OBITUARY NOTICES.

The Scientific Career of Sir Archibald Geikie, O.M., K.C.B., F.R.S.

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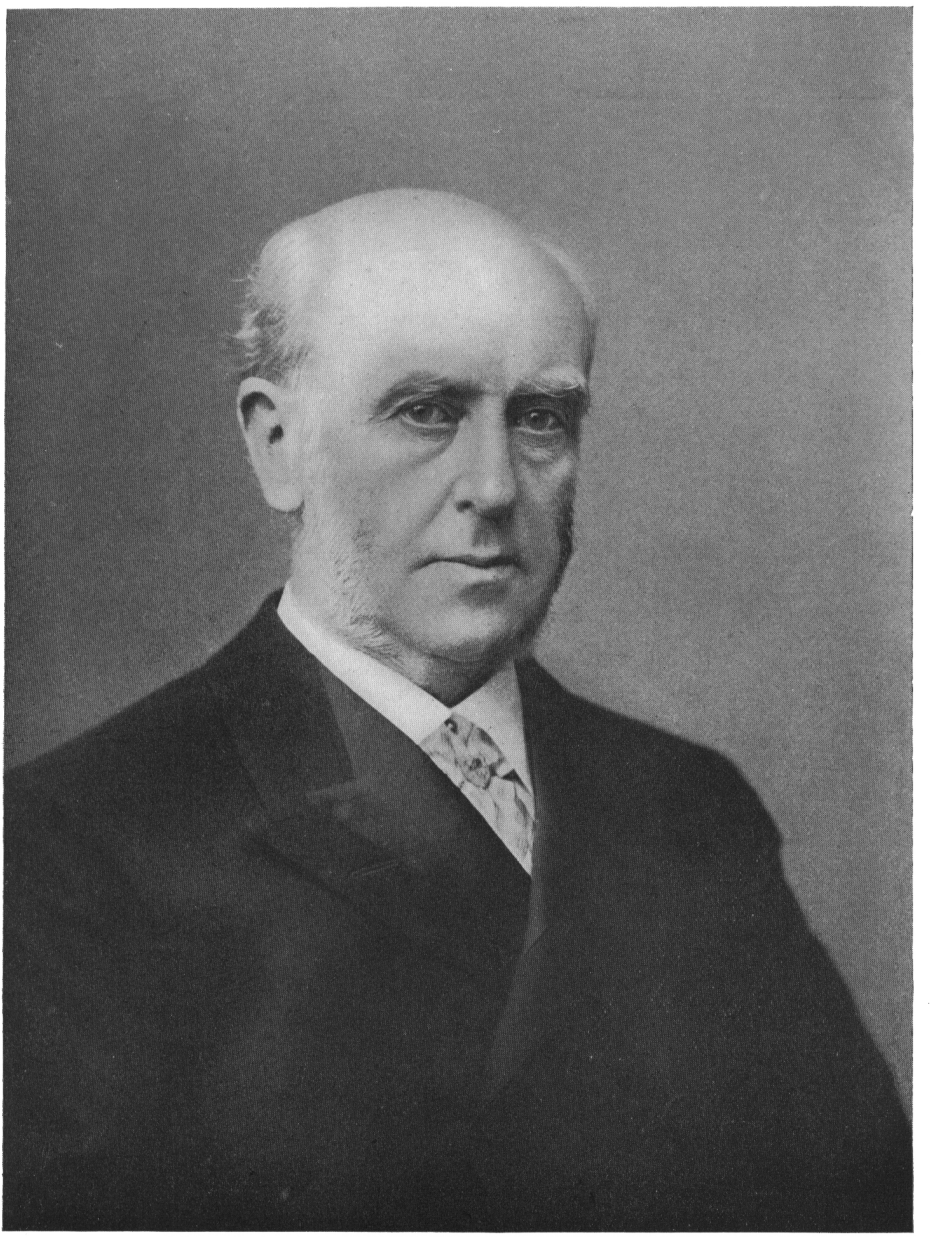
(Read February 23, 1925.)

THE scientific career of Sir Archibald Geikie was one of great distinction. Joining the Geological Survey in 1855, he became Director-General of the Geological Survey of the United Kingdom in 1882; President of the British Association at the Edinburgh Meeting in 1892; President of the Geological Society, London, 1890-92, and specially selected by the Council for a second term of office, to preside at the centenary celebrations in 1907; President of the Royal Society, London, 1908–13.

Honours were showered upon him by scientific societies at home and abroad, and by Universities, which were crowned by the Order of Merit in 1914.

The clue to this successful career is to be found in certain traits of his personality, displayed in his early years and developed as the time slipped past. Prominent among these traits were—his enthusiasm for certain lines of geological research; his firm determination to increase his knowledge of the geological record in his own and other lands; his keen desire to communicate that knowledge to others in artistic form with pen and pencil; his vivid imagination which led him to visualise his interpretation of geological evidence and to present it in clear and convincing terms; his love of literature, ancient and modern, which gave him intense pleasure in the midst of a strenuous life; his unwearied industry and great capacity for work. These qualities combined to make a strong personality which left its mark in every sphere of labour that he undertook. But some of these sources of strength proved to be sources of weakness when he dealt with complicated geological problems in the field.

