneisses frequently show beautifully an imbricated arrangement similar to that found in torrential flood gravels. This is seen particularly well in the conglomerates of Sarah's Den on Strathfinella Hill, where it is very evident that the boulders have been transported from the north or north-west.

Of the many intercalations of finer sediments two persistent belts call for special description. The first occurs between the Strathfinella conglomerates and the top of the volcanic conglomerates of the Arbuthnott group, and is separated from the latter by lenticels of "Highland" conglomerate. It consists of reddish micaceous sandstone—often pebbly, and in places containing so much felsitic debris that it assumes a pink tint—interbedded with red, grey, and chocolate-coloured flagstones which are usually crowded with clay galls. Beautiful ripple-marked surfaces are often conspicuous, and fine examples of sun-cracks are not uncommon. The only evidence of organic life is the presence of worm burrows and castings.

The other belt also occurs near the base of the group, but on the south side of the syncline, and comes on almost immediately above the highest lavas of the Arbuthnott group. It consists of purplish sandstones, with which are intercalated grey and chocolate-coloured sandstones with grey and olive-tinted sandy shales. The best section in this series is at the Den of Morphie (Canterland Den), about two miles east of Marykirk. The shales contain plant remains in great abundance, but the only form determined so far is *Parka decipiens*, which seems to have been the first fossil recorded from this locality. The occurrence of *Kampecaris forfarensis* has been noted by several collectors, probably first by DAVID PAGE, who figured it in the first edition of his *Advanced Text-Book*. This interesting fossil was considered by PAGE to be an anomalous form of isopod crustacean; C. W. PEACH first recognised that it was a myriapod; and a detailed description, based on specimens from Kincardineshire and Forfarshire, was subsequently published by Dr B. N. PEACH.* Dr PEACH gives an excellent drawing of one of PAGE's specimens from Canterland Den. Our knowledge of the fossils of Canterland, however, we owe chiefly to the work of that enthusiastic local collector, the late Rev. HUGH MITCHELL of Craig. In addition to *Parka decipiens*† and *Kampecaris forfarensis*,† MITCHELL discovered *Pterygotus*† sp., *Cephalaspis Lyelli*,† *Parexus incurvus*,† *Climatius scutiger*,‡ and *Thelodus Pagei*. The last is the *Cephalopterus Pagei*§ of POWRIE. It was redescribed and renamed first as *Turinia*

* *Trans. Roy. Phys. Soc. Edin.*, vol. vii. p. 1, 1882.

† *Quart. Jour. Geol. Soc.*, vol. xvii. p. 145, 1861.

‡ *Geol. Survey Mem.: Organic Remains*, dec. x. p. 68, 1861.

§ *Trans. Edin. Geol. Soc.*, vol. i. p. 298, 1870.

and afterwards as *Thelodus* by Dr TRAQUAIR,* who has figured several scales of the Canterland specimen. The Geological Survey collection includes a specimen of *Ischnacanthus gracilis* from this locality. Among material collected in recent years by Dr W. T. GORDON and myself, there are fragments of *Pterygotus anglicus*, and plant remains, among which may be noted the occurrence of casts of large ribbed stems up to two inches in diameter.

A sandy limestone occurring near the top of the Garvock group appears to be the only limestone in the whole of the Lower Old Red Sandstone succession in Kincardineshire. Although at present exposures of the bed are few in number, it seems formerly to have been worked extensively, as, for example, at Balmakewan, at Burn of Balmakelly, and in the south-western portion of the parish of Garvock. Further north it is found at the Bervie Water, near Pitskelly, where it is represented by a calcareous sandstone, with nodules containing fragmentary plant remains. There can be little doubt that this calcareous belt is continuous along the southern limb of the Strathmore syncline. It occupies approximately the same horizon as, and is in all probability a continuation of, the limestone mapped by the Geological Survey in Forfarshire.

The sandstones of this group as a rule contain numerous clay galls, possibly the result of the erosion of beds of the so-called marls. Such an explanation is suggested by a section in the North Esk, south of Balmakewan House, in which may be seen an actual instance of contemporaneous erosion of marls interbedded with the sandstones.

