

	Sample No.	Sample No.
Total solids	5728 5,187	5729 552
Containing :—		
Chlorides (as Sodium Chloride)	1,587	174
Alkalinity (as Sodium Carbonate)	3,364	304
Nitrates	trace	trace
Nitrites	absent	absent
Calcium	4	3
Magnesium	0·2	0·2
Suspended matter	small amount	nil

A very small quantity of sulphates was present in both samples. No examination was made for ammonia.

(Signed) H. MARTIN,
Acting Government Chemist.

WELLCOME RESEARCH LABORATORIES,
GORDON MEMORIAL COLLEGE,
KHARTOUM.

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Tertiary Gravels of the Buchan District of Aberdeenshire.

By J. S. FLETT, F.R.S., and H. H. READ, F.G.S.

CAPPING many of the hill-tops of the Buchan district of Aberdeenshire there are extensive spreads of gravel containing pebbles of white quartzite and of flint. Their north-western limit is on the Delgaty estate, near Turriff, where, at an elevation of 350–400 feet, there is a small patch of quartzite gravel a mile and a half to the north-east of the town. Nearly eight miles to the south, on Windyhills, two miles north-east of Fyvie, a more extensive outlier occurs. These two patches are shown in Fig. 1. The Windyhills spread is nearly a square mile in area, and it occupies the summit of a low flat-topped ridge at an elevation of 370–400 feet. Like the Delgaty gravels, it is evidently the remains of a deposit formerly much more extensive and reduced greatly in area by denudation. It consists mainly of white quartzite pebbles, flint pebbles, and white clayey sand, and its resemblance to the Delgaty gravels is so close that no doubt has been entertained that they belong to the same period and formation.

In Central Buchan, along the top of a low, flat-backed ridge, which may be called the Buchan Ridge, extending from a little north of Ellon to Buchan Ness, south of Peterhead (see Fig. 2), there are great stretches of gravel, consisting mainly of water-worn flints, with a smaller proportion of white quartzite and other pebbles. As a rule these pebble beds are confined to the hill-tops at elevations of 350 feet and over, though numerous scattered flints are found at lower levels. These gravels of the Buchan Ridge differ in several respects from the Delgaty and Windyhills gravels, but their similarity in essentials is so close that none of the previous observers has doubted that they belong to the same series of deposits.

Much attention has been given to the Buchan gravels by Aberdeenshire geologists. Christie¹ of Banff, was perhaps the first to give an account of the occurrence of chalk flints at Delgaty. In 1857 J. W. Salter² described the fossils from the chalk flints of the Buchan Ridge; to this description Ferguson of Kinmundy

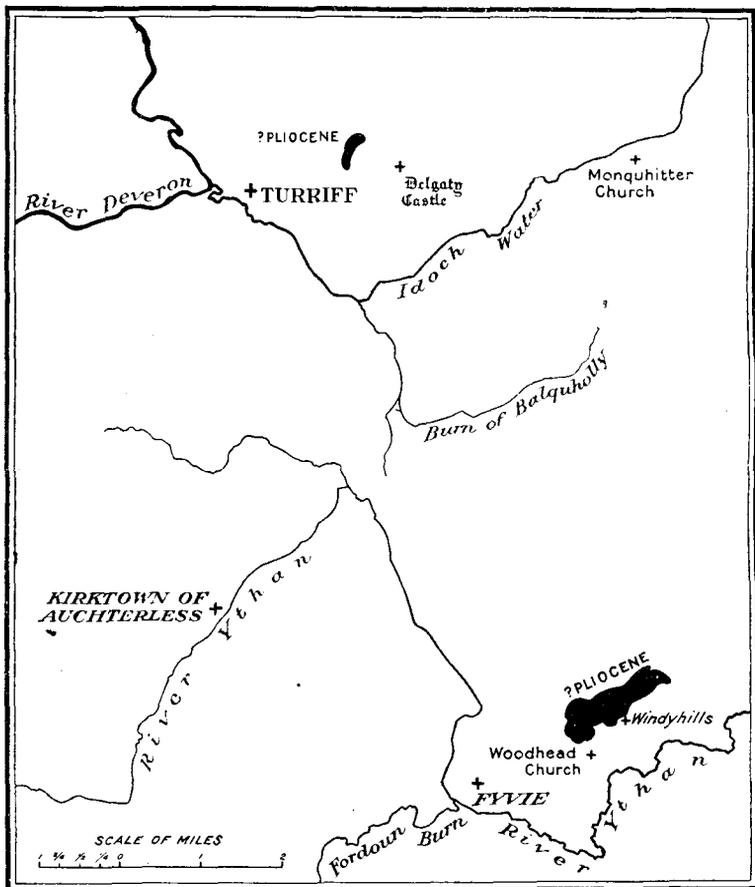


FIG. 1.—The Tertiary Gravels of Western Buchan.

appended a brief account of the distribution of the gravels. These deposits were studied especially by T. F. Jamieson of Ellon, who was intimately familiar with them throughout the area. In his first paper Jamieson described the gravels of the Buchan Ridge

¹ *Edinburgh New Philos. Journ.*, vol. x, 1831, p. 163.