Born in Edinburgh in 1835, and educated at the High School and University, he derived inspiration from the classic surroundings—the scene of the fierce controversy between the Huttonians and Wernerians at the beginning of last century. His finding fossils in the Burdiehouse limestone in his boyhood marked the first stage in his field experience. He read eagerly any geological works on which he could lay hands. Hugh Miller's volume on *The Old Red Sandstone* fired his imagination by its vivid descriptions of the members of the system, its included fish-remains, and



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conditions of deposition. He resolved to follow that descriptive style of writing, as it appealed so effectively to the general reader. Later in life it was superseded by Playfair's *Illustrations of the Huttonian Theory,* which he regarded as a model of lucidity, brevity, and elegance of style. He roamed over Arthur's Seat and the Pentland Hills with Charles Maclaren's volume on *The Geology of Fife and the Lothians* as his guide.

Not content with excursions in the neighbourhood of Edinburgh, he went to Arran with Ramsay's account of the geology of that island in his hand, to examine the metamorphic rocks and palæozoic strata, pierced by the granite masses in the north of the island. This was followed, in his eighteenth year, by a visit to Skye, where he began the mapping of the Lias, in the district of Strath, after a careful study of Macculloch's volume on *The Geology of the Western Islands.*

All these excursions sprang from his own initiative, which showed that he was clearly destined for a geological career, if such could be obtained. Two articles which he wrote on his work in Arran secured an introduction to Hugh Miller, then living in Edinburgh, which led to a close friendship that lasted till the tragic end of Hugh Miller's career. The young geologist paid frequent visits to that home, with his specimens, his maps and notes, receiving in return great encouragement to continue the work. Soon after this introduction, Hugh Miller was asked by Sir Roderick Murchison, who had been appointed Director-General of the Geological Survey, to recommend a young geologist to carry on the mapping in East Lothian, begun by Professor Ramsay in 1854. Archibald Geikie was recommended, and he joined the staff in his twentieth year.

He made the acquaintance of other scientific men in Edinburgh at that time, who were impressed with his enthusiasm for geological research. Dr George Wilson, lecturer on Chemistry in the extra-mural school and Director of the Science and Art Museum, in whose laboratory he did chemical analyses, followed his early progress with great interest, and spurred him on with the suggestion that his goal ought to be a Chair of Geology in Edinburgh University which would certainly be established in the future. Robert Chambers, Professor Fleming, one of the able naturalists of that period, and Professor James David Forbes, whose work among the glaciers of the Alps and Norway is familiar to geologists, befriended him. Forbes, who was Secretary to the Royal Society of Edinburgh for twenty years, appealed to him to contribute papers to the Society, for he regretted the decline of geological research in Scotland since the days of Hutton, Hall, and Playfair. The last time that Forbes addressed the Royal Society of Edinburgh he uttered these impressive

words: "Of all the changes which have befallen Scottish science during the last half century, that which I most deeply deplore, and, at the same time, wonder at, is the progressive decay of our once illustrious Geological School." Archibald Geikie responded cordially to this appeal in later years by communicating his best papers to this Society.

From the point of view of worldly advancement, Murchison was his greatest benefactor. In 1860, after a few years' experience of field work in the Lowlands, the young geologist was requested by Murchison to accompany him in the North-west and Central Highlands to determine the order of succession of the rocks in those regions. From these traverses arose an intimate friendship which lasted till the close of Murchison's life in 1871. During these years Murchison realised Archibald Geikie's great ability, his enthusiasm for geological work, his graphic descriptive power, and showed his appreciation in tangible forms.

Mainly through Murchison's influence he was admitted to the Fellowship of the Royal Society, London, at the early age of twenty-nine, and appointed first Director of the Geological Survey in Scotland in 1867. When Murchison offered to share the endowment of the new Chair of Geology in Edinburgh University, he stipulated with the Government that Archibald Geikie should be the first Professor. In his will Murchison made him literary executor and left him a legacy of £1000. These are striking proofs of the impressions produced by the young geologist on the mind of the veteran, who, before the close of his career, dominated British geology.

The areas fixed by Professor Ramsay, then Director of the Geological Survey of Great Britain, to be mapped by Archibald Geikie in his early official career gave him great gratification. His colleague was H. H. Howell, a coalfield expert, and after completing the survey of the low ground in the county of Haddington, they moved westward to Midlothian. To Geikie was assigned the area west of the coalfield, ranging from Arthur's Seat and the Pentland Hills to the Bathgate Hills, and northwards into Fife. His experience in those areas determined the lines of research in which he did his best work. The evidence bearing on the glaciation of the region, the development of the Old Red Sandstone formation in the Pentland Hills, and the occurrence of volcanic rocks on different geological horizons, suggested fields of investigation that might bear rich fruit.