E. *The Strathmore Group.*

Here are included the highest beds of the Strathmore syncline. They consist in great part of the bright red "marls" which give such a characteristic colour to the boulder clay and the overlying soils of the Howe of the Mearns. The best sections in the group are found in the North Esk between the mouth of the Luther Water and the Gannochy Tower, a short distance north of Edzell. Over most of the great central plain between the Bervie Water and the North Esk the rocks of this group consist almost exclusively of bright red poikilitic "marls." Towards the west and north, however, their place is taken by coarser sediments—flagstones and massive false-bedded sandstones, with occasional lenticels of conglomerate. No fossils have been recorded from these rocks, and this group is the only one in which there is no trace of contemporaneous volcanic activity.

IX. PALÆONTOLOGY OF THE LOWER OLD RED SANDSTONE.

The occurrences of fossils cited above and their localities may be summarised as follows:—

A. *Dunnottar Group.*

Strathlethan Bay.—*Parka* sp.

* *Trans. Roy. Soc. Edin.*, vol. xxxix. p. 595, 1899.

B. *Crawton Group*.

No fossils recorded.

C. *Arbuthnott Group*.

1. Three Wells, near Bervie.—*Cephalaspis Lyelli*.
2. Ford of Dillavaird.—Plant fragments.

D. *Garvock Group*.

1. Canterland Den (Den of Morphie).—*Parka decipiens* and abundance of other plant remains, *Kampecaris forfarensis*, *Pterygotus anglicus*, *Cephalaspis Lyelli*, *Parexus incurvus*, *Climatius scutiger*, *Ischnacanthus gracilis*, and *Thelodus Pagei*.
2. Drumtochty Glen.—Worm burrows and castings.
3. Bervie Water, near Pitskelly.—Plant fragments.

E. *Strathmore Group*.

No fossils recorded.

The above list, it will be seen, does not offer evidence which can be of any great value for purposes of zoning or correlation. *Parka* occurs near the top of the volcanic series and again almost at the base of the Lower Old Red Sandstone, and thus possesses the same extended range as in Forfarshire and Perthshire. The Three Wells and Canterland Den horizon may be correlated with that part of the Forfarshire Old Red which includes the well-known fossil localities of Turin Hill, Farnell, Newtyle, Carmyllie, Leysmill, and Ferryden. According to the distribution of the lava zones on the published maps it seems probable that the Three Wells quarries are on the Ferryden horizon, while the Canterland Den beds are the equivalents of those at Farnell. The rocks of Turin Hill appear to occupy a somewhat higher horizon, but all the fossils found at Canterland Den have also been recorded from the former locality.

X. VOLCANIC ACTIVITY IN KINCARDINESHIRE DURING THE LOWER OLD RED SANDSTONE PERIOD.

Volcanic activity, which had already begun, as we have seen, in Downtonian times, continued to be a characteristic feature in the physical history of the area until far on in the Lower Old Red Sandstone period. Evidence of prolonged, if intermittent, volcanic activity is found in the great development of lavas, tuffs, and volcanic conglomerates, which together form no inconsiderable part of the succession. The lavas include dacites, hornblende-biotite andesites, augite andesites, hypersthene andesites, hypersthene basalts, and olivine basalts, the basic types predominating. The volcanic conglomerates with their associated tuffs consist almost entirely of the debris of already consolidated hornblende and biotite andesites and rhyolites. No trace of volcanic vents has been found. The distribution of the volcanic rocks,

however, suggests that the centres of eruption were situated along two lines, one of which lay north of the Highland fault, while the other is concealed under the North Sea. The former we shall call the "Highland group of volcanoes": the latter includes at least two eruptive foci—one in the vicinity of Montrose, the other off the coast at Crawton—and these we shall designate the "Montrose centre" and the "Crawton centre" respectively.

