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The story of the Forth

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THE SCOTTISH GEOGRAPHICAL MAGAZINE.

THE STORY OF THE FORTH.

By H. M. CADELL of Grange.

(With Illustrations.)

I.—INTRODUCTORY.

FROM its first beginnings in the remote ages of the geological past down to the more recent and better known times of the archæologist, the River Forth has had an interesting and chequered career. The story of the Forth is indeed a long one, and it is not possible now to do more than attempt to draw some rough and general outlines of what observation and theory lead us to suppose has happened at a few separate periods in the life of the river.

The ways and habits of streams and running waters have been much studied by geographers in recent years, but it may be well, for the benefit of any not specially versed in the lore of physical geography and geology, to begin the argument, like Euclid, with a few elementary postulates and axioms, so that there may be a clear understanding of the reasoning on which the conclusions in the following pages are founded.

Nature is a thing of law and order, and although it may not always be very apparent at first sight, it is the fact that law and order prevail among the living waters of the earth as well as among the inhabitants of the plant and animal kingdoms. When a river is found apparently disobeying some general law and following an irregular and abnormal course, then the philosopher may with profit consider the matter and try to ascertain the why and wherefore of the unusual phenomenon and what lessons it may have to teach.

When, for example, rain falls on a sloping roof it naturally runs

straight down to the rhones, and after a shower if we were to notice that it had apparently run obliquely across the slates or even up towards the ridge we should, no doubt, be much surprised and anxious to trace the cause of such a remarkable and unnatural phenomenon. Now in the case of a river its natural course is a straight line by the shortest route from the watershed to the sea. The original surface of the land after it was first upheaved from the sea, where the solid rocks mostly all originated, was covered with streams all running more or less in the direction of its greatest declivity. By and by the rills began to coalesce into a few larger streams with shallow valleys and tributaries. The tributaries ran towards the sea and the main river, and joined the trunk at a more or less acute angle above the confluence. A normal river is thus like a well-developed tree with branches growing upwards from the stem and stretching towards the light of heaven. Some branches may get more light and become stronger than others, and some tributaries may receive more rain and grow larger than others, until in time the young and symmetrical figure grows into a distorted old patriarch with almost no resemblance to its original form.

These may seem truisms too obvious to be worth mentioning, but as we follow the argument the use of referring to them may soon become more apparent. As time goes on the glens grow deeper and larger, and their rivers acquire a prescriptive right of way that becomes ever stronger with the lapse of centuries. Each river has a valley, and there are no dry valleys that have not once been occupied by a river except in a very few abnormal cases. If we find a dry valley it is a proof of some change of circumstances, and to this point we shall return later on.

Now it must not be forgotten that the rivers have made the valleys, and it is not the valleys that have determined the courses of the rivers. The valleys in this country are not due to cracks or sinkings of the surface of the earth's crust—a fact that is easily proved by a little investigation. There are no doubt many cracks and fissures in the rocks, but these run across the country in more or less straight lines, and are never found to wind about like the tortuous meanderings of river beds, nor do they branch from the main stem and subdivide again like the tributaries of a river system. No doubt fissures are occasionally to be found running along the beds of straight river courses for some distance, but this is because fissures mark lines of weakness and broken rock, along which running water, if it happens to be flowing in the same direction, finds it easier to excavate a channel than at places where the rock is quite undisturbed and solid.

The next point to be noted is the two ways in which the rock is worn down. Streams eat their way both downwards into the rock and backwards into the hills. The Cauldron Linn, for example, shows a stream busily engaged in sawing out a notch in a hard dyke of basalt that crosses the Devon below the picturesque gorge at the Rumbling Bridge. The sand and gravel brought down from the Oehils in the course of centuries has enabled the water to grind away part of the barrier, and as soon as the hard rib has been entirely sawn through, the fall will recede into the softer sandstone above the dyke and still further

deepen the ravine up stream. The fall will eat its way back into the hills, and the more water and gravel that comes down the faster will the recession go on. When the water is low and clear there is practically no erosion, but when the stream is in spate, and full of heavy grit and

FIG. 1.—The Cauldron Linn.

sediment, it goes on grinding merrily, like a lapidary's wheel with plenty of diamond dust (Fig. 1).

It is a far cry from the Cauldron Linn to Niagara, but here we see the same process at work on a vastly grander scale. The classic American river has been for centuries eating its falls backward from Lake Ontario towards Lake Erie, and from 1842, when measurements were first made, the falls had retreated, up till 1905, a distance of 265 feet, or at the average rate of a little over 4 feet per annum. Had the water

been turbid and full of sediment the rate would no doubt have been much more rapid, but, issuing in a clear and limpid stream from the great lake above it, it can only work on the rock by undermining the soft shale under the limestone ledge, which falls in great blocks and is ground to powder in the vast cauldron beneath. So rapid is the recession in spite of this want of sediment that the Canadian Fall, formerly known as the Horse Shoe, has completely changed its form, and is now like a

FIG. 2.—The Colorado Cañon.

sharp letter V pointing up stream. It is much less picturesque than when I first visited it twenty-one years ago, and the remarkable power of the cataract in tearing away and removing the hard rock is most impressive.

From Niagara to the Grand Cañon of the Colorado in Arizona is another far cry, but if we turn to that remote wilderness of the Far West we find a still more impressive example of the erosive power of running water, this time, however, far from blue and limpid. The Colorado River has for ages been running like the Nile from a rainy country across a dry desert plateau made up of flat beds of more or less soft rock

of brilliant and variegated tints. It has cut its bed down through several geological formations to a depth at places of more than 5000

FIG. 3.—The Nile at Bab-el-Kalabsha.

feet. The seething stream far down at the bottom of this awful abyss is nothing but a rolling mass of sand and mud liable to sudden floods and changes of level and colour. When I was down the cañon in 1891 the water was comparatively low and had the colour and consistency of

pease soup. The rocks were evidently being rapidly ground down and rolled along in pieces that would soon be broken up and washed away in grains to the Gulf of California. No intelligent person who has ever seen that marvellous river can doubt for a moment that its gorge has been scooped out in the past by the same processes as are still engaged in its excavation.

The illustration (Fig. 2) shows the zig-zag line of the cliffs and valley of erosion as contrasted with the straight lines of the cliffs of elevation which follow the course of fault fissures in the plateau.

To change the scene once more, there are rivers that not only deepen their valleys but scoop out enormous holes in them, so that were they to be temporarily dried up, their course would be marked by chains of deep

FIG. 4.—The second defile of the Irrawaddy.

and narrow lakes separated by dry spaces or ridges of rock. The Nile at the Bab-el-Kalabsha, about 30 miles above the great dam of Assuan, runs between granite walls of no great height, but these drop perpendicularly into water 18 fathoms or 108 feet deep, much below the level of the granite at the dam. The hard sand of the desert is blown into the river and swept along the bottom first downwards and then upwards as the water shallows, so as in course of time to grind out a long, deep trough which can be produced in no other way than by multitudes of hard grains constantly being dragged along by the powerful current (Fig. 3).

A still more striking example of this phase of stream erosion which I have noticed in the course of my travels is to be found in the second defile of the Irrawaddy in Burma, a river whose valley is less known, but at some places far more picturesque than that of the famous water

of Egypt. The Irrawaddy at the second defile, about 600 miles above Rangoon, crosses a range of mountains 4000 feet in height, and as the surface of the water is only 300 feet above sea-level the gap in the mountains is about 3700 feet deep. The river bed in the centre of the defile is full of enormous holes, some of them 27 fathoms, or more than 160 feet, in depth, produced as in the Nile by the swirling, surging current dragging along the grit and soil that is constantly being washed down from the shoals and jungle-clad alluvial banks upstream (Fig. 4).

Let us now come a little nearer the proposition under discussion, and, leaving these far-away rivers, consider for a few minutes another and more theoretical part of the question, arising, however, out of what we have been observing, and relating more closely to what falls to be observed at home. To make the subject abundantly clear I have drawn diagrams showing two model rivers, A and B, at four successive stages in their hypothetical history. (See Plate I.)

Each river has ten tributaries, five on either bank. River A on the left flows over soft strata that constitute the greater part of the original sloping plateau. River B, let us suppose, has the lower part of its course on hard solid granite, tinted darker on the plan, and hatched in section. The granite area being much more durable than the stratified part of the plateau, B will not be able to deepen its bed nearly so fast as A, and the tributaries of A will therefore eat their way downwards and backwards at the greater rate, as shown in the second figure. By and by the lowest of A's tributaries on the left bank may push its way backwards, say along the line of junction of the hard and soft rocks, which may be a fault fissure easy to excavate, and will in time succeed by virtue of its greater declivity in eating into the water-parting and tapping the headwaters of the nearest of B's tributaries. Nothing succeeds like success, and being thus reinforced with more water, this invader of B's territory may go on and next succeed in tapping the upper part of B's main channel, and end by finally decapitating B altogether and drawing off half of its water into A's domain. B will thus become weaker and weaker, and A will wax in the same proportions as B wanes, and the lowest enterprising tributary of A may end in growing greater than the parent stream itself, as shown in the next figure. This tributary may grow so deep as to end in finally tapping not only B's headwaters, but any part of B's basin it can reach, and in this way the final state of matters will be that the second of B's tributaries on the left bank may be diverted into A's basin, leaving B in a miserable condition with hardly anything to live on but fond memories of departed greatness.

The original course of the main river is described by physical geographers as *consequent*, as it is consequent on the original direction of slope. The course of the later tributaries joining it is similarly known as *subsequent*, but sometimes, as we shall see afterwards, rivers flow in a third direction, neither consequent nor strictly subsequent in the sense now used. In the last figure the second tributary of B on its left bank will be seen to have been tapped, so that the water near the confluence with the subsequent tributary of A runs in a direction against the slope of

the plateau and *opposite* to the original direction of flow of river B. A stream that has thus reversed its course is said to have become *obsequent*, a useful term first proposed by my friend, Professor W. M. Davis of Harvard. It is clear that in time A might become so deep as to draw off the whole of B, and in that case the lower part of B would run backwards against the original direction of slope, and the river become entirely obsequent. Good examples of obsequent streams are to be found in various old river-systems, and particularly in the basin of the Forth and Clyde, to which we shall now return.

This area also comprises fresh- and salt-water lochs of great beauty and interest, not only to the tourist in search of scenery and sport, but to the merchant in search of business and the scientist in pursuit of knowledge. These lochs, all more or less long and narrow, are often far deeper than the sea outside, and although mostly outside the Forth district have, as we shall see, a distinct place in the history of that river.