In his early Survey days, in common with the prevalent opinion of that time, he attributed the polishing and grooving of the rocks to the action of currents and icebergs, but under the influence of Professor Ramsay, who had already described the vanished glaciers of North Wales, he adopted

the view, propounded by Agassiz during his visit to Scotland in 1840, that these phenomena were due to the action of land ice. In 1862 he contributed to the Glasgow Geological Society a valuable paper on "The Glacial Drift of Scotland" (published in 1863), which helped to place the investigation of these deposits on right lines. He showed how the rock striations radiated from the main mountain ranges; he described the local character of the boulder-clay, its relation to the underlying rocks, the direction of transport of the materials, its striated pavements, the intercalated deposits of sand and gravel—observations which have stood the test of time. From these phenomena he inferred that during the earlier part of the glacial period Scotland was covered with an ice-sheet after the manner of Greenland, that the boulder-clay was a product of this ice-sheet, and that the stratified beds in the Till marked periods of lessened severity of climate when the ice retired for some distance. He described the inland stratified drift and the fossiliferous marine shelly clays of the Clyde basin, so admirably worked out by Smith of Jordanhill. He suggested that the moraines in the upland valleys indicated the gradual shrinkage of the ice-sheet into local glaciers, and the final disappearance of the ice.

Availing himself of the researches of Smith of Jordanhill, Edward Forbes, T. F. Jamieson, and others, he appended to this paper a list of organic remains from the glacial deposits of Scotland.

This paper proved of great service to British geologists at that time, as it gave an outline of the conditions which probably prevailed during the glacial period in this country, and suggested the lines along which investigation should proceed. It held the field till the publication in 1874 of the well-known volume, *The Great Ice Age*, by his younger brother, Professor James Geikie.

As the Scottish Survey work advanced, it fell to the lot of Archibald Geikie to map in detail large areas of the Old Red Sandstone in Midlothian, Lanarkshire, Ayrshire, and in the counties of Fife, Perth, and Kinross. He also examined the districts surveyed by other members of the staff south of the Grampians. Throughout this region it had been proved that this formation consisted of two divisions, an upper and lower, separated by a marked unconformability, and characterised by different fish-faunas.

North of the Grampians, however, Murchison adopted a triple classification by introducing a middle division, composed of the Caithness flagstones. From their lithological characters and fossil contents he maintained that this flagstone series belonged to a different division of the formation. He argued that the fish-fauna found in this series differed in important points from that occurring in the flagstones, sandstones, and

shales of Lower Old Red Sandstone age in Forfarshire. It was therefore of younger date. He also suggested that the Caithness flagstones might have been laid down during the long interval separating the lower and upper divisions south of the Grampians.

Hugh Miller and Dr Malcolmson had proved the occurrence of the upper division with its characteristic fish-remains in the basin of the Moray Firth, and they further showed that the ichthyolites found in the lower beds in that region resembled those met with in the flagstones of Caithness and Orkney.

Such was the position of enquiry when Geikie began a series of traverses in the basin of the Moray Firth, Caithness, Orkney, and the Shetland Isles. In 1878 he communicated to this Society an elaborate paper on the "Old Red Sandstone of Western Europe" which embodied the results of these traverses. It was intended to be the first of a series, descriptive of the other areas occupied by this formation in the British Isles, but his removal to London in 1882 prevented him from carrying out this intention. The other areas were dealt with at a later date in his treatise on the *Ancient Volcanoes of Great Britain*, with special reference to the records of volcanic action associated with them.

One of the special features of this communication is the vivid description of the geographical changes in Western Europe that followed the marine conditions of Silurian time. Adopting the theory of the lacustrine origin of the Old Red Sandstone suggested by Fleming and Godwin Austin, and supported by Rupert Jones on palæontological evidence, and by Professor Ramsay on lithological grounds, he held that in North-west Europe the Silurian sea gave place to continental conditions with large inland lakes. He defined the areas of the various basins of deposit of the Old Red Sandstone in the British Isles and gave them the following names: (1) Lake Orcadie including the extensive region north of the Grampian range and stretching north to the Shetland Isles; (2) Lake Caledonia or the Mid-Scottish Basin between the Grampian Highlands and the Southern Uplands; (3) the Lake of Lorne extending from the south-east of Mull to Loch Awe; (4) Lake Cheviot, including a part of the south-east of Scotland and north of England; (5) the Welsh Lake, bounded on the north by the Cambrian and Silurian high grounds, its southern and eastern extension being obscured by later formations.

The deposits in Lake Orcadie were grouped by him in two divisions; a lower, comprising the Caithness flagstone series, and an upper, composed of false-bedded sandstones and marls with its characteristic fish-fauna, resting unconformably on the lower as in the midland valley of Scotland.