(a) *The Highland Group of Volcanoes.*—The lavas which emanated from these volcanoes include the dacites and andesites which extend from Temple of Fiddes to the Highland fault near Bogincabers. Two or three basic flows associated with them perhaps belong rather to the Crawton basalt group; but since in the district where the two groups approach one another the nature of the solid geology is obscured by the great development of drift, it is difficult to obtain satisfactory field evidence. The fact that boulders of the basic lavas are absent from the associated conglomerates rather favours the supposition that the basalts came from the east or south-east. The acid andesites never appear in the coast section, and they attain their maximum development in close proximity to the Highland fault. It is not from the lavas, however, that we get the most convincing evidence as to the nature of the eruptions from this Highland centre or centres. One of the most remarkable features in the succession, from the base of the Downtonian to the top of the Arbuthnott group, is the great part played by acid tuffs and volcanic conglomerates. Wherever continuous belts of these can be traced inland they are found to thicken in the direction of the Highland fault. The constant association of their predominating rhyolite and acid andesite boulders with boulders of "Highland" rocks indicates that the material has come from the north or north-west. The extraordinary thickness of the successive volcanic conglomerates implies the removal of a vast accumulation of acid lavas from the Highland area. Throughout the whole of the Downtonian and a considerable part of Lower Old Red Sandstone times there must have flourished, along the tract now occupied by granites and schists, a series of volcanoes whose chief products were rhyolite and acid andesite lavas and rhyolitic and andesitic tuffs. No vents, so far as I know, have been detected in that region; but some of the intrusive masses of quartz porphyry may possibly represent the position of centres of eruption. It is tolerably certain that there is a genetic connection between the quartz porphyries and some of the newer granites of the Eastern Grampians and the igneous rocks of Downtonian and Lower Old Red Sandstone age of south-eastern Kincardineshire.

(b) *The Crawton Centre.*—The lavas erupted from this centre include the doleritic basalts of Tremuda Bay and the porphyritic basalts of the Crawton type. These lava groups thin off to north, south, and west from Tremuda Bay and Crawton, so that the volcanoes from which they came must have been somewhere to the east of the present coast line. I can find no evidence of tuffs belonging to this series. The acid tuffs and volcanic conglomerates, which underlie the Crawton basalts at Kinneff, have come from a centre somewhere to the north-west, and probably belong to the Highland group of

volcanoes. The lavas from the Crawton centre have undergone a considerable amount of contemporaneous erosion, but the boulders thus derived form quite an insignificant proportion in the composition of the interbedded "Highland" conglomerates—they never give rise to volcanic conglomerates such as have been produced from the prolonged denudation of the acid lavas of the Highland group.

(c) *The Montrose Centre*.^{*}—From this centre came the thick accumulation of hypersthene andesites, hypersthene basalts and olivine basalts which constitute the lava contents of the Arbuthnott and Garvock groups. Tuffs again are absent. The reddened character of the upper surfaces of the flows suggested that considerable intervals of time may have elapsed between the outpouring of successive lavas. There is not, however, so much evidence of contemporaneous erosion as in the rocks belonging to the other two centres. "Sandstone-veining" is everywhere a conspicuous feature, and finely bedded shales and mudstones are sometimes intercalated in the lava series of the Arbuthnott group. From such shales in the trap rocks of this series at Ferryden the Rev. HUGH MITCHELL made a collection of impressions which recall the "Upland Fauna of the Old Red Sandstone Formation of Carrick" described by JOHN SMITH. The specimens, now in the Montrose Museum, show trails and footprints of several kinds, burrows, and rain prints. The hypersthene-bearing lavas are remarkable for their fine development of agates; the vesicles of the basalts of the Garvock group contain good specimens of calcite, desmine, and analcite.

The lavas belonging to this centre are present in great force where they appear in the southern limb of the Montrose anticline, but they gradually thin out, and the intercalations of sandstone and conglomerate become thicker as they are traced to the south-west. They thin out in similar fashion in Kincardineshire as they are followed to the north-east; and since no signs of volcanic vents are found in the inland sections, one can only conjecture that the centre or centres of eruption must be concealed to the eastward on the floor of the North Sea.