² "On the Cretaceous Fossils of Aberdeenshire": *Quart. Journ. Geol. Soc.*, vol. xiii, 1857, p. 85.

and of Windy-hills.¹ The quartzite material at Windy-hills, he held, was derived from the underlying Highland Schists, and thus the gravels were local. He gave an outline of the Buchan Ridge along its length. Two years later he gave a sketch-map showing the distribution of the gravels in Buchan.² In 1865 he described the Delgaty deposits in some detail; he showed that the gravels were there covered by boulder-clay, and he grouped these gravels with those of Windy-hills and the Buchan Ridge as *Preglacial Traces*.³ In his last paper,⁴ which may be considered to express his final conclusions, Jamieson says:—

No remnant of pre-Glacial Tertiary deposits has hitherto been found in any part of the area (loc. cit., p. 13).

He now admitted that the material of the gravels is not of local origin, but rolled and long travelled. Most important is, however, his withdrawal from his position that these gravels were pre-glacial. He says:—

The Chalk flints . . . have . . . I suspect, been brought from the Moray Firth by . . . glacial agency. These Flints . . . may have been shed off along the southern border of one of the streams of ice which brought so great a quantity of other debris from the Moray Basin (loc. cit., p. 29).

With regard to the Delgaty section, Jamieson considered the boulder-clay which there covers the gravels to be due to "a recurrence of glaciation after the flints were laid down". Dr. Bremner⁵ has assembled the theories on the origin of these deposits, and has pointed out that a study of the quartzites would be most likely to lead to some definite result.

THE DELGATY OUTLIER.

At Delgaty the quartzite gravel covers a small area, only a quarter of a square mile, on the summit of a hill whose highest point is 399 feet. The base of the deposit may go down to near the 350 feet line. This hill is by no means the highest in the district, as there are others within a few miles of it rising to five or six hundred feet, but these hills have rock at their summits or are covered only by a thin skin of boulder-clay. The country rock is Macduff Slate of the Highland Schists, and red sandstones of the Middle or Orcadian Old Red, and the Delgaty gravel seems to rest on both of them in different parts of its area. Most of the outlier is covered by heath and wood, and there is no cultivation; the exposures in ditches and small overgrown pits are few and unsatisfactory. Fortunately, however, there is a gravel-pit which is being actively worked for

¹ "On the Pleistocene Deposits of Aberdeenshire": *Quart. Journ. Geol. Soc.*, vol. xiv, 1858, p. 528.

² *Quart. Journ. Geol. Soc.*, vol. xvi, 1860, p. 348.

³ "On the History of the Last Geological Changes in Scotland": *Quart. Journ. Geol. Soc.*, vol. xxi, 1865, p. 164.

⁴ "The Glacial Period in Aberdeenshire and the Southern Border of the Moray Firth": *Quart. Journ. Geol. Soc.*, vol. lxii, 1906, p. 13.

⁵ "Problems in the Glacial Geology of North-East Scotland": *Trans. Edin. Geol. Soc.*, vol. x, 1916, p. 344.

pebbles and clay and affords excellent sections, which give a very satisfactory idea of the composition and structure of the deposit. The working face of this pit is at present 8 feet high, and a small excavation in the floor of the pit reveals another foot or two of greyish-white sandy clay with pebbles. The base of the deposit is not anywhere exposed, and the thickness is consequently not known, but is presumably not less than 8 or 10 feet at this place.

The largest pebbles are about a foot in diameter, but the majority are from 2 to 5 inches. Most of them are very well rounded, and the whole deposit gives the impression that the pebbles have suffered much attrition and resemble those found on a sea-beach where wave action has been long continued. Quite nine-tenths of the pebbles are quartzite, of a very fine and pure variety, and all these are perfectly waterworn and rounded. The quartzites are by no means uniform in character. Most are fine-grained, granular or granulitic when examined with the lens, and contain very little felspar or mica. Others, however, have white mica flakes in thin shimmering films, and might be described as very fine-grained white quartz-schists. Still others have a more crystalline appearance, with large areas of clear glassy transparent quartz; no other minerals can be seen in the hand specimen.