He pointed out that Murchison's lower division in Caithness consisted merely of the thick accumulation of sandstones, breccias, and conglomerates that underlie the Caithness flagstone series.

The distinctive feature of the paper was his correlation of the Caithness flagstone series (Murchison's middle division) with the true Lower Old Red Sandstone south of the Grampians. He admitted the marked differences in the lithological characters and fossil contents of the deposits in the two areas, but he contended that the palæontological distinctions are probably not greater "than the contrast between the ichthyic faunas of adjacent but disconnected water basins at the present time."

Much new information bearing on the distribution and field relations of these deposits was embodied in this communication. The main features in the geological structure of Caithness were indicated; the great overlap at Reay in the north of that county, where the higher members of the flagstones rest unconformably on the crystalline schists, was clearly established; his suggestion that the fish-bearing bands and associated strata in the Moray Firth basin are the equivalents of part of the higher portion of the Caithness flagstone series has been confirmed by the later detailed mapping of the Geological Survey. He also recorded for the first time the unconformability between the Upper Old Red Sandstone and the Caithness flagstones visible on the west coast of the island of Hoy, Orkney.

In accordance with his classification, the Caithness flagstone series and associated strata were grouped with the lower division of the system in the official publications of the Geological Survey. But after his retirement from the Survey, the palæobotanical evidence threw new light upon the problem. The researches of Dr Kidston and Mr P. Macnair showed that the assemblage of plants found in the Caithness flagstones differed from those met with in the Lower Old Red Sandstone south of the Grampian Chain, and ought to be referred to a middle division. The triple classification based upon the plants harmonised with that advanced by Dr Traquair based upon the fishes. The value of this evidence was appreciated by the Geological Survey in 1902, and the threefold grouping of the system has been adopted in the official publications since that date.

Turning now to volcanic geology, we enter a sphere of research in which Archibald Geikie laboured with great success. This branch of enquiry roused his enthusiasm and led him to study volcanic phenomena in the British Isles and other lands. As his knowledge of volcanic activity in different geological periods increased, he showed great aptitude in modifying his opinions in accordance with fresh evidence.

In mapping the areas assigned to him in Midlothian, West Lothian,

and Fife in his early official life, he frankly acknowledged his obligations to the clear descriptions of Charles Maclaren, whose work was far in advance of its time. These descriptions proved the occurrence of volcanic action in Old Red Sandstone and Calciferous Sandstone time. His own field work in the Bathgate Hills showed that volcanoes were active at intervals during the Carboniferous Limestone period on higher horizons than those of the Arthur's Seat volcano. He recorded the prevalence of later intrusive dykes traversing the Carboniferous strata. From his own researches and the work of other investigators, he prepared a paper on the "Chronology of the Trap Rocks of Scotland," published in the *Transactions* of this Society in 1861. In the map illustrating this communication the Trap Rocks are referred to the Old Red Sandstone, Carboniferous, Oolitic, and Tertiary periods. In accordance with the classification of Edward Forbes, the extensive basaltic plateaux of the West Highlands were assigned to the Jurassic period, except the lavas at Ardtun, in Mull, which are associated with the well-known leaf beds described by the Duke of Argyll. This grouping was corrected in an important paper that appeared in the *Proceedings* of this Society in 1867, in which he suggested that the basaltic plateaux, extending from the North of Ireland along the West Coast of Scotland to the Faroe Islands and Iceland, were all erupted probably during the Tertiary period. Even at that date he emphasised the importance of the system of intrusive dykes, which in his opinion was possibly the most striking manifestation of Tertiary volcanic activity.

While mapping the volcanic area in Fife between Burntisland and the Saline Hills, he visited the Auvergne in Central France, with its extinct but recent volcanoes, to increase his knowledge of volcanic phenomena. The evidence, which appealed strongly to his imagination, is described by him in the following artistic style:—

"To one who had been at work for some years among a set of old and fragmentary volcanic rocks, trying to piece together porphyrites, dolerites, basalts, and tuffs, the sight of those Puys, with their fresh cones and craters of ashes and scoriæ, and their still perfect floods of lava, was inexpressibly instructive. Merely to cast the eye over the landscape was of itself a memorable lesson. The scene was exactly what was needed to enable one to realise the character of those old British Carboniferous Volcanoes of which such mere fragments now remain. High up among the uplands of Central France my eye was ever instinctively recalling the hills and valleys of Central Scotland, and picturing their original scenery by transferring to them some of the main features in the landscapes of Auvergne. The imagination easily filled again with a sheet

of deep blue water the broad expanse of yonder Limagne. Vines, and acacias, and mulberry-trees seemed to melt of their own accord into stately *sigillariæ, lepidodendra,* and *calamites*; the orchards and corn-fields along the slopes began to wave a dense underwood of ferns and shrubby vegetation; some of the cones rose fresh and bare, others were dark with a growth of araucarian conifers, and there, with but little further change, lay a landscape in the central valley of Scotland during an early part of the great Carboniferous period."