XI. HYPABYSSAL INTRUSIONS OF LOWER OLD RED SANDSTONE AGE.

The hypabyssal intrusions include dykes of quartz porphyry and biotite porphyry, and thin sills and dykes of lamprophyre and dolerite. Quartz porphyry dykes are found at Cowie, at Clochnahill, at Allardice Castle, and on the shore near Hallgreen Castle; the peculiar Lintrathen type occurs in the North Esk and Clattering Bridge sections. A group of dykes, appearing at intervals along a line extending from the Carron Water near Mill of Forest by the Hill of Seabeg and Fawside, Kinneff, to the coast at the Pintill Stone, may be classed as biotite porphyries. An intrusion of olivine dolerite, which behaves sometimes as a sill, sometimes as a dyke, has been traced from Cadden Castle to Shieldhill, and, shifted by the Whistleberry fault, again appears in the neighbourhood of Crowhillock. It has produced marked contact alteration in the tuffs

^{*} See also *Ancient Volcanoes of Great Britain*, vol. i. p. 299.

of the Crawton group. A very poor exposure of a dolerite accompanied by similar types of metamorphosed tuffs is seen at Mudlin's Den, near Hallgreen, at approximately the same stratigraphical horizon. Numerous thin sills and narrow dykes intruded into the same volcanic conglomerate and tuff zone between Bervie and Todhead are lamprophyric in character. Their occurrence is restricted to this horizon. They are all much decomposed, and resemble the lamprophyre dykes belonging to the volcanic series of the Pentland Hills.

The above minor intrusions belong to a comparatively late phase in the volcanic history of the area. Most of them are intruded into, and are therefore younger than, the lower portion of the Crawton group; others cut the older part of the Arbuthnott group. There is no evidence to show that any are younger than the hypersthene andesite and basalt series.

Comparing the Kincardineshire Old Red Sandstone with a typical Scottish Carboniferous succession, one is struck at once with the almost entire absence of intrusive sills. A few thin sills occur, but none at all comparable with the massive intrusions of Carboniferous age. In marked contrast again with the volcanic members of the Lower Old Red Sandstone of other areas,—such as the Cheviot group, or the Lorne plateau—is the relatively poor development of the dyke phase. The paucity of sills and dykes may reasonably be correlated with the absence of vents. It is worthy of note, too, that dykes of presumably Old Red Sandstone age show a marked increase in number in the belt of schists which intervenes between the Highland fault and the newer granites; and further, that the development of minor intrusions in the Old Red Sandstone area reaches a maximum at the coast line between Johnshaven and Braidon Bay. Such a distribution of the hypabyssal intrusions strengthens the suggestion that the volcanic centres were situated along two lines—one in the area now occupied by the Dalradian schists, the other to the east of the present coast line.

XII. PHYSICAL CONDITIONS DURING THE LOWER OLD RED SANDSTONE PERIOD.

The Lower Old Red Sandstone of the Midland Valley of Scotland is characterised everywhere by the development of coarse conglomerates. A study of the succession in south-eastern Kincardineshire brings out very clearly two points: (1) the total thickness of coarse conglomerates is far greater than that of the finer sediments; (2) the coarseness of the average conglomerate is remarkable even for a Scottish Old Red Sandstone district. At many horizons the boulders average about two feet; and frequently the magnificently rounded boulders of quartzites, granites, schistose grits, and other "Highland" rocks measure from three to seven feet along their longest diameter. It is difficult, indeed, to realise that the rounding and transportation of these boulders has been accomplished by the agency of moving water, either by waves or by mountain torrents. Not only are the blocks well rounded, but the hard, fine-grained, homogeneous types show remarkable curved fractures, "chatter markings," which indicate in no

uncertain fashion the treatment to which they were subjected before they were finally buried in the wonderful gravels of Old Red Sandstone times. The conglomerates, whether we regard them as old beaches or as stream gravels, and the finer sediments with their prevalent ripple marks and sun-cracks, can only represent shallow water conditions; the association of remains of myriapods and plant debris in the latter undoubtedly indicates deposition in close proximity to a land area. The formation offers no evidence either of marine or of deep-water conditions of sedimentation.