From the point of view of the geological historian, lakes, however they may have originated, are only to be looked upon as temporary and evanescent features of the ever-changing landscape. They constantly receive from the surrounding hills and glens streams of turbid water full of sediment, but the outflowing river is always clear and limpid, all the detritus having been separated in the calm water and left behind as in a filter. Filters, however, become choked up in time, and so do lakes, and the whole country is dotted over with old lake beds that have become overgrown with peat or silted up, many of them within quite recent times. Their outlets have also been deepened by the effluent streams, and the shallower ones may thus have been often drained quite dry. Many countries, like the United States, India, and Australia, have perfectly dry scenery with none of the glittering spots of fresh water that add so much to the attractiveness of the Scottish landscape.

It is only in countries where lakes have been produced at a comparatively recent time that they still exist in large numbers. Time was when there was none in Scotland, or at least very few in our upland glens and straths, but the Great Ice Age arrived and passed slowly by, covering the land like Greenland with a mantle of solid ice and snow, and when at last the glaciers melted away and the frozen flood subsided, the worn face of the land appeared once more to view, but now all flecked over with bright streaks and pools of shining water.

Countries that have been under ice, such as Canada, Scandinavia, Finland, and Patagonia, are sprinkled over with countless numbers of lakes and tarns, which have some relation to the local river-systems. As rivers of water scoop out hollows in their beds, so do rivers of ice in their valleys, especially where these are narrow and constricted, but ice being much more solid than water, has power to grind down its channel far more effectively. Besides this, the pressure on the bed of a glacier hundreds or even thousands of feet thick, as many of the Scottish glaciers must have been at one period, is far greater than that which the largest river can bring to bear on the gravel it is sweeping along. No doubt, as we have seen, if rivers were to dry up, as they often do in Australia,

PLATE I.—Four stages in the development of a river system.

PLATE II.—LOCH LONG AND LOCH LOMOND DISTRICT, SHOWING VALLEY SYSTEM.

The regions left white are under 500 feet above sea-level, and each gradation of tint represents a rise of 500 feet.

chains of lakes and pools would be found scattered along their track, but these would be quite insignificant compared to the deep basins in rocks where ice has been at work. The glaciers merely accentuated and deepened the old river valleys, but did not produce new ones. The rivers were on the ground long before the glaciers, which were only temporary tenants that appeared on the scene and occupied the valleys during an important but limited period. While the ice prevailed the rivers' work was suspended and their ordinary habits were changed, but only for a time, to be quickly resumed as soon as the climate again became normal.

It is thus apparent that, except for the rivers, the ancient Scottish landscape was a dry one, and we may leave the lochs out of account and consider them filled up and their beds no more conspicuous than other parts of the glens during the earlier chapters in the ancient history of the Forth.

II.—THE FIRST BEGINNINGS OF THE FORTH.

While engaged on the staff of H.M. Geological Survey, mapping the rocks of the Dumbartonshire Highlands in the district of Loch Lomond and Loch Long, many years ago, my attention was drawn to what seemed a singular feature of the whole river system in that part of the country. The subject had apparently never been discussed before, and I ventured to explain the hypothesis that suggested itself to me in a short paper in the *Scottish Geographical Magazine* for 1886. The general conclusions then arrived at still seem perfectly sound, and in view of the fresh knowledge we now possess of the geographical conditions and facts relating to the physical history and development of rivers and river systems, which have been carefully investigated in recent years by many eminent observers, it may be of interest to return to the subject and pursue it a little further now.

This district, it is to be noted, is not situated within the existing Forth basin, but is entirely drained by the Clyde, and therefore may appear at first sight to have nothing whatever to do with the valley system of the eastern river. On closer scrutiny, however, some important peculiarities soon become apparent, which, as we follow up the line of investigation, lead us to conclude that notable changes have taken place in the local river systems since the stream originated in the middle of the Tertiary age, and that this part of the Argyllshire and Dumbartonshire Highlands had in fact a great deal to do at one time with the Forth and its many tributaries.

On glancing at the map (Plate II.), two topographical features at once arrest our attention in the mountainous district of Cowal and Dumbartonshire, between Loch Lomond and Loch Fyne :

1. With the important exception of the Loch Long depression, the main valleys and glens, including the upper part of the Clyde, have a general trend towards ESE. or SSE.
2. The watersheds between what are now the main valleys are not situated midway between but close to the eastern sides of these glens.

The country between Loch Lomond and Loch Long is a triangular plateau of clay-slate and metamorphic schist, with twelve principal mountains varying in height from about 2000 to 2400 feet, separated from one another by deep glens. The deepest and shortest of these is the narrow pass between Arrochar and Tarbet where the two lochs nearly meet, and the neck of land between them, $1\frac{3}{4}$ miles in length, is at the highest point only about 160 feet above sea-level. This remarkable gap across the high plateau is not occupied by any stream of importance, and if it is due to erosion it must have been excavated by some stream long ago cut off or dried up. It may be mentioned that two basalt dykes have been traced along its course running in an ENE. direction from Argyllshire to the Loch Lomond ridge. These dykes have perhaps decomposed more easily than the metamorphic rock, and have no doubt been instrumental in directing the course of the original stream and giving the pass a more northerly trend than the other glens leading to Loch Lomond which we shall now notice.

Four and a half miles below Tarbet we come to Inverbeg, at the mouth of Glen Douglas, where the Douglas Water enters Loch Lomond at a small alluvial delta projecting from the foot of the steep mountain slope into the deep water. The Douglas Water has a comparatively straight course of four and a half miles, and Glen Douglas, which forms the second gap through the mountains, is only five miles in length between Loch Lomond and Loch Long. The highest point in the glen is about 500 feet above sea-level, and only half a mile from Loch Long. The surrounding mountains are over 2000 feet in height, and the glen is therefore cut right through them to a depth of over 1500 feet. The watershed is along the ridge of Creagan Hill, and on the actual slopes of Loch Long, and the tributaries of the Douglas first flow down the western sides of the mountains towards the sea, but, urged by some mysterious force, they turn eastwards towards Loch Lomond through the deep cut of Glen Douglas, although their course is thus lengthened by four miles. The West Highland Railway along Loch Long approximately follows the watershed at this place, and the observant passenger can get a short glimpse of how the streams run from Loch Long right down Glen Douglas to Loch Lomond.

Glen Luss, about three miles further south, is likewise trenched right across the plateau, but not to such a depth as Glen Douglas. The Luss Water from mouth to source has a course of about six miles as the crow flies, and its head tributaries rise about a mile and a half from Loch Long.

Glen Fruin again has the same south-easterly trend, but is a longer and wider valley. The Fruin Water rises about a mile from Garelochhead, and two miles from Loch Long, and reaches Loch Lomond at Arden after a course of ten miles.

The next valley to the south of Glen Fruin is the submerged trough of the Gareloch, once doubtless the line of a river that ran in the same direction. To this we shall return again.

The Dumbartonshire glens thus agree in ending in a water parting close to the shore of Loch Long, and in having streams that all flow in

an easterly or south-easterly direction in deep and well-defined courses through the plateau.

If we now cross Loch Long into "Argyle's Bowling Green" and the adjacent rugged mountainous coast of Argyllshire, we find the same physical peculiarities in evidence. The water parting hugs the east shore of Loch Fyne, and the glens are trenched through the heart of the mountains in such a way that the streams flow away south-eastwards towards Loch Long, and, with the exception of the Kinglas Water, no considerable stream is seen to run in a westerly direction to the Loch Fyne Valley. The most conspicuous case is that of the River Cur, which drains the country south of Loch Goil, and enters the Clyde at the head of the Holy Loch. This stream, after following a steep mountain course to the south-west for four miles, reaches a point near Strachur less than 150 feet above sea-level, and only half a mile from the shore of the loch. Urged eastward by the same apparently inscrutable principle, instead of flowing on to Loch Fyne and reaching the sea by the shortest path, it wheels sharply round to the left, and turning its back on the coast, plunges into the deep defile of Loch Eck, a glen which joins the Loch Long valley at the mouth of the Holy Loch, fourteen miles from the turning-point at Strachur. This defile is very narrow, and is excavated almost to sea-level through a mountain plateau over 2000 feet in height. The level of Loch Eck is only 67 feet above the sea, and the bed of the valley, now partly filled by alluvium, is no doubt considerably below sea-level for a long distance up.

Loch Goil occupies the next cut through the plateau north of the Holy Loch. The valley ends in Hell's Glen, a deep defile whose highest point is about a mile and a half from Loch Fyne and a little over 700 feet above sea-level. This trench is not so deep or long as that of Loch Eck, but it has one peculiarity of note. It abuts on Loch Long in such a way that its axis is in line with that of the Gare Loch, which suggests that the two were originally one valley.

Glen Croe, the northmost of the side glens on Loch Long, also forms part of a deep defile through the ridge to Loch Fyne. But in this case there is another equally large stream at the west end—the Kinglas Water—and the water parting at Rest-and-be-thankful is midway between the two sea lochs. Glen Croe is very deep and narrow, and skirts the south side of Ben Arthur (the Cobbler), which is nearly 2900 feet in height. The mountains at the head of Loch Long and Loch Fyne form the highest ground on the west side of Loch Lomond, and Ben Ime, the tallest of the group, is 3318 feet in height. The rainfall on their crests is large, and the streams where steep have considerable erosive power.

Loch Long ends at Arrochar in Glen Loin, which runs northward for three miles, and if produced a mile or two further would strike straight into Loch Lomond. But here another circumstance falls to be noted. Glen Loin is crossed at right angles by the Inveruglas Water, which truncates the apex of the triangular plateau and discharges into Loch Lomond. This stream rises in the wild granitic plateau

beyond Loch Sloy, and runs south-eastward for 3 miles in a deep V-shaped glen between Ben Vorlich and Ben Vane. Loch Sloy (Fig. 5), the former home of the "wild Macfarlanes' plaided clan," occupies a mile and a quarter of the glen. It is 812 feet above sea-level and 2280 feet below the crest of Ben Vorlich. The lochan is a lonely and desolate streak of water overhung by barren mountains and studded round with the moraine heaps of the old glaciers that once covered the plateau, radiated out into the glens, and finally melted away long before the wild clansmen likewise radiated into the low country, gradually melted away, and at last disappeared from the

Ben Vorlich.

FIG. 5.—Loch Sloy.

Ben Vane.

inhospitable region. This little corner is mentioned, as it will be found to illustrate a point in the process of development of the river system to which reference will again be made.

On the east side of Loch Lomond, exactly opposite the line of the Inveruglas Glen, the Arklet Water enters the valley at Inversnaid. Glen Arklet is a little over four miles long from Inversnaid to Loch Katrine, and forms the only deep gap through the Ben Lomond ridge. Loch Arklet is 463 feet above sea-level, and the ground to the north of it is more than 2100 feet high. The gap is thus cut some 1600 feet down into the ridge, and this, like the other facts that have been cited, is, as we shall see, a point of some significance in the topographical history of the district. (See Plate IV.)