In 1868 he visited the volcanic district of the Eifel in Germany, and in 1870, at the request of Poulett-Scrope—author of the well-known volume on *Geology and Extinct Volcanoes of Central France*—he undertook an examination of the volcanic districts of Southern Italy and the Lipari Islands. He was impressed by the contrast between the comparatively low craters of the Phlegrean Fields, where the eruptive materials consist mainly of tuffs with few lava flows, and the great crater wall of Monte Somma, whose lavas are piled on each other to a great height and pierced by innumerable vertical dykes filling fissures made at successive eruptions. An attack of malarial fever prevented him from carrying out his intention of examining the Lipari Islands.

Another stage in his pursuit of the study of volcanic phenomena in Scotland is marked by an important paper contributed to the Royal Society of Edinburgh in 1879, on the "Carboniferous Volcanic Rocks of the Firth of Forth Basin—their Structure in the Field and under the Microscope."

As his field work proceeded in the Lothians and Fife, he felt the necessity of applying the microscope to the study of the igneous rocks in order to gain definite knowledge regarding their internal composition and structure. He realised that much new light might be thrown on the history of volcanic action in this region by this field of enquiry.

In his historical sketch he notes with pleasure that the igneous rocks of the Edinburgh district furnished Hutton with the evidence whereby he established the igneous origin of "whinstone" (basalt) and led to the famous experiments of Hall which laid the foundations of experimental geology.

The volcanic masses were grouped by him in four subdivisions: (1) Necks or Vents; (2) Intrusive Sheets and Dykes; (3) Contemporaneous Lavas; (4) Tuffs. A notable feature of this communication was the prominence given to the numerous necks or vents occurring in the Lothians, Fife, and Stirlingshire, from which proceeded showers of ashes and sheets of lava. Most of them were regarded as belonging to different

stages of Lower Carboniferous time, while others were supposed to be later than the folding and faulting of the Carboniferous sediments, and were referred to the Permian period. The occurrence of these vents and their wide distribution is one of the valuable contributions made by Archibald Geikie to Scottish volcanic geology.

In the petrographical part of this paper he acknowledges Allport's researches on the Carboniferous dolerites round Edinburgh and gives an outline of his own investigations. Subsequent petrographical work has shown that he did valuable pioneer work in this branch of enquiry, for he was the first to describe many important features of the microscopic characters of these rocks.

Archibald Geikie's discovery of proofs of volcanic action during Permian time in Scotland is of special interest. While mapping the Mauchline district in Ayrshire, he recorded a series of contemporaneous lavas and tuffs underlying the Permian sandstones of that region, and forming a ring of higher ground between the Carboniferous and Permian sediments. This discovery was announced in the *Geological Magazine* in 1866. Similar types of lava were mapped by him in the Thornhill basin in 1868, where they are also associated with Permian sandstones. He laid special emphasis on the occurrence of volcanic necks in excellent preservation in Ayrshire which he referred to this period. Some of the smaller ones rise through the ring of Permian lavas, while others occur in the upper division of the Coal Measures. They are filled with agglomerate, pierced in some cases by igneous intrusions.

In describing the volcanic phenomena of Permian age, he suggested that the great series of volcanic vents in East Fife probably belonged to this period. He also suggested that the coarse agglomerates of the Arthur's Seat volcano, and the associated igneous rocks, which, in his opinion, marked a second period of volcanic activity, were probably erupted during Permian time. But the subsequent detailed mapping of the Geological Survey led him to accept Maclaren's later interpretation, confirmed by Professor Judd, that these coarse agglomerates occurred within the vent from which the lavas and tuffs of the hill had been discharged during one period of volcanic action in Lower Carboniferous time.

Another great opportunity of extending his knowledge of volcanic phenomena occurred to Archibald Geikie in 1879. He had arranged to give a course of lectures at the Lowell Institute, Boston, in the autumn of that year, and he resolved to spend the summer in traversing the extensive lava-fields, drained by the Snake River, in Idaho, on the Pacific slope of the United States. The vast floods of lava in that region, with no visible

cones and craters, were explained by Richthofen as being due to fissure eruptions. Hitherto Geikie had regarded the Scottish volcanic plateaux as having issued from local vents, but this visit widened his conceptions. The great lava-plain looked as if it "had been filled with molten rock which had kept its level and wound in and out along the bays and promontories of the mountain slopes as a sheet of water would have done." The Snake River has cut a gorge through this plain, which exposes a succession of sheets of basalt to a depth of several hundred feet. No central cone from which these lavas might have been erupted was visible; only a few cinder cones of secondary origin appeared at wide intervals on the basaltic plain. The suggestion then occurred to him that the Tertiary volcanic plateaux of Western Europe might have had a similar origin.