The composition of the conglomerates shows clearly that, throughout the whole of Lower Old Red Sandstone times, the Highland area was undergoing extensive denudation. The extraordinary abundance of jaspers, cherts, and "green rocks" as pebbles in the lower conglomerates necessitates a former wide extension of the Upper Cambrian rocks—they may, indeed, have extended far over the Eastern Highlands. The frequent occurrence of boulders of the "Haggis rock" type of greywacké, again, may mean that Ordovician strata (now probably represented by the narrow belts which Mr BARROW has designated the Margie series) were present in considerable force on the north side of the Midland Valley. In the conglomerates below the Crawton lava zone there is an alternating predominance of pebbles of Upper Cambrian rocks and of acid andesites, and this suggests that at successive periods the supply of Jasper and Green-rock material was temporarily cut off by the discharge of acid lavas from the Highland group of volcanoes. The distribution of granite boulders, too, is of supreme interest; and, while I cannot at present give a detailed account of this, the occurrence of pebbles of granites belonging to the so-called "newer granite" types of the Highlands in the lowest conglomerates is sufficient to show that some at least of these are of pre-Old Red Sandstone age. Such granites may represent the plutonic equivalents of the oldest "Caledonian" volcanics, which, as I have shown, are certainly not younger than the Downtonian, and may perhaps be older. The most striking characteristic of the youngest conglomerates is the marked predominance of pebbles of flaggy gneisses, and along with this may be noted the gradual decrease in the proportions of those of jaspers and cherts and acid volcanic rocks as the former increase in number. Hence, towards the end of the period the "Highland Border" rocks and the Upper Silurian-Old Red volcanic series had either been protected by the overlap of the highest beds to the north and west, or had already been to a large extent removed by denudation.

Conclusions such as the above are suggested by the general observations recorded in the present paper. It is hoped that further detailed investigation of the distribution of the boulders in the conglomerates will throw important light on the history of the Eastern Highlands in early palæozoic times.

Nowhere in Kincardineshire does the distribution and character of the volcanic conglomerates suggest the destruction of volcanic islands and the consequent formation of coarse beaches. The constant association of "Highland" boulders with those of volcanic origin, and the thickening of the volcanic conglomerates when traced towards the Highland fault, point conclusively to the Highland area as the source of the

material. It seems to me that all the conglomerates are old torrential gravels rather than beaches, and for two reasons. (1) The composition of the conglomerates is suggestive. In the magnificent section at Crawton, for example, the rocky foreshore coincides in position with the eroded surface of the Crawton basalt, with many of the hollows still filled with conglomerate. This uneven junction may be traced round an isolated stack which extends seawards for about twenty yards, and may be followed again in the cliff section to the north. If the overlying conglomerate were an old beach, one would expect it to contain a big proportion of boulders of the lava, whereas only a very few can be seen, and that in an exposure, which, as indicated above, extends over a considerable area. Indeed, in all the conglomerates the admixture of rock types brought together from widely separated areas suggests powerful torrents as the chief eroding and transporting agents. (2) The numerous storm beaches on the Kincardineshire coast have received their constituent boulders in large part "ready made" from the disintegration of the local Old Red Sandstone conglomerates, and may, therefore, well be compared with the latter. Both show a characteristic imbricated arrangement of their boulders, and, since the general trend of the coast is parallel to the Highland Border, and therefore probably to the successive shore lines of the Old Red lake, we should expect the boulders of the conglomerates—if those represent beaches—to overlap in the same manner as the stones of the modern beach. Wherever the imbricated arrangement has been observed, however, in the conglomerates, it indicates that the boulders were placed in their present position relative to one another by currents coming from the north or north-west.

There can be no doubt, I think, that the accumulation of the boulders and their exquisite rounding must be ascribed mainly to the action of torrential rivers rather than to wave action along the shores of a lake. None of the beaches of the great fresh-water lakes of the present day are at all comparable with the coarse conglomerates; but the latter recall at once modern torrential flood gravels and the fluvio-glacial gravels of late Glacial times.

In short, the coarse conglomerates of our area represent the coarse torrential gravels swept outwards from a lofty "Highland" mountain range on to the margin of a wide frontal plane, across which extended a great shallow fresh-water lake or chain of lakes where were accumulated the finer gravels, sand, and silt now consolidated to form the finer conglomerates, sandstones, and shales. To the north and west along the flanks of the mountains, and to the east beyond the limit of the present land, stretched two lines of active volcanoes. The former supplied the acid lavas and tuffs, and, indirectly, the volcanic conglomerates; from the latter were extruded the basalts and basic andesites. The eastern volcanoes may have formed a chain of volcanic islands, but no evidence of that has been detected within the area with which we are concerned.