When we come over to the south side of the Firth of Clyde above

Gourock we find the same eastward trend of the principal tributaries and glens, which generally run more or less in the opposite direction to that of the main river. The Gryfe Water, which rises at the head of Strath Gryfe, a little more than two miles south of the Clyde at Port Glasgow, instead of flowing northwards down the steep slope by the shortest route to the sea, takes a long eastward journey in an independent glen of its own to join the River Cart, which enters the Clyde near Renfrew, about twelve miles further up.

The Black Cart Water, issuing from Castle Semple Loch, flows north-eastwards for eleven miles, along a deep and well-marked gap used by the Glasgow and South-Western Railway, which runs straight through the Renfrew hills from Johnstone to Kilbirnie and Dalry. At the watershed the bottom of the gap is only about 200 feet above sea-level, while the hills on the north-west side of the glen rise to heights of over 1000, and those to the south-east to over 800 feet.

Four or five miles further east the ridge is crossed by another smaller trench running also north-eastwards past Neilston and Barrhead, 300 to 400 feet deeper than the surrounding country. This is occupied by the Cowden Burn, a small tributary of the White Cart. The line of this gap, if produced, would cross the Clyde at Rutherglen and make an acute angle with the main river below the confluence, instead of the obtuse angle that would be natural in a normal tributary.

If we now visit the country between the Forth and Clyde we again find in the Campsie ridge evidences of an older and comparatively disused river system. The first feature in the district is the well-marked narrow trench that crosses the country in a straight line between Clydebank, Kilsyth, and Larbert. This channel is occupied by two insignificant streams, the Kelvin flowing west towards Glasgow, and the Bonny Water, a tributary of the Carron, which runs eastwards and enters the Forth at Grangemouth. These two streams rise at a place called Kelvinhead, two miles east of Kilsyth, where the height of the valley bed and the water parting of the country is only about 150 feet above mean sea-level. This remarkable gap is used for the Forth and Clyde barge canal, and is one of the routes suggested for the proposed ship canal across Scotland. It is not produced by faulting of the strata, and is evidently the work of an ancient and swift river with great erosive power, well able to excavate a deep gorge in hard rock, which the puny streams that now wimple gently along the hollow could never have done.

If we prolong the line of this valley to the west, it is found to run exactly in line with the gap we have just noticed in the Renfrew hills at Castle Semple.

The Campsie and Kilpatrick hills, which form the south-western continuation of the long Sidlaw and Ochil range, consist of great flattish terraces or beds of hard volcanic rock resting on softer sedimentary strata. These separate plateaus evidently form the detached parts of what was once a single long flat-topped ridge or table-land stretching away northwards from what is now the Kelvin and Bonny valley to the

base of the Highland mountains. The plateau has been worn away by the Forth on the north, and bisected in the centre by Strathblane, a deep, broad glen that runs south-eastwards almost exactly in a straight line with the eastern side of Loch Lomond. Strathblane extends southwards past the village of Campsie and Lennoxton and joins the Kelvin Valley west of Kilsyth. The watershed is at Ballagan, near Campsie, and the western end of the glen forms the course of the Blane, a small stream running westwards into the Endrick, which enters the east corner of

FIG. 6.—The Clyde river system.

Loch Lomond at Buchanan Castle. The height of the watershed is a little over 250 feet at Campsie, and, as the adjacent Strathblane hills are over 1600 feet in height, a breach more than 1300 feet in depth has been cut in the plateau long ago by some river of more importance than any of the existing local burns. The excavation of this breach in the plateau has been originally facilitated by a large fault which runs obliquely across it and has produced a line of weakness like that in the Forth valley at Stirling.¹

¹ An interesting account of the changes in the local drainage system of the Campsie plateau is given by Mr. E. B. Bailey in the *Geological Survey Memoir of the Glasgow District*, 1911, pp. 198-201.

Now it is possible, I think, to fit these data together, and to construct the general framework of the story they have to tell. An inspection of the accompanying map of the Clyde river system shows it to be altogether abnormal and irregular, quite unlike the plan of a consequent stream following a definite course to the sea (Fig. 6).

In the part of the country under consideration the principal rivers and valleys are thus seen to follow a general easterly, south-, or north-easterly course, but with one notable exception—the Clyde, which flows in exactly the opposite direction. The Clyde is apparently an obsequent river above Gourrock, and the Glasgow district is evidently the site of an ancient battlefield between two contending rivers, such as A and B in Plate I, where the Clyde has, like A, become the victor, and brought the long struggle to an end by decapitating the Forth, and greatly diminishing its former grandeur. The Clyde has been the Highland robber and the Forth the Lowland sufferer by this ancient invasion from the wild West. A large part of the original territory of the Forth, some 1200 square miles in extent, has apparently been cut off, and the water drawn aside from its ancient channels.

When first I suggested in 1886 that the Clyde and its tributaries originally ran into the Forth, some geologists in the West were offended at the notion that the Clyde was a usurper and the predatory habits of Dumbarton and Argyllshire dated back to such a remote antiquity—habits that, once formed, lingered for ages before they were finally eradicated. But a quarter of a century has not altered my opinion, and, indeed, the study of other river systems has only served to strengthen it. To make a long story short, the appended map (Fig. 7) indicates what I believe may have been the general outline of the river system of the Forth, if not at the very beginning, certainly at an early stage in its career, when the valleys were several hundreds of feet shallower than they are in our time.¹

The excavation of the original valleys dates from a considerably later time than the Miocene age, but, as we have seen, they were in existence long before the Glacial period. In surveying the high ground at the head of Loch Lomond I once traced a large basalt dyke right across the Loch Sloy defile and over Ben Vorlich, at a height of 2950 feet. Now this dyke, which is only one of many in the district, was injected from below into a fissure which ran eastwards across the country towards Loch Katrine, at a time when the deep valleys had no existence, otherwise the molten lava would have escaped at the lowest point, flooded the valley beds, and never reached up to the top of the plateau. The glens have thus, like teeth cut in a saw, been notched out of the basalt veins since the Miocene age, when volcanoes were numerous in the western isles, and multitudes of dykes were injected into cracks in

¹ My old friends and former colleagues, Messrs. Peach and Horne, in their account of the Scottish Lakes in the *Report of the Bathymetrical Survey* by Sir John Murray and W. L. Pullar (1910), refer at pp. 465-6 to the origin of the Forth and Clyde valleys, and offer a somewhat different explanation of their early history. No doubt there is room for discussion, but I still venture to think my old riverbeds will hold water, if not at every loop, at least in most of the deepest pools.

FIG. 7.—Map of the probable ancient river system of the Forth.

the Highland plateau. The Ice Age intervened after the rivers had excavated their valleys, and although, as we shall see, the glaciers produced important changes, they were not instrumental in producing the valleys themselves.

The ancient Forth and Clyde watershed at the period in question was evidently along a range of mountains west of Loch Long. This range formed the seaward boundary of the north-west of Europe, and must have been much higher and more imposing than the half-submerged fragments that now remain. The western sea lochs were then river valleys, and the Firth of Forth the bed of a great river flowing far beyond the mouth of the present estuary. The great size of the Firth of Forth, which forms the most conspicuous notch in the coast between the Moray Firth and the Thames, shows how large the ancient river must have been at one time.

But here the reader may well ask: "How do you know that the long trough of the Firth of Forth was not really produced by a bending down or subsidence of the land?" To this very reasonable objection I reply, "See how the Carron, Avon, Almond, Water of Leith and other main tributaries run in an easterly or north-easterly direction, and not straight northwards by the shortest route to the sea. Had there been a sinking down of the land to produce the main valley, the water would have run down the declivity like rain on a roof perpendicularly to the contour lines and not at an oblique angle or nearly parallel to them." No, the trend of the side valleys is clearly the result of some widespread original cause that has stamped permanently on the face of the country the pattern of the first river system.

There was one important difference between the eastward and the westward flowing waters. Those flowing west had not nearly so far to go as those flowing eastwards, to their ultimate oceanic destination. The consequence was that the latter, flowing at a lower gradient, had probably less velocity and therefore less erosive power than the former. In this case, unlike that illustrated in the diagram, it was thus not the greater hardness of the bedrock but the lower gradient, that put the Forth at a disadvantage in the struggle for supremacy with the Clyde. Then again most of the rain clouds which come from the Atlantic would condense on the part of the range next the coast, and so the westward flowing streams would receive at their sources more water than those in the drier eastern region.

The ancient Clyde and its tributaries would thus have most erosive power, and be best able, when fairly started, to eat back into the borders of the plateau originally in the Forth domain, and when once the invader became strengthened and the defender weakened by these conquests, the process of acquisition would become ever easier.

We are not now concerned with the part of the Clyde valley below Wemyss Bay. Let us suppose a large river running southwards off the plateau towards the Irish Sea, with its head tributaries in Loch Striven, the Kyles of Bute, Loch Fyne, and the Clyde valley below Dunoon. Each of these, well replenished by the heavy rainfall, like Niagara on a small scale, ate its way back into the mountains, slowly at first, no

doubt. The eastmost branch gradually managed to work back and northwards till it crossed and penetrated the soft sandstone on the watershed at Dunoon and tapped the headwaters of the eastward-flowing tributary of the Forth, now the upper part of the Firth of Clyde. The bed of the eastward-flowing river, with its long seaward course, was no doubt situated at a higher level than that of the invading river, and probably occupied a comparatively flat valley. When once it was tapped at the head the whole drainage of the Loch Eck valley was diverted southwards into the thriving Clyde. The additional volume of water increased the flow of the river, and this tributary became more important than its next neighbour at Loch Striven, and went on deepening its course and extending its territory. To make the subject as clear as possible, the accompanying imaginary bird's eye view is intended to show what may have been the general appearance of the ancient Forth and Clyde valley at this stage, when the Clyde was about to break through into the Forth basin near what is now Dunoon. (Plate III.)

The original slope, while it determined the general direction of flow, was not the only factor in shaping the trend of the river courses. The rocks might be so inclined, and the land surface so grained, that the work of excavation became much easier in some directions than others. If we try to draw the point of a nail obliquely across the grain of a fir-board, the moving point will describe a series of zig-zags—the result of the struggle between the draughtsman's hand and the lateral resistance of the fibre of the wood to a point drawn obliquely across it, and this will illustrate the operation of the forces determining the minor changes in the directions of the valleys.