Inspired by this conception, he revisited the West Highlands at intervals for several years to continue his investigations among the Tertiary Igneous Rocks. He was also impelled to do so by the remarkable interpretation of the volcanic history of that region advanced by Professor Judd. In a paper communicated to the Geological Society on "The Ancient Volcanoes of the Highlands" in 1874, Professor Judd described the basal wrecks of five great extinct Tertiary volcanoes (Skye, Mull, Rum, Ardnamurchan, and St Kilda); the one in Mull was estimated by him to have reached a height of 14,500 feet. They indicated three periods of volcanic activity. The first was marked by the extrusion of acid lavas and tuffs connected with plutonic masses of granite, the second by basaltic lavas and tuffs related to deep-seated masses of gabbro, and the third by the discharge of lavas from small sporadic cones after the great central volcanoes had become extinct.

At last, after a quarter of a century of intermittent labour in this subject, Archibald Geikie presented in 1888 to the Royal Society of Edinburgh his great memoir on "The History of Volcanic Action during the Tertiary Period in the British Isles." In the preparation of this monograph he acknowledges the assistance he received from several of his colleagues. A prominent feature of it is the elaborate description of the system of basic dykes, the importance of which he recognised early in his career. His main conclusions may thus be briefly summarised.

Owing to enormous horizontal tension, a series of more or less parallel fissures arose in Tertiary time in a tract of country including the North of England and Ireland, the southern half and the West Coast of Scotland—a total area of about 40,000 square miles. Molten material rose up these fissures, thereby giving rise to the numerous basic dykes which are the distinctive feature of the volcanic region. The basalt plateaux are

supposed to be due to streams of lava issuing from these fissures and from vents occurring along these lines of weakness. After these sheets of lava had accumulated to a great thickness, they were injected by laccolitic masses of gabbro, and sills and veins of dolerite. At a later period the gabbros and basalt lavas were alike disrupted and pierced by acid igneous rocks, ranging from granites and granophyres to porphyries and felsites. Crustal movements again ensued, whereby another series of fissures was established, now filled with basic dykes that traverse alike the basalt plateaux, the later gabbros, granophyres, and granites.

It is interesting to observe that these main conclusions were confirmed by Dr Harker in the course of his detailed mapping of the central mountain group of Skye for the Geological Survey. But from the recent exhaustive memoir issued by the Geological Survey on the *Tertiary and Post-Tertiary Geology of Mull, Loch Aline, and Oban*, it is evident that the volcanic history of Mull is much more complicated than Sir A. Geikie or Professor Judd imagined. Mull is regarded as a volcanic centre of extreme complexity which "has repeatedly served as a focus of fissure eruptions; but it is doubtful whether the lavas still spared by erosion are not, in the main, the products of a central volcano, an idea always linked with the name of Professor Judd."

His last contribution to this branch of geology was his comprehensive treatise on the *Ancient Volcanoes of Great Britain*, which appeared in 1897. It presented a summary of the knowledge then ascertained regarding these volcanoes, and embodied the results of his own researches and of others who had worked at volcanic problems in the field and in the laboratory. It traversed a wide field of enquiry, for the opening chapters of the treatise are devoted to the discussion of the general principles and methods of investigation of volcanic phenomena, which are followed by detailed descriptions of the proofs of volcanic activity in Britain ranging from pre-Cambrian to Tertiary time.

In the traverses with Murchison in the North-west and Central Highlands in 1860, Archibald Geikie had to deal with problems of fundamental importance connected with the geology of the Highlands. The researches of Macculloch, Murchison and Sedgwick, Hay Cunningham and Hugh Miller, showed that the belt of quartzites and limestones in the West of Sutherland and Ross are succeeded eastwards by metamorphic rocks that stretch across the Great Glen to the eastern border of the Highlands. Accepting Salter's determination of the fossils found in these limestones by Mr C. W. Peach, Murchison regarded these strata as Silurian (now known to be Cambrian by Mr A. Macconochie's discovery of the *Olenellus*

fauna in the Fucoid beds). He contended that these Silurian strata pass *conformably* below, and are overlain by, the metamorphic rocks to the east, and inferred that this metamorphic series must belong to the same system. This interpretation meant a radical change in the geological map of Scotland, for the area occupied by these altered strata amounts to about 11,000 square miles.

Professor Nicol, on the other hand, maintained that no conformable upward succession from the fossiliferous limestones and associated strata to the overlying schists is to be found. He held that the line of junction is a line of fault "everywhere indicated by proofs of fracture, contortion of the strata, and powerful igneous action."

It fell to the lot of Archibald Geikie to traverse rapidly with Murchison the line of junction in the county of Ross, where, owing to stupendous inversions and overthrusts, the prevalent dip of the fossiliferous strata and the Eastern Schists is towards the east-south-east. He was misled by the apparent superposition and especially by certain deceptive sections in which the Eastern Schists rest with similar dip and strike upon the undisturbed Silurian rocks. Eventually he accepted Murchison's interpretation.