XIII. UPPER OLD RED SANDSTONE.

A narrow interrupted belt along the coast in the neighbourhood of St Cyrus is occupied by rocks which, in their lithological characters, are markedly different from the Lower Old Red Sandstone. No fossils have been recorded from these beds. In the Geological Survey map they are assigned to the Upper Old Red Sandstones, and recent work has fully confirmed this view. As Dr HICKLING* has pointed out, the lithological and stratigraphical evidence together show conclusively that the isolated patches at St Cyrus, Buddon Point, and Arbroath must be regarded as outliers of the extensive tracts of Upper Old Red Sandstone of the Carse of Gowrie and the north of Fife.

The St Cyrus outlier consists of two separated areas—one extending from Rock Hall fishing station to East Mathers, the other from Kirkside to the mouth of the North Esk. In each case, but particularly in the southern tract, the solid geology is to a very large extent obscured, partly by raised beaches and blown sand, partly by boulder clay.

The rocks of the Rock Hall and East Mathers area include cornstones, calcareous sandstones, bright red marls, and red false-bedded sandstones and grits—an association of sediments of frequent occurrence in the Scottish Upper Old Red Sandstone. The dip of the beds is always low, and the total thickness of strata exposed cannot be very great. At Arbroath, as has been shown by Dr HICKLING, the basement beds consist of about 200 feet of conglomerates and sandstones derived chiefly from the disintegration of sandstones and conglomerates of Lower Old Red Sandstone age; at Buddon Point there is a good development of the higher, cornstone, type of sedimentation. In the St Cyrus outlier the base of the series is nowhere visible, since the junction with the older rocks is everywhere a line of faulting and not a natural boundary as indicated in the published maps. On the road leading from the shore to Milton of Mathers there is exposed a group of bright red sandstones and grits, which in all probability underlie the cornstone horizon, and may represent part of the Arbroath series. The sandstones contain occasional rounded pebbles, and among these I noted a chatter-marked boulder of jasper, derived most likely from a conglomerate of the Lower Old Red Sandstone. The cornstone group includes typical cornstones, often with a marked development of chert, flesh-coloured sandstones with a matrix of crystalline calcite, sandstones with calcareous nodules, soft red marls, and red false-bedded sandstones. At Rock Hall the main exposure of cornstone is underlain by a bed of conglomerate made up of fragments of limestone, chert, and sandstone of types found locally in the Upper Old Red series, and obviously indicative of contemporaneous erosion. It is beyond the scope of this paper to give a detailed petrographic account of the curious variations in the sediments of the cornstone group, but such an investigation would undoubtedly throw valuable light on the conditions which prevailed in Upper Old Red Sandstone times.

* *Geol. Mag.*, dec. 5, vol. v. p. 403.

Between Kirkside and the North Esk the Upper Old Red Sandstone is almost entirely concealed under blown sand and raised beach deposits. The best exposures are found at Kirkside fishing station, where the rock consists of a massive false-bedded white sandstone dipping at low angles to the north-west. Neither the top nor the base of the sandstone is seen, but it is at least 30 feet thick. The direction of strike of the beds suggests that they occupy a position not far below the cornstone of Rock Hall, and they may perhaps be regarded as the equivalents of the thick sandstone which underlies the cornstone series at Buddon Point. Similar sandstones occur also in close proximity to the Lower Old Red Sandstone lava series in the small stream which flows past Pathhead.

From the North Esk to Kirkside the junction between the Upper and Lower Old Red Sandstone is clearly a fault, the line of which skirts the base of the conspicuous cliff feature of 25-feet-beach times. Its position is readily detected from the occurrence of patches of fault breccia, sometimes veined with barytes. A prolongation of the same fault again forms the boundary at Rock Hall, where it is well seen in the cliff section.

The northern margin of the outlier on the coast section near East Mathers is also a fault trending south-east, and bringing the cornstone horizon against the conglomerates and basalts of the older series. As it is traced along the old 25-feet-beach cliff, the fault changes in direction to east-and-west. The next inland exposure showing the character of the boundary is at the south end of the wood of Den Finella, and here again there is clear evidence of faulting, the red sandstone underlying the cornstone horizon being separated from the older lavas by a brecciated sandstone. Westward from Den Finella the solid geology is to a large extent obscured by drift deposits, but the distribution of the lavas and the occasional exposures of sandstone of Upper Old Red type indicate that the fault gradually changes in direction to south-west and north-east.