In the several parts of the district there is evidence of such a struggle having taken place in the early days of the river valleys. The water was trying to flow south-eastwards, and the strike or grain of the plateau, particularly in the Cowal area, was towards the SW. or SSW. The tendency was therefore to deflect the stream towards the south. This is best seen in the Cur valley, which has all the appearance of having originally extended in a perfectly straight line from Strachur to Ardentenny at the mouth of Glen Finart. Glen Finart ends in a wind-gap at the bend of Loch Eck, and the lower part of Loch Long is probably the south-eastern prolongation of the original valley. The Holy Loch and Glen Massan may have been another parallel valley at first, but owing to the grain of the rock between these valleys, the Cur found it easier to abandon its original track and bend in a more southerly direction towards Glen Massan. This geological feature, combined with the prevailing tendency of subsequent streams to run southwards, appears to have made the recession of the falls in all cases greatest towards the north, and all the invaders accordingly traversed the Forth and its tributaries in that direction. The lower part of Loch Eck is thus probably on the course of an original tributary of the River Massan which ate its way northwards and stole the headwaters of the Finart at an early stage. The decapitated Finart was thus unable to do much digging, and the Loch Eck defile became the principal glen.

The advancing Clyde next pushed out an arm northwards and suc-

PLATE III. —Bird's-eye view from the supposed ancient watershed of the Forth and Clyde.

ceeded in cutting off the upper part of the Loch Gail and Gareloch river, and, following the line of one of the numerous joints or weak places on the site of Loch Long, it apparently cut off a small piece of the head of Glen Douglas, which remains in Collessan Glen, and finally reached Ben Arthur and diverted the Glen Croe Water into the lower channel, drying up the gap leading to the Loch Lomond valley at Tarbet.

Now I need scarcely say that it is not easy, particularly for those who have not made a special study of such matters, to picture to the mind how all this has taken place, nor to realise the vastness of the time these operations involved, but all the circumstances seem to show that this has undoubtedly been the general course of events in the evolution of the valley system of the district.

The last stream to be cut off was the Glen Croe Water, and this is no doubt the reason why the gap at Arrochar is the deepest that crosses the Dumbartonshire Highlands. The River Croe had more time to work down its bed before it was decapitated, or rather curtailed, and had therefore excavated its glen to a greater depth than the other streams. When the River Cur was curtailed its glen was no deeper than the top of the wind-gap at Whistlefield above Garelochhead, 320 feet at least above the present sea-level, but the bottom of the old Glen Croe between Arrochar and Tarbet only rises to a height of 160 feet. Since it was dried up it has probably not been reduced much in height, as it has no important streams to wear it down, and the glaciers that deepened the other glens flowed across and not along its axis.

Although the Loch Long glen is nearly all submerged, it is still possible to trace the same process of erosion going on in Glen Loin, its northern prolongation beyond Arrochar, and this helps to illustrate the method on which these glens seem to have been originally formed. The head of the valley for a mile above Arrochar is filled up with the alluvium of the stream which, instead of eroding, is here depositing a delta at sea-level. Could the land be lifted and the valley again dried up, a waterfall would at once be produced in Glen Loin which would work its way up the glen towards Loch Sloy. But out of Loch Sloy there is another stream, the Inveruglas Water, running eastwards across the course of Glen Loin into Loch Lomond. Now there will be a competition between these two streams as to which one can deepen its bed fastest, and in this connection another circumstance must be noted. The surface of Loch Lomond is at present about 23 feet above sea-level, and so long as it thus remains above the level of Loch Long, the streams running into the sea-loch will have the advantage over those flowing to the inland basin of so much more of a fall. In course of time the Inveruglas Glen will be worn down nearly to the level of Loch Lomond, but deeper it cannot go unless Loch Lomond also subsides. At the same time the Loin Water will continue to lower its glen, and if, as we have supposed, the land were to be upheaved so as to dry up Loch Long, but not Loch Lomond, which is an inland lake, the work will be hastened and the Loin will at last break through the watershed and draw off the Inveruglas to the south. The Long valley will thus be deepened for three miles, and

the last mile of the Inveruglas Glen will be dried up, leaving a deep, short wind-gap similar to the one at Arrochar and Tarbet. The Loin, thus reinforced by the much larger volume of the stream issuing from Loch Sloy, will receive a fresh lease of life and will go on eating back its glen into the mountains, and finally draining the little lochan entirely away. Thus in the remote future Loch Long might, especially if a slight submergence were to occur, be found to have pushed its way far back through the defile between Ben Vorlich and Ben Vane into the plateau west of Ardlui.

In all this district the massive metamorphic schists are intersected in different directions by great vertical master joints, and no doubt the very straight course of Loch Long is partly due to these lines of cleavage running parallel to the valley. The steep mountain slopes are often covered with immense blocks and heaps of rock that have slipped down in large slices, and at some places, particularly in the gap at Tarbet, deep fissures can be seen high up on its southern slopes which mark the lines of incipient landslips. Stones dropped into some of these rents can be heard rattling a long way down into the mountain side, and some day, when perhaps there is an abnormal snow or rainfall, pieces of the loosened mountain side will move downwards and no doubt alarm the inhabitants by the exhibition of a geological phenomenon that happily is not now very common on a large scale in the district.

While this was probably something like the early history of the valley, the other tributaries of the pushful Clyde were not idle. It must be mentioned that the rocks at the turn of the estuary above Dunoon are soft Carboniferous or Old Red Sandstone strata much more easily eroded than the tough old Highland schists further north, and the high ground on the south side is made up of hard volcanic rocks, the continuation of the Campsie and Kilpatrick range. Between these two hard tracts the Clyde has dug its channel. When the first breach had been made into the old Forth valley between Holy Loch and Gourrock, the head of the stream flowing east was diverted to the south, and very little water was left to feed the Forth from this source. The next part to be tapped was the water in the previously decapitated Gareloch valley, and there may have been a waterfall where it entered the Clyde near Greenock. As the process went on the whole of the upper reach of the ancient Forth became in time obsequest, and it did not take much further trouble for the Clyde to draw off the remainder of the old river as far east as Kilsyth, through the outlet at Gourrock. The sedimentary rocks in that district are more or less easily eroded, and the deep breaches through the harder volcanic ridge of the Campsie, Kilpatrick, and Renfrew hills, had been already cut out by the older river. All this work, it must be remembered, was done at the time when the river beds were above the level of the gap at Whistlefield, at least 320 feet higher than at present, and the firths and lochs had no existence. The general subsidence of Scotland at the Glacial period finally submerged these old valleys and converted the deepest of them into arms of the sea.

If the ancient Clyde, on this hypothesis, entered the Forth by the col at Kelvinhead, which remains still about 160 feet above sea-level, it

follows that all the river basin to the west must have been then at a higher level than the col.¹ Supposing for the sake of argument we disregard the probable additional height of the whole ancient land surface above the sea and take the level of the Kelvinhead watershed when last occupied by the old river at 160 feet above ordnance datum. If now the river had a fall of say 4 feet per mile, which is a moderate gradient, the distance from Kelvinhead to Gourrock being 33 miles, the whole fall would be 132 feet and the height of the valley at Gourrock 292 feet above its present level. At this gradient the river bed would be at Whistlefield, which is 9 miles further on, 36 feet higher, or 328 feet above sea-level. The actual height happens to be 320 feet at that spot, and this helps to show roughly how much higher the bed of what is now the Clyde must have been at the time of which we are now speaking. No doubt the absolute height above the sea was far more than this, as the whole country must have been far above the present sea-level, but that does not affect the present argument.

If we were to fill up the Clyde at Dunoon by a dam only 200 feet high, and make a smaller barrier at Castle Semple Loch, the Clyde and all its tributaries would submerge the Glasgow district again and overflow into the Forth by way of the Kelvin valley.

The Loch Lomond valley appears to have a somewhat different history from that of Loch Long. It is, I believe, in the main an old consequent valley, and the Ben Lomond ridge marks part of an original water-parting between two tributaries of the Forth. The southern broad part of the loch, with its beautiful archipelago of low islands, is entirely excavated out of soft sandstone, and the great fault that forms the junction line between the metamorphic and sedimentary rocks runs across it in a NE. direction past the north side of Inchlonaig.

As already noted, the east side of Loch Lomond as far north as Tarbet trends nearly in a straight line, striking south-eastwards for the Strathblane gap in the Campsie plateau, and this seems to be the line of the old consequent river valley. Above Tarbet, however, the glen narrows and runs almost due northwards. At this slight bend the ancient mouth of Glen Croe comes in, and here it seems to me the original valley ended and split into two smaller glens. Glen Croe, whose history we have already considered, was the larger, and the smaller one ran straight northwards for about two miles, ending originally in a corrie below Inversnaid and Upper Inveruglas.

This may appear at first sight a curious conclusion, but it seems to be warranted by the following evidence:—

At Inversnaid, exactly opposite Upper Inveruglas, the Ben Lomond ridge, as we have seen, is notched by the deep gap of Glen Arklet, which runs through to Loch Arklet, and is at its highest point only 463 feet above sea-level. This is the only pass through to Loch Katrine, and is cut across a ridge of mountains more than 2000 feet in height. It is thus

¹ This is the height of the surface of the ground only, but the true rock bed of the col is less than this. Recent borings in the valley have proved that there is a covering of 60 feet of soil and drift over the rock a short distance west of Kelvinhead, and thus the height of the rockbed of the ancient channel may have been less than 100 feet here.

some 1600 feet deep, and lies exactly in the line of the Inveruglas Glen, which is also of great depth. Glen Arklet is manifestly the eastern continuation of that valley, and the two were connected at a time when the Loch Lomond river was 500 feet higher than at present. The panoramic sketch (Plate IV.) from the top of Ben Vorlich shows the Loch Katrine valley, Loch Arklet and Glen Arklet crossing the Ben Lomond ridge at Inversnaid.

The ancient outlet of Loch Sloy was thus in its lower reaches a straight valley about six miles long that apparently joined Strath Gartney on the site of what afterwards became Loch Katrine, or perhaps its waters overflowed into the valley of Loch Chon and Loch Ard and broke through the Menteith Hills at Aberfoyle in the Forth valley.

Now, if this be so, it is clear the Loch Lomond stream did a little stealing like its neighbour of Loch Long. The small tributary supposed to have run northwards from Tarbet seems to have followed the prevailing fashion, eaten its way north and tapped the eastward-flowing Arklet-Inveruglas Water, no doubt occupying a more elevated glen, as the Loch Long river was doing a few miles away. The Inveruglas stream was drawn off and a dry wind-gap left through the Ben Lomond ridge, which in course of time formed the bed of the obsequent little River Arklet well known to tourists at the falls of Inversnaid. The new dam of the Glasgow waterworks across the glen above Inversnaid will have the effect of sending the water eastwards into Loch Katrine, and changing the Arklet from an obsequent to a consequent river once more.