The results of these traverses were embodied in a joint paper communicated to the Geological Society, London, in 1861, "On the Altered Rocks of the Western Islands of Scotland, and the North-western and Central Highlands." Murchison's interpretation of the structure was therein described and illustrated by sections in such convincing form that it met with general acceptance for many years.

In 1878 the controversy was reopened and Murchison's position was shown to be untenable by several investigators. Dr Hicks, Professor Bonney, and Dr Callaway made important contributions to the problem.

Professor Lapworth grasped the true solution of the geological structure of that region. In 1883 he began a series of articles in the *Geological Magazine* on "The Secret of the Highlands," based on his detailed mapping of the Durness-Eireboll region in 1882, but owing to severe illness this series was never completed. He therein demonstrated the inversion of the Silurian strata on the east side of Loch Eireboll and the unconformable junction of the basal quartzite with the old Archæan floor on the east side of the fold at Ant-Sron. From his paper on "The Close of the Highland Controversy" (*Geol. Mag.*, 1885), and from the "Obituary Notice of Charles Lapworth," by Professor Watts and Sir Jethro Teall (*Proc. Roy. Soc.*, 1921), it is clear that he recognised that the Archæan Gneiss had been driven over the fossiliferous quartzites on Ben Arnaboll by a gently-inclined overthrust fault. Along this plane of movement, and at other localities, the original

rocks had been crushed and rolled out into types which he termed mylonites. On the shore at Heilim, on the east side of Loch Eireboll, he observed that the serpulite grit had been repeated many times by clean-cut faults, a striking illustration of imbricate structure. All these phenomena were shown in the field in 1883 to Sir Jethro Teall by Professor Lapworth.

The Durness-Eireboll region was mapped by us in 1883-4, when we reached conclusions practically identical with those of Professor Lapworth regarding the stratigraphy and metamorphism of the rocks, in complete ignorance of his results (see "Close of the Highland Controversy," p. 98, *Geol. Mag.*, 1885). It was then proved in the course of the Geological Survey work that under extreme lateral pressure the rocks behaved like brittle rigid bodies; they snapped and were driven westwards in successive slices, so that crystalline gneiss and schist are made to rest upon fossiliferous strata of Silurian age. It was further shown that the Eastern Schists were driven westwards by the Moine thrust—the most easterly and most powerful of the series—for a minimum distance of ten miles over all underlying thrust masses till they rest upon the unmoved Silurian (Cambrian) Limestone in the Durness basin.

The evidence proving these conclusions was carefully inspected in the field by Archibald Geikie, who had never had an opportunity of examining the Eireboll sections. He was completely convinced that Murchison's interpretation of the structure must be abandoned, and he took the earliest opportunity of making a public declaration to this effect. A report giving the results of the work by Peach and Horne, with a preface by Geikie, containing a frank confession that he had been misled and that he had accepted the conclusions of his colleagues, appeared in *Nature*, 13th Nov. 1884.

In dealing with the geological structure of the Silurian rocks of the Southern Uplands, he accepted the order of succession adopted by Nicol and Murchison, and was largely influenced in holding this opinion by the doctrine of Colonies. This theory was introduced by Barrande, the distinguished palæontologist, to explain the intercalation of fossils, belonging to higher zones, in lower portions of the Silurian succession in Bohemia. These precursory fossiliferous bands were termed Colonies. The distribution of the bands of graptolite shale in the Southern Uplands as mapped by the Geological Survey was regarded as an instance of the precursory appearance of the higher graptolite forms in the Moffat region and their disappearance in the Lead Hills district.

But the researches of Professor Lapworth furnished the key to the solution of the structure of the Chain. He demonstrated a definite

faunal sequence in the graptolites which is persistent though the strata may be inverted by folding. He further proved a great variation in the character of the contemporaneous sedimentary deposits; the black shales of the Moffat region, ranging from Arenig to Llandovery time, about three hundred feet in thickness, being represented in the Girvan area by several thousand feet of sedimentary deposits.

Reference must be made to Archibald Geikie's tenure of the Chair of Geology for eleven years in Edinburgh University. In spite of the difficulties which confronted him at the outset, geology not then being required for any degree, his success was remarkable. The students formed a mixed assemblage—some who were interested in the subject and wished practical training, some who intended to follow other branches of natural science, and some who turned to geology for the pleasure it gave them. He set himself to lay the foundation of a class museum and introduced petrographical methods of studying rocks with the microscope when that branch of enquiry had not advanced far in this country.