Taking the quartzites as a whole, we may say that they have well-defined characters, which are: (a) their white colour; (b) their great purity; (c) their highly metamorphic and crystalline texture. They are certainly not derived from the local rocks, which, as already said, are Macduff Slates and Old Red Sandstone, and, furthermore, there are no known Aberdeenshire or Banffshire quartzites from which it seems possible they could have been derived. The Durn Hill and Cullen quartzites of Banffshire contain usually biotite and orthoclase, which give them a yellowish or pinkish colour when they are weathered. The quartzite and pebbly grit bands of the Macduff Slates are even more impure. Quartz veins are not common in N.E. Scotland, and most of the Delgaty pebbles are not derived from quartz veins. Altogether their origin is a problem on which little light has been thrown by the investigations of the geologists who have studied the rocks of the Eastern Highlands. Their lithological characters, however, are so well marked that it is seldom difficult to identify one of these pebbles in any of the superficial deposits of the district.

Less than one-tenth of the pebbles are flint, and these have the general character of flint pebbles wherever met with. They range up to 9 inches in diameter, and it is not seldom apparent that they are less perfectly rounded than the quartzites, though many of them are extremely waterworn. The flint is soft and brittle and cracks readily under the hammer; the broken faces have often a dull or waxy lustre; pure black flint is practically never seen, but grey, brown, red, and greenish colours are prevalent. Often the flints have a thick dull rind, which is grey or white, and sometimes

they are completely altered to a white mass resembling chalk in appearance. These changes indicate long continued weathering *in situ*, probably by percolating water.

The matrix of the pebble bed varies somewhat in composition and abundance, but is on the whole remarkably uniform. It may be described as a sandy clay always containing quartz grains, but, when wet, distinctly plastic and tough. There is little evidence of stratification in this pit, though the pebbles are not quite evenly distributed in the different layers; no proper bedding or current bedding can usually be seen, but streaks occur, often several feet in length, in which the sandy, clayey matrix is more than usually abundant. Such bedding as can be detected or suspected is horizontal. In the floor of the pit a small excavation had been made which we were informed was for the purpose of working a clayey stratum; this clay is found especially suitable for patching drains.

The working faces of the Delgaty Pit show very clearly that the pebble bed is covered by boulder-clay. This forms a layer, about 2 feet thick, of tough brownish sandy clay, with pebbles of many local rocks and some far-travelled stones derived from districts to the north-west. In the boulder-clay there are also some pebbles of quartzite from the gravel below, and these increase in numbers in the deeper parts of the boulder-clay. The base of the glacial deposit is fairly well marked by the change of colour. No disturbance of the gravels immediately beneath the boulder-clay is to be seen. In Lower Banffshire and neighbouring parts of Aberdeenshire we have found that the south-easterly drift is the earliest of which traces have been preserved.

In the wood, to the south-west of the gravel-pit, there is an old adit or tunnel in the Delgaty gravel, which had been formerly worked for a fine white, sharp sand, which, we are told, was used for scouring kitchen tables. The roof of this adit is formed by stiff brownish boulder-clay, held together by tree roots.

The real base of the Delgaty deposit is not exposed, and the deposit parts now being worked are quite as free from local rocks as any other part of the pebble bed.

THE WINDYHILLS OUTLIER.

This outlier is situated about 2 miles N.E. of Fyvie Church at the top of a low ridge at an elevation of about 400 feet. Perhaps half of the ridge is slightly over the 400 feet contour; the height of the margin of the deposits is not less than 360-370 feet. The underlying rocks are slate and knotted rocks of the Macduff and Fyvie groups of the N.E. Scottish metamorphic rocks; these contain bands of dark, impure, pebbly grit and quartzites in many places. The area covered by the pebble beds is about a mile and a half long in an E.N.E.-W.S.W. direction, and nearly half a mile in breadth. Heather and wood cover most of the ground, and cultivation stops practically at the margin of the gravels, but a

thin sprinkling of white pebbles in the surrounding fields shows that the deposit had once a more extensive distribution. This also makes it somewhat difficult to lay down a definite margin for the outlier on the map.