There still remains for explanation the northward extension of Loch Lomond, and here I admit the evidence is not very clear. It looks to me as if the Clyde by this time had drawn off the lower part of the Loch Lomond river, and there was thus a much greater fall towards the south than to the east. In this way the southward flowing tributaries of the Clyde would be eating their way backwards into the plateau much faster than the headwaters of the Forth. There is no clear evidence of a line of fault, but there may well have been a straight series of joints or a line of weakness at this place which produced two original glens in the line of the Loch Lomond valley, and the ancient Inveruglas Water may have been joined on the north by a large stream on this line opposite the very place where it was being tapped from the south. When the barrier was cut through, the northern tributary thus ran straight on down the line of the crack, which in time became greatly deepened and widened with the additional volume of the confluent waters from the high plateau to the north and west, and was finally still further excavated by glacier action to a depth of more than 600 feet below sea-level.

The river, whose headwaters thus probably at first ran from the Ben Ime and Loch Sloy plateau, eastwards towards the Trossachs, would form an important feeder to the great tributary of the Forth that originally excavated the glens of Loch Katrine or Loch Chon, which are now occupied by far smaller streams than their size seems to warrant.

The Douglas and Luss waters were, no doubt, branches of the

PLATE IV.—View eastward from Ben Vorlich (3092 ft.), showing Loch Lomond, Loch Katrine, Loch Arklet, and the obsequent Arklet valley at Inversnaid.

original Loch Lomond river. The Fruin and Finlas glens probably mark the sites of two branches of another considerable stream that ran south-eastwards through the gap at Alexandria, now occupied by the River Leven. All these points can best be followed by reference to the appended map of the old river system.

After all these depredations the south-western branch of the Forth shrank up and became obsequent from Kilsyth westwards, and the northern branch, above the confluence at Grangemouth, became henceforth the main trunk of the river.

The Forth crossed the volcanic ridge of the Campsie and Ochils at Stirling, having, no doubt, sought out its weakest place, where the rocks were not only dislocated by several great fractures, but the hard whinstone beds of the two ranges had thinned away at their outcrop to a narrow neck through which the river had no difficulty in selecting and clearing out a passage. Above Stirling the country is principally made up of Old Red and Carboniferous Sandstone beds, and the degradation of these was regulated by the rate at which the river was able to deepen its gorge in the harder whinstone barrier between Stirling Castle and the Abbey Craig, at the foot of the Ochils.

The lowering of the Loch Lomond valley went on at the same time, and in the gap at Balfroon there are traces of a channel between that old branch of the Forth and the present river, before the Clyde had completely won in the race of degradation, deepened its bed, and sucked away the last vestiges of the original tributary. The Teith, flowing from Loch Katrine and Loch Lubnaig, is an old tributary from the north, but the Allan Water, like the Devon, is apparently a more modern and partly an obsequent stream, belonging to a later period. Both the Devon and the Allan enter in the wrong direction and cannot be considered as part of the original river system.

It is noteworthy that the Forth below Stirling has no large tributaries from the north. On the south, however, besides the Carron, three normal rivers enter the Firth, and run north-eastwards in old valleys nearly parallel to the Kelvin-Bonny glen. The River Avon, on the west boundary of Linlithgowshire, although it has now a sharp kink to the west at Linlithgow Bridge, no doubt once continued its north-eastern course to the main river below Blackness. The ancient valley was deeply trenched across the hard volcanic ridge, which must have once formed a single range extending continuously through West Lothian from the site of Bathgate to what is now Bo'ness on the shore of the estuary. The hollow in which the romantic old palace and loch nestle in picturesque serenity was part of the original Avon valley before the Ice Age, the last three miles of the present glen above Inveravon being a comparatively recent excavation.

The Almond, which bounds the county on the east, is also apparently another old consequent stream. It too has slightly changed its course at the mouth. The old glen ran under Dalmeny House, and the gorge between Cramond and Craigiehall was excavated after the Ice Age. At that time the whole country was first swept by a great glacier or continental ice sheet, and when the ice melted the land was

left so deeply buried under drift and clay that the rivers were often unable to recognise their old valleys, and had to start afresh to cut out new beds through the solid rock at the places where the ancient tracks had been lost and could not be recovered. The Almond, and its principal tributary the Breich, run for twenty-two miles in an almost perfectly straight course towards the north-east. The original Almond valley may have been continued at an early stage south-westwards across the line of the Clyde near Wishaw and Shotts to Strathavon, and been decapitated like the higher tributaries of the Forth, but that part of the Almond watershed is over 700 feet above sea-level, and the traces of the ancient valley system are somewhat faint in this district.

The Water of Leith and the North Esk in Midlothian both flow in the same general direction, one on each side of the Pentland ridge.

Those rivers of the Lothians have neither robbed their neighbours nor been much disturbed themselves in the course of their comparatively even history.¹ The rainfall being here much lighter than in the west, and the country flatter, their erosive power has been less than that of the higher tributaries of the Forth, and there has thus been little of eventful episode to record in their career.

But the Clyde did not rest content with robbing the Forth of so much territory. It worked its way as a subsequent river south-eastwards by Lanark, and appears to have ended by also invading the Tweed basin and drawing off some of the headwaters of that old consequent river at Biggar. But this is a question which does not concern the present investigation. The reason why the western river was able to wear down its valleys faster than the eastern streams is no doubt that the fall was greater to the west, and the rainfall was also much heavier next the Atlantic seaboard than elsewhere. The land surface was a vast sloping plateau culminating in high mountains with a steep fall towards the Atlantic Ocean, and a long gentle inclination eastwards towards the mainland of Europe, of which Scotland was then but the north-western corner.

III.—THE BURIED CHANNELS OF THE FORTH VALLEY.

The next chapter in this fluvial chronicle relates to events of a far later period, when the existing river-system was well established. The land, as we shall soon be able to prove, still stood at a higher level in relation to the sea than it does in our time, but the rivers had deepened their valleys more than 500 feet since the events that have just been discussed. As there were no lakes to act as regulators and filters to the streams, the rain, when it fell, rushed down the glens in angry turbid torrents and hastened the work of valley erosion.

The evidence for the original valley-system described in last chapter is based on observation of the superficial and orographical features of

¹ In Mr. J. Cossar's interesting paper on the Edinburgh district in the *Scot. Geog. Mag.* for 1911 at p. 599, a good example is given of a small depredation of the South Esk, which at Borthwick has captured two streams originally belonging to the river Tyne.

the country, that any one can study with good maps and eyes for the physiognomy of the landscape. But now we have to deal with a different kind of evidence altogether, evidence far more difficult and costly to obtain, but once acquired, perfectly sure and unimpeachable.

In some parts of the Forth and Clyde area that have been referred to as made up of soft carboniferous rocks, large quantities of coal and ironstone have been mined, and discovered by boring during the past century. While the pursuit of mineral wealth was the object of the boring, incidentally a great deal of important scientific knowledge has at the same time accumulated, relating to the nature and depth of the superficial soil-covering of the land in these districts. Many hundreds, and even thousands of bores and shafts have been sunk to the rock, and by collecting and examining the records of these—a most laborious piece of work—geologists have been able to prove that both in the Forth and Clyde basins there is a system of buried river channels far below the present surface under or near the existing rivers and their tributaries. These are all filled up, and so deeply buried under beds of clay, sand, and detritus that, but for the operations of the mineral explorer, their presence and depth would never have been discovered or perhaps even suspected.

It is interesting here to note that in the Niagara district also a great deal of boring for oil and gas has been going on in recent years, and Dr. J. W. W. Spencer has, by examining and collating the records of the drillings, been able in the same way to discover and trace out the ancient buried channel of the river which, it appears, once ran by quite a different course from Lake Erie to Ontario.

No doubt the phenomenon is not an isolated one, and buried channels exist at many other places in this country under the principal rivers and estuaries, but where there is no valuable mineral to search for it is not likely that much boring will be undertaken for purely scientific purposes. A bore 300 feet deep through loose materials is a difficult operation, costing perhaps a pound a foot; and the expense has been so great that it is to be regretted a good many bores that had been begun have been given up, where the “surface” became very thick, at places where it would be of great scientific interest to find out the exact depth from the ground level to the solid rock.

The existence of buried river channels in Scotland seems to have been first discovered in 1869, when Dr. James Croll described in the *Transactions of the Edinburgh Geological Society* the results of an examination by Mr. James Bennie and himself of some two hundred and fifty bores made in the valleys of the Kelvin and Bonny rivers on both sides of the water-parting at Kelvinhead. They traced the course of two gorges below the glacial drift filling the old gap, and running for most of the way along the lines of the existing streams. The eastern channel entered the sea at Grangemouth at a depth of 260 feet below mean sea-level, and the western in the Kelvin valley was found to be 306 feet below the surface of the ground at Duntocher, near the Clyde at Old Kilpatrick. The buried channels of the Glasgow district have been lately investigated in much greater detail by the Geological Survey, and

in the memoir published in 1911 a contoured map is given by Mr. Hinxman and Mr. Carruthers showing the pre-glacial topography of the valley very clearly.

Since Dr. Croll's time a great deal of mineral exploration of various kinds has been carried on, and in the Forth valley I have collected many fresh data and done some boring on my own account, all of which has helped to throw fresh light on the old river system as it existed both immediately before and after the Great Ice Age.

The Almond.—The Almond river, which now joins the sea at Cramond, had an older channel in pre-glacial times under Dalmeny House where the Dolphinton Burn now enters the sea. In the numerous borings for oil shale in that locality the course of the buried gorge has been accurately traced for about nine miles to the south-west. The Almond runs at places through glacial drift on the line of its original channel, but at a higher level, and at others it flows along a gorge more recently excavated in the rock. The old river was a steep one, no doubt, with numerous falls. Between Carlowrie and Midcalder the gradient was very high, about 31 feet per mile, and if this gradient was uniform the river must have entered what is now the estuary about 200 feet below the present sea-level. Carlowrie Haugh as seen from the Almond viaduct on the Edinburgh and Glasgow Railway is a comparatively tame little strath north of Ratho station, between low hills of whinstone, but at that time it was a picturesque glen more than 200 feet deep, and the half-buried crags of Dolphinton and Dundas were then high and prominent objects in the landscape.¹

The Avon.—The River Avon has for the most part cleared out its pre-glacial valley, but, as already mentioned, there can be little doubt its original course to the Forth lay in the direct line of its upper valley west of Linlithgow. The deep hollow, now the bed of Linlithgow Loch, between the volcanic range of Cockle Roy and Bonnytoun Hill is, no doubt, part of the ancient Avon valley which, as has been proved by borings, was continued north-eastwards in a straight line and reached the main river on the east side of what is now the low basalt promontory of Blackness, but was then a conspicuous crag in the Forth valley. During the Ice Age the Avon valley became blocked up with drift, which is at places more than 100 feet deep, and the part east of Linlithgow was, when the great glacier retired, so obliterated, that the river found it easier to make a tack to the west and double round across the neck of soft rock west of Bonnytoun Hill, escaping by a shorter and steeper north-west passage to the Forth at Inveravon. The subsequent channel thus produced was in time deepened into a gorge which the river has occupied ever since. The Avon is a smaller stream than the Almond, and I have not yet found any traces of a very deep buried gorge along its course such as exists in the latter valley.