By his lectures, which were given in a clear and attractive form, and especially by his class excursions, he was an inspiring teacher. Edinburgh is an ideal centre for practical training in field geology, but in addition, at the end of each session, he carried out a long excursion, lasting a week or ten days, to examine special problems in the field. Receptive students who took part in these excursions felt the influence of his personality. He thus describes the impression produced on one of his former students by these practical demonstrations:—

"These students' rambles and the love of geology which they fostered have dwelt ever since those days in Sir William Herdman's memory, and though he has become eminent in another field of natural science, he has assured me that it was the remembrance of his experience in the Geology Class at Edinburgh and its excursions, which led him in recent years to found and endow a Professorship of Geology in the University of Liverpool. It is not always that a teacher lives to see the fruition of his labours. Certainly no incident connected with my professorial career has given me keener pleasure than this generous liberality of a former student."

Archibald Geikie's eminent services as an exponent of geological science in his class-books and text-books demand special mention. His experience in the field during his early official career enabled him to test the truth of the principles laid down by Hutton and illustrated by Playfair regarding the evolution of the earth's surface features. The potency of the ordinary agents of denudation in hollowing out valleys was not admitted by some of the leading geologists of that time. Even

Sir Charles Lyell, who was the great exponent of the uniformitarian school, contended towards the close of his career that the principal valleys in almost every great hydrographical basin "have been due to other causes besides the mere excavating power of rivers."

Geikie was an ardent follower of the views of Hutton and Playfair. He was impressed with the remark of Desmarest when pointing out the value of Hutton's contributions to the natural history of the earth and the physical geography of Scotland: "It is to Scotland that Hutton's opponents must go to amend his results and substitute for them a more rational explanation." Geikie was convinced that Scottish topography furnished no grounds for such opposition. He produced in 1865 his volume on *The Scenery of Scotland viewed in connection with its Physical Geology*, which gave an excellent popular description of the Huttonian principles of earth-sculpture, as illustrated by the country he knew best. He showed with great clearness and artistic style how the ordinary agents of denudation—rain, rivers, the sea, the wind, and moving ice—acting upon different types of rock, had carved out the distinctive varieties of Scottish scenery. As the volume was based on personal acquaintance with the physical features of the country, and a knowledge of its geological structure then ascertained, it immediately arrested attention. Its success was marked; it ran through three editions, the later editions incorporating the more important advances in Scottish geology.

In view of the success of this volume, he then projected a series of educational works on Physical Geography and Geology to meet the public demand. In 1873 he contributed to Macmillan's elementary science series a Primer on each of these subjects—a task which cost him excessive labour. His aim in writing the *Physical Geography Primer* was to stimulate habits of observation of the common phenomena of everyday experience. It ranks as one of his best educational achievements. These Primers were followed by Class-books on the same subjects, for which there has been a great demand. The great educational value of these publications is beyond doubt. Their success is due to his teaching being permeated with the Huttonian conceptions of natural forces now in operation and to the exquisite literary form in which the lessons are presented.

These Primers and Class-books were meant to be the precursors of his great *Text-book of Geology*, the first edition of which appeared in 1882. This volume was intended for the use of students and professional workers in the science, and so well did it meet the requirements of the

time that the whole issue was disposed of in a comparatively short period. One of the valuable features of the book was his analysis of the research done in other countries in each of the great divisions of the geological record. It reflected extensive reading and the careful preparation of brief summaries of the results achieved. He made a strenuous effort to keep each successive edition abreast of the research of the time, and, in dealing with his own record, he frankly abandoned positions which he had previously held when new evidence proved that they were erroneous. The fourth edition, published in 1903 after his retirement from the Survey, is notable for copious references to the geological literature of other countries, which cost him enormous labour. It is also notable for the qualification which he attached to Huttonian teaching, as he thought uniformitarianism had been pushed too far:—

"It has often been insisted upon that the Present is the key to the Past; and in a wide sense this assertion is eminently true. . . . While, however, the present condition of things is thus employed, we must obviously be on our guard against the danger of unconsciously assuming that the phase of Nature's operations which we now witness has been the same in all past time. . . . For aught we can tell, the present is an era of quietude and slow change compared with some of the eras that have preceded it."

A reprint of the fourth edition of the Text-book was issued in 1924.

His active brain and fertile pen enabled him to produce several biographies in the midst of other onerous labours. He completed the *Life of Edward Forbes*, begun by Dr Wilson; he wrote the *Memoirs* of James David Forbes, of Murchison, of Ramsay, who succeeded Murchison as Director-General of the Geological Survey. The *Life of Murchison* is of permanent interest to geologists from his vivid sketches of the Founders of Geology in Scotland and England, and from his description of the achievements of Sedgwick and Murchison in establishing the Cambrian, Silurian, and Devonian systems.

In concluding this outline of Sir Archibald Geikie's scientific career, we may express our belief that his future reputation will rest mainly upon his splendid services as an exponent of geological science rather than upon his own original researches. Be that as it may, it is certain that in the roll of eminent Scottish geologists who have passed, including Hutton, Hall and Playfair, Murchison and Lyell, Hugh Miller and Charles Maclaren, Ramsay and Nicol, James Geikie and Croll, Traquair and Kidston, he will take a prominent place as one who laboured strenuously to promote the science which he loved so well.