Between Mill of Woodston and West Mathers there are no exposures showing the junction of the older and younger rocks. The brecciated character of the basalts at the former locality, however, suggests the presence of an east-and-west cross fault between the two main faults described above. In short, the boundary between the Upper Old Red Sandstone of the St Cyrus outlier and the Lower Old Red Sandstone is everywhere a line of faulting.

XIV. INTRUSIONS OF [?] CARBONIFEROUS AGE.

In addition to the hypabyssal intrusions of presumably Lower Old Red Sandstone age described above, there occur in south-eastern Kincardineshire a number of quartz dolerite dykes and teschenite sills, whose affinities are rather with the rocks of the Scottish Carboniferous volcanic series.

(a) *Quartz Dolerite Dykes*.—As will be seen from the accompanying map (Pl. II.), there are numerous occurrences of quartz dolerite dykes having a general east-north-

easterly trend. The dyke described by Professor FORBES* belongs to this group. First seen in close proximity to the Highland fault in the Burn of Balnakettle, it appears again at Coventree quarry, at Phesdo quarry, in several of the gorges on the eastern slopes of the Strathfinella hills, in the Rectory quarry, Drumtochty, and finally in the Broomy Brae quarry, near Auchinblae—a distance in all of about eight miles. Another example, which may be traced for about the same distance, is seen in the North Esk, near Capo, in the Luther Water between South Muirton and Luther Bridge, near Marykirk station, at the Burn of Balmakelly (where it is at present being quarried for road “metal”), and in a small stream north of Craig of Garvock. Other dykes, occurring sporadically and traceable only for short distances, are found at Stonehaven harbour, in the Carmont railway cutting, in the North Esk near the House of the Burn, at Birnie Road siding, and at Johnshaven. The last example presents features of considerable petrographical interest which will be discussed in my paper on the petrography of the igneous rocks of the area.

These dykes are of the same type, and probably belong to the same period of intrusion, as the late Carboniferous east-and-west dykes of Central Scotland.

(b) *Teschenite Sills*.—On the rocky foreshore between Bervie Bay and Gourdon there is a considerable development of igneous rocks, including a soft green “serpentine.” The “serpentine” was formerly mapped as an intrusive dyke, the other igneous rocks are contemporaneous porphyrite lavas. From the field evidence, however, it is apparent that all are intrusive, and, indeed, that all belong to the same intrusion—a sill with a maximum thickness of about 180 feet—consisting of a soft central portion of highly decomposed doleritic rock or “serpentine,” above and below which is a hard, fresh olivine analcite dolerite or teschenite. The teschenites are in places rich in acid “segregations.” Towards the top and bottom of the intrusion they become strongly porphyritic with tabular crystals of plagioclase felspar, and such parts of the rock present a deceptive resemblance to the Crawton basalts. Junction specimens show the chilling of the upper and lower margins, and clear evidence of the intrusive character of the mass is seen from the way in which the igneous rock everywhere interdigitates with the overlying and underlying conglomerates and tuffaceous sandstones. Another small teschenite intrusion occurs at Bob’s Cove, Kinneff.

These alkali-rich intrusions have in all probability been derived from the same magma as the Carboniferous volcanic rocks of the Midland Valley. Their affinities are certainly with an “Atlantic” series rather than with the “Pacific” or calc-alkali series to which the lavas and intrusions of the Lower Old Red Sandstone period so obviously belong.

XV. SUMMARY OF THE CHIEF STRUCTURAL FEATURES.

Along the greater part of its course across Kincardineshire the Highland fault forms the boundary between the Downtonian-Lower Old Red Sandstone series and the older

* *The New Statistical Account of Scotland*, vol. xi., *Kincardineshire*, p. 72, 1845.

rocks to the north-west. From St Mary's Chapel to Garron Point (see Sketch-map, fig. 1) a small area of Upper Cambrian occurs on the south side; and at Kirkton in the extreme west [?] lavas of Old Red Sandstone age are found on the north side of the fault. In the coast section at Craigeven Bay, and again in a small stream near Elfhill—the only two localities at which the actual line of dislocation has been observed,—the Highland fault in the Kincardineshire area is an overthrust, not a normal fault as has been supposed.