Many small pits have been opened in the pebble beds, principally with the object of obtaining road metal. Most of these pits are abandoned and overgrown, but there are three or four, widely scattered, still in use, and these furnish very good sections of the different parts of the mass. The largest pit is on the south side about the middle of the outlier, and this is probably the best exposure at present available for examination.

In this pit the working face is about 12 feet high. No boulder-clay is seen above the gravels. The deposit is in every respect very closely similar to that of Delgaty. The pebbles are perfectly rounded white quartzite and quartz-schist, with a small proportion of rather decomposed flints. Stratification is barely visible, though not completely absent, and there are streaks less rich in pebbles, 12 feet or more in length and somewhat lenticular in outline. The bedding is horizontal and undisturbed. The matrix is white or pale yellow, sometimes very rich in fine scales of white mica, but never so quartzose that when kneaded with the fingers it is not distinctly plastic and coherent. The peculiar characters of the quartzite pebbles of Delgaty which give that deposit such a marked individuality are all seen at Windyhills, and there is no room for doubt that the pebble beds of these two localities, which are 8 miles apart, belong to the same series. Some of the pebbles in the Windyhills pits are composed of black and blue quartz, others are of a decomposed whitish chert.

The other smaller pits at Windyhills exhibit the same features, and do not merit a special description. They are all in pebbly beds and have been dug for pebbles; if there are sandy or clayey facies of the deposit they are not now being worked. An exception occurs, however, in a small pit near the west end of the outlier, on its south side; in this a brown clay was dug, full of slate fragments, and with comparatively few quartzite pebbles. It seems that we have here a part of the floor of slate on which the gravels rest, but the relations were not absolutely clear. A somewhat similar clay is visible in a small pit in the wood near by. Here large angular fragments of the underlying metamorphic rock are abundant in a brown clay. A small excavation with a pick showed that these rock fragments increase in number and size below, and it is probable that the underlying solid rock would be met with in a short distance. This bed, at any rate, contains no other rocks, and the fragments are angular. It does not seem likely to be a boulder-clay, though that possibility was not absolutely excluded.

With this possible exception, the base of the gravel is not visible. On the other hand, there was no good exposure showing overlying boulder-clay. Scattered erratics of local rocks may be found on the

surface of the outlier, and at its edges, especially on the north side, it seems to be overlapped by a thin skin of boulder-clay, but no good section proving this was observed. The evidence led us rather to believe that, like many of the adjacent hill-tops, Windyhills rises through the general spread of drift which mantles all the lower ground; the pre-glacial rocks thereby emerge at the surface.

From a consideration of the evidence detailed above, certain conclusions seem to be reasonably clear.

The Delgaty and Windyhills deposits exhibit peculiarities which demonstrate that they are essentially the same. They are parts of a deposit once probably continuous, the relics of an extensive sheet of gravels, sands, and clays, now almost wholly removed by denudation. It is very significant that they both occur at elevations of 360–400 feet; possibly they rest on an old platform, at any rate, they indicate submergence. It seems impossible to believe that they are stream gravels, as this would involve the former existence of a river system, of which no other traces can now be found. Almost certainly they are marine, and point to a general depression of this part of Scotland amounting to at least 400 feet.

As regards their age, only two points are certain. They are post-Cretaceous because they contain flints with chalk fossils; they are pre-glacial because they are covered by a boulder-clay which is, so far as we know, the earliest glacial deposit of the district. It seems safe, accordingly, to regard them as Tertiary.

All the available evidence points to the conclusion that these gravels are *in situ*, and almost undisturbed. No boulder-clay has been found beneath them, and the field evidence indicates that they rest immediately upon a platform of the older rocks. No veins of boulder-clay can be seen in the pits. We know of many large erratics that have been transported by ice without having their stratification greatly disturbed. But the nature and size of these gravel masses, their composition, the freedom from contortion, veining or intercalations of boulder-clay, and, above all, their remarkably uniform elevation above sea-level, point unmistakably to their interpretation as pre-glacial accumulations. The ice in this part of Aberdeenshire was perhaps comparatively thin and moved slowly. In many places the rotten rock below the boulder-clay shows that locally the ice had little excavating power. Many of the peculiar quartzite pebbles of Windyhills type are found in the glacial deposits, and show that much destruction of these beds took place; what remains is probably only a fragment which has escaped erosion.

GRAVELS OF THE BUCHAN RIDGE.