The Carron.—The Carron is a much more important stream than the Avon, and although, as explained above, it now only represents a

¹ See the author's paper on the "Buried Channel of the Almond," *Trans. Geol. Soc. Edin.*, 1903, p. 194.

fragment of the ancient river, it has, with its main tributary, the Bonny Water, been able in pre-glacial times to erode a deep and well-marked gorge, especially in the lower part of its course between Camelon and the sea at Grangemouth. I have gone over most of the evidence collected by Mr. Bennie and Dr. Croll, which has been supplemented by more recent mineral explorations, but have not found much to add to their results. Quite recently the Carron Company's workings in the Main and Upper and Lower Coxrod coals at Carronshore have encountered the buried gorge (Fig. 8). In a bore near the present river at Carronbank, about 430 yards north-west of Dalderse Mill Farm, the depth to the rock was 285 feet, and the channel was filled chiefly with sand and loose materials. The surface of the ground is here about 22 feet above mean sea-level, so that the bed of the buried valley is 263 feet below Ordnance Datum at this spot. Neighbouring bores have proved the depth of surface deposits to be between 100 and 200 feet on either side, so that the deep channel forms a hollow 50 or 60

FIG. 8.

feet below the level of the deepest part of the neighbouring rock surface. The section given by Dr. Croll at Towncroft near Grangemouth is three-quarters of a mile further down the river, where the depth was found in two adjoining bores to be 42 and 45½ fathoms, or 252 and 273 feet respectively. In the adjoining Main coal workings of the Grangemouth Colliery, still further east, the coal was cut off to the south at a depth of 43 fathoms by a wall of clay running eastwards towards the mouth of the present river. From this point to Carron the course of the buried gorge has been accurately traced for three miles. It is, as I have already noted, a very difficult and costly business to bore a hole 40 or 50 fathoms down into running sand, clay, and loose materials, and some of the bores did not succeed in reaching the very bottom of the channel. This is no doubt unfortunate, geologically, but it must have been deeper downstream than at Carron, and the Towncroft bores probably did not strike the very lowest point. In No. 6 pit workings at Carronhall Colliery the Main and the Upper and Lower Coxrod coals were cut off by the clay down to a depth of about 248 feet, but a level mine was successfully driven at a depth of 271 feet right under the trough, which proves conclusively that its deepest point at Carron goes

down to 248 feet at least, but not so deep as 271 feet. As the coast at Grangemouth is three miles further down stream, and a river able to excavate such a gorge must have been fairly swift and steep, it follows that the depth at the present coastline must be at least 280 and perhaps 290 feet below the surface. If, like the old Almond valley, it had a fall of as much as 30 feet per mile, or even only 10 feet, the depth would then be considerably over 300 feet. This point is important in connection with what follows later.

The old glen seems to have been from 400 to 500 yards wide at this place, but as most of the boring and nearly all the mining has been carried on along the north or left bank there is no very decided evidence as to the exact width of the deepest part of the trough. It apparently was not much more than 500 yards at any place, and was certainly less at some spots. Superficial deposits of the Carse near Grangemouth cover the rock surface to a depth of more than 100 feet, showing how great has been the erosion of the old Forth valley before the great submergence at the Glacial Period. But in that old rocky land surface there had been scooped out glens 100 or even over 200 feet deep, and no doubt there were numerous side gullies and branches the courses of which we may never be able to trace.

River Devon.—The last of the old tributaries of the Forth of whose buried course I have been able to obtain a record, is the Devon between Tillicoultry and the Abbey Craig at Stirling.

The Devon is in some ways the most remarkable tributary of the Forth. It runs westwards for the last twelve miles of its course, against the flow of the main river, and seems, according to the code of common fluvial law, to have no legal right to be in that position. The Devon, from the Crook westward, with its abnormal course, is a much younger tributary of the Forth than the others we have considered, and in this respect it shares the character of the Allan Water. Both are upstarts and robbers of other rivers' territory, and do not belong to any part of the old consequent river system of the Forth.

The Devon has two distinct sections. The higher reach of the river issues from the deep trench across the centre of the Ochils, the southern end of which is called Glen Devon, and the northern Glen Eagles. Now Glen Eagles is the only deep pass across the range, and is occupied by a comparatively small stream running past Auchterarder into the Tay. But to go back to the original river system this gap, whose present water-parting is about 750 feet in height, probably marks the course of a consequent river flowing first south-eastwards from the Glen Artney Forest, and then eastwards by Loch Leven to the lower part of the Forth valley, or more likely north-eastwards from Loch Leven along the valley of the Eden between the Forth and Tay, at a time when all the land behind the Ochils was more than 750 feet above sea-level.

The volcanic ridge of the Ochils was a hard plank to saw, and the Forth valley being now worn deeper at the Stirling gap than the higher-lying part of the Devon north of Glen Eagles, the tributary of the Allan Water succeeded in eating its way back and drawing off to the south-west some of the headwaters of the old Devon. The Tay was also at

work, and its tributary stream the Ruthven Water also invaded the territory from Auchterarder on the north. Gradually Glen Eagles was thus dried up and became the bed of an obsequent stream running north into the Ruthven Water and the Tay. The other end of the old Devon Pass was attacked in the same manner by a tributary of the Forth eating its way back along the great fault-line skirting the southern face of the Ochils. In time the river was tapped by this industrious newcomer at the Crook of Devon and the water diverted into the south-western channel, now the lower Devon valley, so as to dry up the headwaters of the ancient Eden.

The Great Ice Age, it must be explained, was not a single continuous cold period, but was subdivided by one or more so-called *interglacial* periods with a more or less mild climate. This part of the Devon valley may have been excavated during one of these intervals after the greatest cold had ceased. The reason for this supposition is the fact that the buried gorge is filled, not with the hard boulder clay produced under the great ice sheet of the coldest period, but with gravel and the red glacial clay deposited in sea water after the large glaciers had retired to the mountains, and at a time when the land was submerged and the sea stood at about 100 feet above its present level.

The above seems to me the most feasible explanation of the peculiar course of the river, but its history by no means ends with this episode. We have now to do with the later history of the Devon after the twelve-mile reach below the Crook had been permanently established. It is indeed difficult to see why, before the land was so much denuded down, the river should not have found its way directly south-eastwards past Saline to the Forth at Torry Bay. The reason probably is that the line of least resistance was along the great fault which skirts the Ochils and runs obliquely across the Forth at Stirling. The Forth had found a weak place to break through at Stirling, where the great faults that traverse the country had split the whinstone plateau with a line of cleavage the river was not slow to take advantage of. A small tributary no doubt began to run off the slope east of the Abbey Craig into the Forth, and worked its way upwards and eastwards along the line of the Ochil fault. As the Forth was deepened and the soft carboniferous strata were gradually worn away, the harder volcanic rocks of the Ochil range became more prominent, and the easiest path for the water to follow was along the junction of the hard and soft rocks. Once the little stream had started it kept its course, and as the main valley grew deeper, the tributary fed by streams from the high ground to the north was correspondingly deepened. After it had eaten its way back and tapped the old Devon, it would, like other predatory streams, be greatly enlarged and strengthened with the acquisition of so much more water.

From Tillicoultry to the base of the Abbey Craig, a distance of six miles, the river runs in a straight course along an alluvial flat at the foot of the abrupt face of the Ochils, and further out the ground rises slightly and the rocks of the coal measures appear on the surface in a low ridge extending continuously down to the Forth. A great deal of mining and boring has been done in this alluvial strip and along the

river banks, and many bores have disclosed a deep and narrow gorge all the way from Tillicoultry to Blair Mains near Blairlogie. So far as I have been able to discover, no boring has been done to the east of Tillicoultry, but as the river is on alluvium all the way to Dollar, this buried gorge no doubt runs up past Dollar to the place where the river can still be seen at work extending the chasm, but at a higher level, in the well-known falls of the Cauldron Linn and the Rumbling Bridge.

The buried gorge which we shall now consider was, I believe, first proved by boring in the year 1826 on Alva estate, west of Tillicoultry. In that year one bore near the river found the depth to the rock to be 241 feet, and in several others more than 150 feet. In 1873 a neighbouring bore apparently nearer the centre of the channel went down 318 feet before reaching rock. In 1887 a third deep bore was made close to the river at Kersiepow, about half a mile further up, which proved the depth to be no less than 336 feet. A fourth bore made in 1872, close to the road at the public park on the west side of Tillicoultry, exactly a mile further up than the Kersiepow bore, struck the rock at 342 feet. This bore is on the 50-foot contour line at the foot of the hill slope, and shows that close to the Ochils the old gorge has been excavated to a depth of almost 300 feet below the present sea-level.

This is the highest bore in the old valley that I have heard of, but at Glenochil Distillery, near Menstrie, a mile and a half below Alva, another bore was made for water which went down 330 feet before reaching the rock. The last of these interesting borings on the line of the old gorge was made so recently as October 1910. It was made at Blairmains, on Powis estate, two miles west of Glenochil, and proved the depth to the rock to be 305 feet. The ground is there about 40 feet above sea-level.

The old Devon thus occupied the deepest buried gorge that has been disclosed beneath the tributaries of the Forth, showing it to have been a swift river with great erosive power. The breadth of the channel at Alva was less than half a mile, and at Craigmill, at the east side of the Abbey Craig, seven miles below Tillicoultry, where it joined the Forth, it was not more than 600 yards across. The hard basaltic escarpment of the Abbey Craig projecting from the Ochil ridge deflected the last mile of the otherwise straight channel, causing it to bend southwards to the confluence with the Forth.

River Forth.—The course of the buried channel is shown on the map (Plate V.). The figures are the depths in feet of different bores through the surface deposits to the solid rock. The panorama (Plate VI. Fig. 9), is intended to show what may have been the appearance of the Forth valley at Stirling as seen from the Abbey Craig at that time, and Fig. 10 on the same plate is a sketch from the same spot of the valley after being filled up to its present level before the human period.

There has recently been a great deal of boring for coal in the Carse of the Forth between Stirling and Alloa, and I am indebted to the various land and coal owners for kindly allowing me to use the information they

PLATE V.—Buried Channels of the Forth and Devon.