A strong unconformity separates the Upper Cambrian and the Downtonian.

The dominating structural feature is a continuation of the well-known synclinal fold of Strathmore, the axis of which passes out to sea near Maiden Kaim. In the area to the west of Elfhill there is a tendency to set up a steep-limbed anticline, pitching out to the south-west against the Highland fault, and succeeded towards the north at Bogincabers by an inverted syncline. Convincing evidence of the character of the Elfhill anticline is obtained in the Water of Bervie section, where various beds in the Arbuthnott group can be traced round the fold; in the vicinity of Bogincabers a thick covering of drift obscures the solid geology, but the distribution of the hornblende andesites is strongly suggestive of the presence of an inverted synclinal fold.

An important dip fault crosses the Strathmore syncline from Thornyhive Bay to the Highland fault near Fetteresso, and the southern limb of the syncline is traversed by two sets of powerful faults, trending respectively south-east and north-west, and east-north-east and west-south-west. Frequently also along the same limb—and especially in the southern part of the area—there occur “shatter belts” marked by conspicuous breccias, which form the dyke-like features seen on the foreshore north of Johnshaven. Along these dislocations, however, little, if any, vertical displacement has been effected.

The Upper Old Red Sandstone series is everywhere faulted against the Lower.

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XVIII. EXPLANATION OF PLATES.

PLATE I.

- Fig. 1. Ruthery Head, near Stonehaven. The white line indicates the position of the unconformable junction between the Upper Cambrian (C) and Downtonian (D).
- Fig. 2. Ruthery Head. Nearer view of another part of the unconformable junction shown in fig. 1. The broken white line marks the position of a small fault.
- Fig. 3. Craigeven Bay, Stonehaven. Downtonian rocks in the foreground; Upper Cambrian strata of Garron Point on the far side of the bay.
- Fig. 4. Coarse conglomerate resting on eroded surface of Crawton basalt at Crawton. The photograph shows finer conglomerate filling cracks in the lava.
- Fig. 5. "Sandstone veins" in basalt on shore near Whistleberry, Kinneff.

PLATE II.

Geological Map of South-Eastern Kincardineshire. [Geological lines on area north of the Highland Boundary fault are taken from maps of H.M. Geological Survey.]

PLATE III.

Horizontal sections along lines A, B, C, and D of Plate II.

<i>x.</i> Dalradian schists.	<i>Cr.B.</i> Crawton basalt.
<i>a</i> ¹ . Upper Cambrian.	<i>o.Ac</i> ¹ . Hypersthene andesite and basalt.
<i>b.</i> Downtonian.	<i>q.F.</i> Quartz porphyry.
<i>Br.</i> Basement breccia of Downtonian.	<i>t.D.</i> Teschenite.
<i>Di.</i> <i>Dictyocaris</i> horizon of Downtonian.	<i>M.</i> Quartz dolerite.
<i>c</i> ¹ . Lower Old Red Sandstone.	<i>F.</i> Fault.
<i>c</i> ² . Upper Old Red Sandstone.	<i>H.F.</i> Highland fault.
<i>V.</i> Volcanic conglomerate and tuffs.	<i>T.</i> Thrust plane.
<i>Rc</i> ¹ . Dacite.	<i>u.</i> Unconformity.
<i>h.Ac</i> ¹ . Hornblende and augite andesites.	

R. CAMPBELL: ON THE GEOLOGY OF SOUTH-EASTERN KINCARDINESHIRE.—PLATE I.

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R. CAMPBELL: ON THE GEOLOGY OF SOUTH-EASTERN KINCARDINESHIRE—PLATE II.

R. CAMPBELL: ON THE GEOLOGY OF SOUTH-EASTERN KINCARDINESHIRE—PLATE III.

Fig. 1. Section along line A of Map (Plate II.). Horizontal and Vertical Scales: 24"=1 mile.

Fig. 2. Section along line B of Map (Plate II.). Horizontal and Vertical Scales: 1"=1 mile.

Fig. 3. Section along line C of Map (Plate II.). Horizontal and Vertical Scales: 1"=1 mile.

Fig. 4. Section along line D of Map (Plate II.). Horizontal and Vertical Scales: 1"=1 mile.