About 15 miles east of Windyhills there is a low flat-backed ridge that runs in an east-north-east direction from Whitestone Hill (530 feet) and Dudwick Hill (572 feet) to Stirling Hill and Buchan Ness (see Fig. 2). The flint gravels of this Buchan Ridge are very

well known, and have been described by Ferguson¹ and Jamieson.² The length of this ridge is about 10 miles, and it is not crossed by any important valley. Towards its eastern end the ridge is cut through by a narrow channel at North Aldie, which Dr. Bremner³ has shown to be a glacial overflow channel. It was not possible for us to make a minute examination of the whole of this ground, but we have visited a number of selected localities for the purposes of comparing these gravel deposits with those of Windyhills and Delgaty.

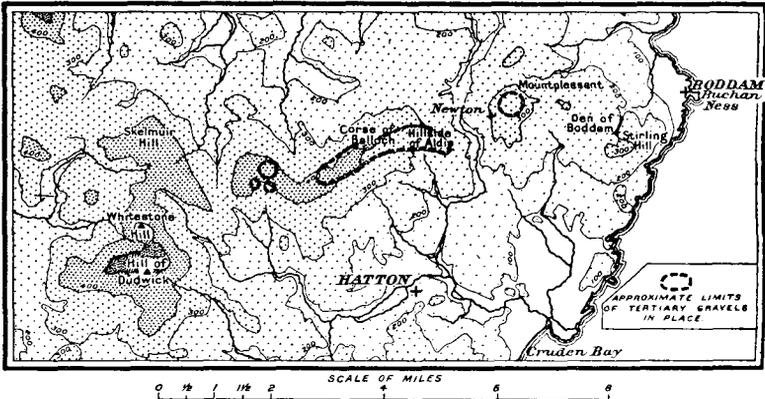


FIG. 2.—The Buchan Ridge. (Contour intervals of 100 feet; height indicated by depth of stippling.)

Towards the west end of the Ridge, about Dudwick Hill, quartz and flint pebbles are numerous in the soil of the fields and on the surface of the moors, but in the numerous shallow pits and drains which we inspected we saw nothing strictly comparable with the Windyhills deposit, and our conclusion was that beneath the soil there was a brownish boulder-clay, in which many flint and quartzite pebbles had been incorporated along with fragments of a large variety of local rocks. Further east, however, at the Corse of Balloch the superficial deposits are of different character. There is a great deal of thick peat in this area which is being extensively dug for fuel; immediately below the peat there are great sheets of gravel, apparently hardly disturbed. By far the greater part of the pebbles are well-rounded flints from 2 to 7 inches in diameter; these form about 80 per cent of the whole accumulation. The remaining pebbles are principally white quartzites, in which all the types characteristic of Windyhills and Delgaty are represented. The matrix is a whitish, or sometimes yellow, sandy clay, varying in

¹ Op. cit., *supra*.

² Op. cit., *supra*.

³ Op. cit., *supra*, p. 339.

character, but often extraordinarily like the clays that accompany the pebbles at Windyhills and Delgaty. On the surface with these pebbles occur fragments of slate, knotted schist, pebbly grit, granite, norite, hornfels, and other rocks of local derivation.

Unfortunately, the few natural exposures are very unsatisfactory and there are no pits at present being worked, as these pebbles are not used for road metal except on the farm roads. Consequently it is very difficult to obtain an exact idea of the composition and structure of the beds and their relations to the glacial and metamorphic rocks.

At the east end of the Corse of Balloch the peat gets thinner and cultivation encroaches on the area of gravel. At Hillside of Aldie traces of many shallow pits are visible. They are now nearly filled up, but we were told that they were sunk in search of a whitish clay which it was thought might be of value. Samples were examined, but it was reported that the material was not of economic value, though when the clay was washed it was possible to make clay pipes from it. Some of these pits are said to have been 10 to 12 feet deep in the gravel without reaching the subjacent rock. The whole surface of the ground is covered with rounded flints and quartzites, while pebbles of metamorphic rocks, deeply weathered, are numerous. We dug for about 3 feet into the gravel, and after a foot or so of peaty soil with iron pan, we reached apparently undisturbed flint gravel embedded in yellow and whitish clayey sand. The pebbles were all very well rounded flint and quartzite; the flint had a thick white weathered crust, and when split open presented a waxy rotten appearance, like the flints at Windyhills.

At North Aldie it was possible to lay down the margin of the outlier with fair definiteness at 300 feet. Below that the pebbles were frequent in the soil, but were obviously transported down the slope. The deposit seemed to rest directly on the granite, which is here the country rock.