FIG. 9.—Confluence of the Forth and Devon before the deep channels were buried.

FIG. 10.—The same place after the old glens were filled up.

PLATE VI.—Panoramas from the Abbey Craig at Stirling at different periods in the history of the Forth.

obtained as to the nature and depth of the superficial deposits in that part of the Forth valley.

At present we are not considering the kind of deposits found in these borings, but only the evidence they give of the depth and position of the buried river channel. It would have been a matter of great scientific interest if a single bore journal in the Carse of Stirling had disclosed 300 feet or more of "surface," but out of a large number I have collected not one bore seems to have reached the rock head at such a depth. Several of them, owing to the great difficulty in penetrating so great a thickness of loose material, after going down a considerable way, stopped and never reached the rock at all. So far as I have been able to ascertain, the deepest surface bore in this part of the Carse was at Causewayhead, near the river north of Stirling, where the alluvial deposits were found to be 216 feet deep. At the river south of Cambuskenneth Abbey, the rock was reached in two bores at 103 and 130 feet respectively, and a continuous series of bores extending to Drypow, 2 miles to the south-east, show the depth of surface to be between 60 and 145 feet. From these it is clear the old gorge must run further north than the line from Cambuskenneth to Drypow. But there has also been boring north of this line, and it appears the rock is only 10 fathoms or less below the Carse between the mouth of the Devon at Cambus, and the mouth of the Powis Burn at Manor Castle. Indeed, in boring for a railway bridge opposite Cambus, the rock was found only 30 feet under the bed of the Forth. Two bores were however made south of this line, one at the Haugh of Blackgrange, and the other at Bandreath, in which the depth to the rock had dropped to 105 feet, and these seem to be near or on the north side of the gorge we are in search of. No borings have been made along a belt of ground three quarters of a mile wide and two miles long, on the centre of which lies the old Polmaise House and policies at the east end, and the Haugh of West Grange at the west. If there is a deep gorge here it must occupy that position. As we follow it down the valley it must run through Tullibody Inch, Alloa Inch, and South Alloa; but it clears Alloa Harbour, as the rock is not deep on the north side of that part of the river. Borings to the south of South Alloa disclose only 75 feet of surface, and all the way down to Dunmore the rock is found at very shallow depths. On the north side of Clackmannan Pow, opposite Dunmore, it is only 84 feet down, and it is clear that the ancient gorge, if it exists at all, must exactly correspond with the present river-course between Alloa and Kincardine. Coal workings have been carried on along both sides, but none have gone under the actual river bed, which at Dunmore is about quarter of a mile broad. Kincardine Ferry is 4 miles below Alloa, and the rock is quite shallow on the Kincardine side, but on the south bank at Higgin's Neuk, in a boring made by the North British Railway for a proposed tunnel about 1890, the depth of surface was found to be 164 feet. This no doubt indicates the south side of the gorge. The distance from high-water mark at Higgin's Neuk to the opposite bank at Kincardine is half a mile. Below Kincardine the river-bed widens into the regular estuary. At Powfoulis, three

quarters of a mile below the ferry, a boring made by the Carron Company in 1904, 600 feet from the river, proved the depth to the rock to be 144 feet, and another bore, close to Powfoulis House and 2000 feet back from the bank, passed through 164 feet of surface before touching rock. The depth to the rock is less than this in the parts of the Carse further back from the river, so that there is no possibility of the deep gorge being situated anywhere except under the existing channel at this place.

At Grangemouth the Forth is joined by the Carron, and if we produce the line of the latter we find it runs across the Firth towards Culross and Torry Bay. In a paper read before the Edinburgh Geological Society in 1881 I gave reasons for supposing that Torry Bay is on the site of another part of the buried river channel. The bay forms the arc of a circle, with a chord of three miles, stretching through Preston Island from Culross to Crombie Point. The coast recedes three-quarters of a mile back from this line, in the centre of the bay. In the centre of the bay, which is entirely dry at low tide, there is a reef of sandstone rocks, known as Craigmore, extending south-westwards for three-quarters of a mile from Preston Island to the edge of the foreshore at low-water mark. This is only an island at high tide, when the foreshore and the rest of the reef is covered. A belt of mud, three-quarters of a mile or more in width, sweeps round the bay between the island and the shore, the west end of which is generally submerged under a tongue of water known to seamen as The Strath. Now it is clear there must be some geological reason for this. The shore of the bay is backed by low cliffs, and the sea does not eat away its coastline at this sheltered place. If it did, the sandstone island—the only island not of whinstone in the Firth—would have been the first part to be washed away. The only explanation appears to be that at one stage of the history of the valley, before erosion had gone so far, Preston Island belonged to West Lothian and not to the Kingdom of Fife, and during the Glacial Period the river course was changed by the glacier, that like a good engineer straightened as well as deepened this part of the valley, and wiped out the old sinuosities of its track.

The evidence is not, however, entirely circumstantial. Coal-mining was carried on by Sir Robert Preston of Valleyfield, who a little more than a century ago sunk three pits on the island, and lost a great deal of money in them, partly, perhaps, because he did not know about the old river channel that separated the island from the rest of his domain. The deepest shaft was sunk to forty-six fathoms, and a water-level was driven 270 yards in a NNE. direction from the bottom of it towards Torry. At the end of this level the clay seems to have been reached at 276 feet below the surface, when the workings were abandoned in 1811. My father, who told me of the deep trough that Sir Robert had found, did some boring himself in the bay in 1839, and found the depth to the rock at the end of the old pier at Torry to be sixty-three feet. In another bore made more recently in the bay, but 870 yards further west, the depth was 120 feet, and in a third boring 200 yards still further west, and probably past the centre of the bend, the depth of surface was sixty-four and a half feet. The ancient Moat Pit of Sir George Bruce in the

sea opposite Culross, to which King James VI. made his famous visit, belonged to quite a different colliery from that at Preston Island. The Culross Moat, which was connected by a subterranean passage with the shore, was sunk in the rock under the foreshore, some distance to the north of the old gorge. It was destroyed by a great storm in 1625, and the remains of the structure can still be seen in a heap of stones on the mud. There was, however, another old pit on the foreshore nearer Preston Island, called the Valleyfield Moat, the ruins of which are also faintly discernible. The position of the Valleyfield Moat enables us to trace out tolerably accurately the course of the buried channel lying between it and the Craigmare reef. The Moat lay 1100 yards NW. from the island, and the breadth of the deep channel between is probably not much more than 500 or 600 yards.

Why, it may be asked, was the old river originally deflected northwards towards Culross? The reason probably is that the hard ridge of the Bathgate and Bonnytoun hills, made up of volcanic rock interbedded with the coal-bearing strata, extended much further north than the promontory of Bo'ness before the Glacial Period, and formed an obstacle in the path of the river, which at all other places between Stirling and Queensferry had only soft strata to work upon. The whinstone beds, which originally came from a volcano to the west of Linlithgow, thin out towards the north, and the river found an easier path round the end than across the back of the volcanic ridge. The influx of the Carron at Grangemouth may also have helped to push the stream towards the north at the confluence.

At Crombie Point, on the east side of Torry Bay, where coal was being worked in the eighteenth century, before the colliers received their liberty, tradition records a sad accident that has some bearing on the present investigation. The submarine workings suddenly tapped a bed of running sand that burst in and spread death and destruction through the mine. The late Mr. William Hurst, formerly locomotive superintendent to the North British Railway, who was a native of the district, writing in 1881, told me that sixty years previously an old collier in Fordell, named William Ramsay, had related to him how his grandfather, who was then a slave, had lost his life in the disaster. No doubt the miners suddenly struck the buried channel at an unexpected depth.

From Crombie Point eastwards it is not possible to trace the gorge with much accuracy. Lines of borings were carried across the estuary at three places in 1864 by the promoters of the first Forth Bridge scheme of Mr. (afterwards Sir) Thomas Bouch, the engineer of the first unfortunate Tay Bridge. It was found that there was everywhere an enormous depth of soft silt, even where the water was deepest. The late Mr. Thomas Wyllie, the contractor, who carried out the borings from the side of a steamer, told me that one day he pushed the boring rods right down into the mud without any trouble to a depth of twenty-seven fathoms. Mr. D. Westland, C.E., has kindly lent me the Parliamentary plans, notes of boring operations, and evidence given by the promoters, from which it appears that in May 1864 two bores went

down 166 feet from low-tide level without getting to the bottom of the silt. In 1865 another set of borings was made between Blackness and Charlestown, and one of these, only about 500 yards from the coast at Charlestown, was sunk to a depth of 231 feet below low-water level without reaching the bottom of the mud. Boring through such materials was a marvellously quick operation. The deep bore just referred to, including the time required to put in the tubes, was begun in the dead of winter on 20th January 1865 at 9.30 A.M. and by 10.30 P.M. the work was completed and the rods drawn up.

More recently a great deal of boring has been carried out at Rosyth, and a few bores have been made at Crombie Point about which Colonel Exham, R.E.,¹ has kindly given me information. These were not so deep as the old borings of 1865, but they tell the same tale. Outside low-water line the rock slopes steeply down under an immense deposit of soft silt, and it is only near the shore that the hard boulder-clay is to be found resting on the solid rock. The ancient river channel was outside the Du Craig, and the abyss between the south side of Binar rock and the bridge, where the water alone is 41 fathoms deep, no doubt marks this part of its course. The south face of the Du Craig is a steep precipice plunging down to an unknown depth under mud, covering thick beds of red clay and other glacial deposits, but between the Du Craig and the north shore the rock surface is not very far down, and there is a good foundation for naval works.

When the Forth Bridge was begun I had many opportunities of visiting the works, including the deep foundations of the south cantilever which are built on the hard boulder-clay that extends most of the way from Inchgarvie to the south shore. The depth half way between Inchgarvie and the south shore, where the water is 37 feet deep, was found in the borings for Mr. Bouch's proposed bridge in 1870 to be 102 feet from high-water level to the top of the till which overlies the rock. No doubt the deep gorge of the old river was on the north side of Inchgarvie where, but for the water that fills it, the chasm is still open to a depth of nearly 40 fathoms.

That some parts of the old bed of the Forth are far deeper than 300 feet there is, however, direct evidence. In the submarine coal workings at Bridgeness and Bo'ness, on the writer's estate of Grange, directly opposite Crombie and Preston Island, the seams have been worked northwards to the outcrop where they have been abruptly cut off by a steep barrier of boulder clay, full of ice-worn stones and boulders of various kinds of travelled rock foreign to the district. The edge of this barrier has been followed westwards in the workings for more than a mile, and the greatest depth at which it has been encountered opposite Bridgeness is no less than 570 feet below high tide level at a distance of nearly half a mile from low-water line. But so far there is no evidence that this is the deepest part of the buried valley, as the rock abuts against a more or less steep face of clay the bottom of which has apparently not yet been reached.