On the hill-top a mile or so further east, near Newton and Mountpleasant, the same phenomena are repeated. The lower slopes are granite and red boulder-clay, with mounds of glacial gravel and sand. As the 300-ft. contour is approached pebbles of flint and quartzite become very numerous in the fields, and above that level we pass suddenly on to beds of solid flint gravel capping the hill-tops. The field exposures indicate that this gravel has a nearly horizontal base resting upon a platform of granite, which shows minor irregularities in the form of low granite ridges emerging through the gravels. At least 90 per cent of the pebbles are flints from 2 to 7 inches in diameter, very well rounded, and deeply weathered. Pebbles a foot long are rare. Pure white quartzite pebbles are always present, though only in subordinate amount, and there are also local granite and schist pebbles. No stratification is visible. Large erratics of granite occur scattered over the ground, but we saw no section which established the relations

between the gravels and the boulder-clay. Most of this high ground, in fact, has little boulder-clay upon it, and probably any such deposit was originally thin and irregular in its distribution, and has been largely washed away by rain.

BODDAM DEN.

Towards the east end of the Buchan Ridge, about a mile and a half south-west of Buchan Ness and a mile north of Longhaven Station, a remarkable dry valley runs northwards across the granite hill. It is about 70 feet deep, and is occupied by only an insignificant streamlet; the floor of the valley is covered with peat, and its northern half is converted into a lake by means of an artificial dam. The course of the channel is at first north-east, then north, and it opens into flat country at each end.

As pointed out by Dr. Bremner,¹ it is undoubtedly a temporary glacial channel, by which melt water from ice sheets has escaped across the ridge. On both sides of the valley the slopes are steep, and on the west side are covered by flint gravel; on the east side also the gravel occurs, but towards the north end of the channel granite crops out on the eastern slope. Many small pits have been opened in the flint gravel, and on the banks of the reservoir the waves have cut good sections 10 feet or less in height. An examination of these shows that the gravel is not washed by stream action. There are no sandy layers, bedding, or current bedding such as are usual in materials deposited by glacial outwash, and it is entirely different in character and composition from the glacial gravels of this district. The surface characters are in some measure affected by rainwash and soil slips from above, but a small pit which we dug for about 2 feet at the north-east end of the dam exposed true flint gravel with yellowish and white fine plastic clayey sand as matrix, exactly similar to the deposits at Hillside of Aldie, Mountpleasant, Delgaty, and Windyhills described above. The pebbles are perhaps 90 per cent of flint; the remainder are the quartzites typical of these deposits. The characters, in fact, are those of undisturbed Tertiary beds.

A careful scrutiny of the exposure at the locality mentioned showed that this gravel is overlain by reddish tough boulder-clay, containing pink felspars and fragments of the Peterhead granite, which is the country rock. The gravel, we hold, is lying in a valley originally cut in the Tertiary platform, filled up by the flint gravel and re-excavated at the close of the glacial period. The coincidence seems remarkable, but it may be suggested that the presence of a gravel-filled hollow would probably determine the situation of the glacial overflow channel by the rapid deepening of any stream-course which happened to coincide with it. This patch of flint gravel apparently marks the eastern end of the Tertiary deposits preserved in this district.

¹ A. Bremner, *op. cit.*, p. 339.

CONCLUSIONS.

We have now described the gravels of Buchan, and have given our reasons for regarding them as relics of Tertiary beds of possible Pliocene age. If our contention is correct, the amount of erosion since Pliocene time is seen to be very great.¹

These Aberdeenshire deposits appear to rest on some kind of platform near the 400 feet contour. This at once recalls the well-known Pliocene platform of Cornwall, described by Clement Reid, Mr. George Barrow, and others. Further, there is a great likeness in position and stratigraphical relations between the Aberdeenshire gravels and those from near Berkhamstead, described by Mr. C. T. Gilbert and Mr. Barrow.² It appears likely, then, that in this distant corner of N.E. Scotland there are traces of Tertiary features and deposits similar to those of Cornwall and Hertfordshire.

The contents of the Buchan gravels are dominantly quartzite in the west and flint in the east parts of the outcrops. With regard to the source of the materials, few definite statements can yet be made. The quartzite is certainly not derived from any Aberdeenshire or Banffshire quartzite. The only rock known to us which is at all like it is the Scarabin quartzite in the county of Caithness. The confirmation of this suggestion requires a more detailed petrological and field study than we have yet been able to give.

¹ Cf. George Barrow, *Proc. Geol. Assoc.*, vol. xxx, 1919, p. 36 et seq.

² *Quart. Journ. Geol. Soc.*, vol. lxxv, 1919, p. 32.