¹ The engineer in charge of the works up till the end of 1911.

PLATE VII. —Buried Channels under the estuary of the Forth.

FORTH VALLEY KEY MAP

It is, however, doubtful to me whether this is to be regarded as the original preglacial river bed, or a later rock basin deepened by glaciers like the western lochs, which are sometimes more than 600 feet in depth. If the original Forth ran round Torry Bay, as I have suggested, it could hardly have occupied another and deeper channel at Bo'ness at the same period. I am rather inclined to think that Torry Bay marks the site of an original loop in a more or less serpentine channel, which, according to the common habit of rivers, was subsequently cut off by the river straightening its course. The large glacier of the Ice Age under which the hard boulder clay was manufactured moved in a straight and even course, and no doubt scooped out the underlying soft rocks to a considerable depth and produced a true rock basin extending for several miles like a straight gutter along the centre of the valley. In the workings of the Grangemouth Colliery five miles further west the boulder clay under the foreshore has also been approached from below, but at a depth of only 215 feet, but this is at a greater distance from the centre of the channel than the Bridgeness workings. Further mining developments are necessary to solve the problem completely, but, as has been already mentioned, the undoubted buried river gorge of the Devon is entirely filled with fine red silt, mud and gravel, apparently all deposited by water, and not with hard boulder clay firmly compacted by the pressure of huge glaciers. The other buried river channels all contain more or less sand and gravel of fluvial origin as well as local beds of true boulder clay.

But what we have been considering is mainly the action of running water and the origin of the old river system, and not the effect of the Ice Age on the Forth district. That episode is too important to be adequately dealt with at the end of this chapter, and all that I have done is to make a few passing references to it in connection with the other points relevant to the discussion.

This discussion of the buried channels is of interest for two reasons, one of them scientific and the other economic. From the first standpoint it is clear that since the river occupied the deep channel a great submergence has taken place. We saw that in the Devon valley the old river bed reached down to 300 feet below sea-level, and the Carron was probably also as deep at the mouth. But the changes in level were regional and not confined to one part of the country. In the Clyde basin Mr. Bennie found the buried channel of the Kelvin at Duntocher to be also about 300 feet deep, which shows that the amount of submergence of Scotland was at least 300 feet. No doubt there is also a buried channel under the bed of the Tay to which reference will again be made.

But the Devon, the Carron, and the Kelvin were only tributaries of much larger rivers which carried all the sediment away to a great distance and kept the side valleys quite clear. Between Stirling and Kincardine we saw that the main river must have had only a narrow gorge, the maximum depth of which has not yet been fathomed by the borer's tool. But if the channel had a small width it must have had steep sides and a great depth to vent a large volume of water. The

FIG. 11.—The ancient Forth valley at Queensferry with the shadow of the future Forth Bridge cast across it.

buried gorge of the Kelvin was found to have perpendicular and even overhanging walls at some spots. It must likewise have had a steep declivity and a swift current. Now let us take the gradient of a river such as this at say seven feet per mile, which is much less than that of some of its tributaries, but is nearly the average declivity of the Colorado River for 218 miles through the Grand Cañon district. Let us now multiply this by the distance between Stirling and Queensferry—23 miles as the crow flies—and we find that we must add about 160 feet to the depth of the gorge, which below the bridge must thus be at least 460 feet below the level of Inch Garvie. In other words, if the land were again upheaved to its ancient position, and the water and mud were swept away, the north cantilever instead of stretching across the sea at a height of 120 feet, would be found to span a chasm 160 feet deeper than that of the Zambesi, with a swiftly rolling torrent no less than 580 feet below the level of the rails. (See Fig. 11.)

But the old river, no doubt, ran far beyond the Bridge, and therefore the whole elevation of the land above its present level was probably far more than 400 or 500 feet. The North Sea between Scotland and Denmark is, except at a few places, less than 50 fathoms deep, and therefore, if the land were lifted even 300 feet, *that vast expanse of ocean would nearly all be dried up*, and the British Islands would become merely a mountainous portion of the European continent projecting out into the North Atlantic.

At the time we are speaking of, the buried river shows that this was the condition of our country; the North Sea had no existence, and we had no silver streak drawn around our shores by a kind providence, but only a vast plain on our eastern border, across which the Forth, Tay and other rivers meandered away outwards and perhaps became tributary to some greater river flowing into the Arctic Ocean. If the climate was no colder than it is now, the addition of 500 feet to the mountains would also raise the higher summits above the snow-line, and the melting snows in spring would greatly add to the floods in the Highland rivers.

The second or economic aspect of the subject relates to the effect of these concealed channels on mining and tunnelling operations. Serious accidents have happened at other places besides Crombie Point, where old river courses have suddenly been met with. Dr. Croll says the late Mr. Dawson of Carron told him that about eighty years ago the miners in the Carronshore pit cut into the trough of the Carron at a depth of forty fathoms, and the running sand rushed in with irresistible pressure and filled the working. Mr. Bennie described a similar disaster where the old Kelvin gorge was struck in a colliery near Duntocher at a depth of fifty-one fathoms, and the sand burst in and killed several miners.

Various proposals have been made to connect the north and south shores by driving tunnels under the Forth, but in view of the hidden river bed, it is perhaps well that none of these have been attempted. In 1880, after the fall of the Tay Bridge, a scheme was set afoot to run a tunnel from Hound Point to Donibristle instead of risking a dangerous bridge. From a copy of the plan in my possession it appears that there

was to be a line of railway running from Granton along the shore to Cramond where the tunnel was to begin. At Cramond the line was to be continued underground in a tunnel running downwards at a gradient of 1 in 75 until at Hound Point near Dalmeny it had reached a depth of 200 feet. At this depth it was to bend northwards under the sea and run to Donibristle on the north shore, where it was again to bend eastwards and emerge to the west of Aberdour. Now it will be clear from what has been said that this scheme was proposed in entire ignorance of two buried channels crossing the line of the railway, both considerably deeper than the tunnel level. First the old channel of the Almond at Dalmeny House, more than 200 feet in depth, would have to be pierced by the tunnel, which was proposed to be only 100 feet deep at that place, and secondly the far larger buried channel of the Forth probably filled with mud and sand to a depth of over 400, and perhaps 600, feet. Fortunately for the promoters the scheme never even reached the experimental stage.

Another proposal to tunnel the Forth at Kincardine Ferry, already referred to, was made by the North British Railway Company in 1890-91, when parliamentary plans were prepared, and some preliminary boring was begun. The tunnel was to be only about 59 feet below low-water level, and as the buried channel is more than 300 feet deep here, and it is probably full of soft mud and sand, the making of a safe tunnel through it would have been a very costly and dangerous piece of work if, indeed, it was feasible at all.

Another practical point may be noted in conclusion. When the original ill-fated Tay Bridge was designed in 1870 it was expected that the solid rocky bottom that had been found near the shore on both sides would extend all the way across the estuary and afford a good foundation for the heavy brick piers on which the superstructure was to rest. But alas for these unscientific expectations! After the bases of fourteen piers had been safely laid from the north side to a distance of 516 yards along the line, the rock suddenly began to slope down to an unknown depth, and when No. 15 pier was sunk it only touched the rock on the north side, but the south side having a soft bottom caused the structure to cant over so dangerously that it could not be righted and had to be demolished. This led to the alteration of the whole plan, as the greater part of the bottom was found to be soft from No. 14 pier to the south shore, and unable to bear the heavy superstructure originally designed for the piers.¹ It is now a matter of history how, on the dark stormy night of 28th December 1879, this frail cast-iron superstructure proved unequal to the strain, and the thirteen large spans in the centre gave way about a year and a half after the bridge was opened, precipitating a passing train into the deepest part of the river with ninety passengers, not one of whom escaped to tell the tale. The Board of Trade inquiry proved that the fault lay principally in the cast-iron columns bearing the girders, which had been badly made and too cheaply

¹ *Vide* Mr. Albert Grothe's description of the (*First*) *Tay Bridge; its History and Construction* (Dundee, John Leng and Co., 1878), written just after the opening of the railway.

erected, and as they were an afterthought consequent on the belated discovery of the buried channel, it becomes evident now that the engineers' want of geological knowledge of the old river system was an important contributory cause to that terrible calamity. Engineers cannot afford to discard scientific evidence, and this investigation may perhaps be of use in connection with other schemes for bridges over or tunnels under British estuaries, as buried channels will no doubt be found to exist at many other places besides those I have spoken of.

THE BRITISH ANTARCTIC EXPEDITION

THE *Terra Nova*, the ship of this expedition, arrived at Akaroa, New Zealand, on April 1, without Captain Scott, who has remained in the Antarctic for another season's work.

According to the reports brought back by the ship, the task of laying down depots last year proved very difficult owing to the great severity of the weather. In March 1911 three ponies were lost as the result of a blizzard, and the greatest hardships were endured during these terrible storms. The winter temperatures were moderate, and the arrangements for the lighting and heating of the hut proved quite satisfactory. In mid-winter Dr. Wilson, Mr. Cherry Garrard, and Lieutenant Bowers made an expedition to Cape Crozier to observe the incubation of the Emperor penguins at their rookery. Some eggs in different stages of development were obtained, but the temperatures were exceedingly low (rarely above -60° F., often below -70° , with a minimum of -77°), and storms of great severity were encountered.

The final start for the southern journey was made on November 2, marching being carried on by night, and the day used for resting, so that the ponies might have the benefit of the higher day temperatures. The motors had to be abandoned after 60 miles owing to the overheating of the air-cooled engines, but they dragged heavy loads over the worst part of the Barrier in a highly satisfactory fashion. The weather was very bad during the advance, severe storms being experienced, especially in early December, when a southerly gale raged for four days, accompanied by a very heavy snowfall. The new snow made progress over the Beardmore Glacier excessively difficult, and reduced the day's march to scarcely five miles. Later better progress was made, averaging 13-23 miles per day. By January 3rd the party had reached $87^{\circ} 32' S.$, at a height of about 9,800 feet. They were thus some 150 miles from the Pole, which Amundsen (cf. p. 204) had reached more than a fortnight previously. On the following day Captain Scott sent back his last supporting party, and went forward himself with four companions, these being Dr. Wilson, Captain Oates, Lieutenant Bowers, and Petty Officer Evans. The returning party consisted of Lieutenant Evans and two companions, and they had a terrible journey owing to the fact that Lieutenant Evans was attacked by scurvy, and while still nearly a hundred miles from the Discovery Hut proved unable to go any further. His two companions, Crean and Ashley, dragged him for a considerable