have yet been met with in any of the slate rocks of this district. The members of the Geological Survey have classed them as Palæozoic, and the name has been retained here, though its meaning is so wide and indefinite.

ADDENDUM.—Since the above paper left my hands I have again visited the volcanic district by way of Kuripapanga, and I find that the sands referred to as being seen at Blowhard underlie the limestones and pass into streaky clay-sands, which are the upper beds of the slates. In two places near Blowhard Secondary rocks appear similar to those seen at Kuripapanga. On the hill known as "Gentle Annie," beyond Kuripapanga, there is to be seen on the roadside a large limestone boulder. This rests on the slates, and is, I suppose, a remnant of the limestones which once covered the whole of the hills in this district. The highest limestones appear about midway between Erehwon and Ruapehu, at a height of 4,720ft. They rest on the Secondary rocks, and are full of fossils, mostly bivalves.

ART. LI.—*Artesian Wells: No 2.*

By H. HILL, F.G.S.

[*Read before the Hawke's Bay Philosophical Institute, 7th October, 1889.*]

Plate XXXI.

As an addendum to the paper read by me two years ago* on the artesian-well system of Hawke's Bay, the following additional facts will be found of interest and importance. For those not acquainted with what is known as the Heretaunga Plain, it may be explained that in this paper it includes the district extending from Napier to Pakipaki, with the Borough of Hastings towards the centre. The distance between the two places is about eighteen miles, with a breadth varying from eight to ten miles. Within certain limits this plain is an artesian water-bearing basin sloping to the north-east, and troughing on the south-east to the north-west, and on the north-west side to the south-east; thus forming a syncline between the two opposite exposures extending for about ten miles.

Since the date of the paper referred to, which treated as fully of the subject under notice as it was possible to do with

* "Trans. N. Z. Inst." vol. xx., p. 282.

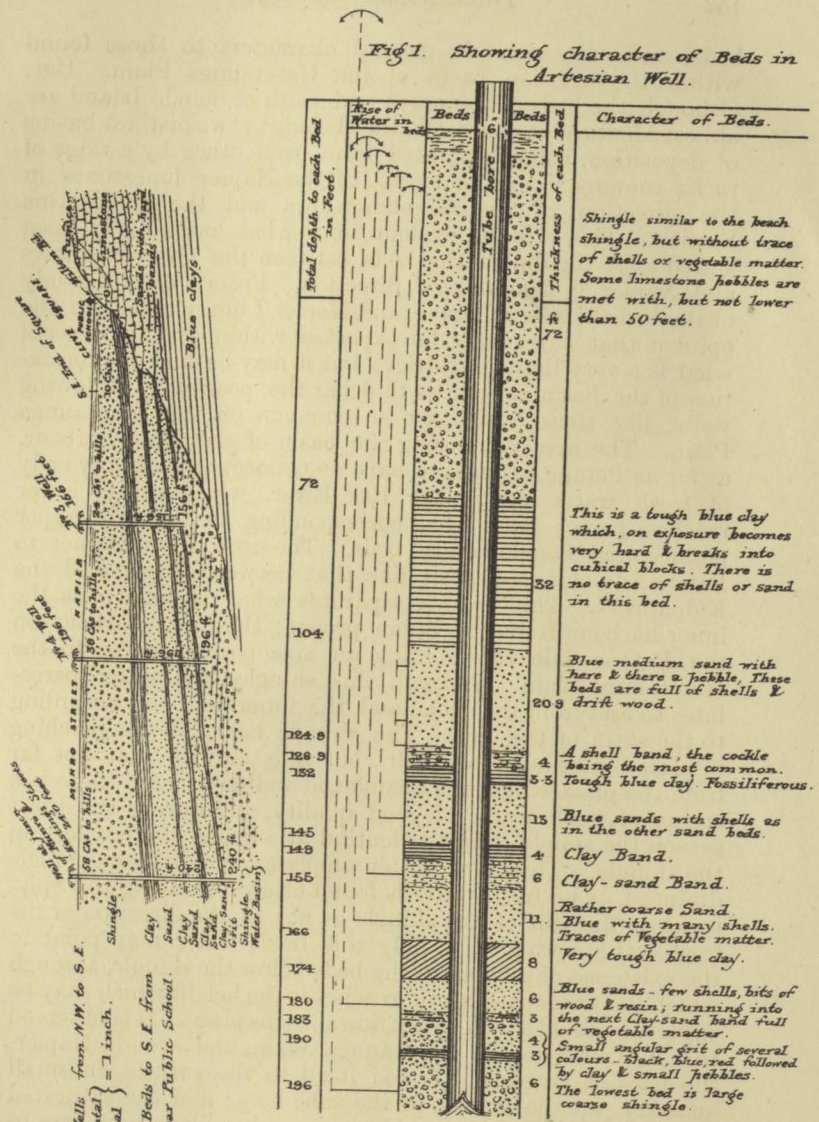
the data then available, many wells have been sunk in various parts of the plain, and, as far as I am aware, they all tend to show the truth of the inferences drawn by me as to the formation of the artesian basin in the district under notice. But among the numerous sinkings which have been carried on to supply the growing wants of population and settlement there are four wells, or, rather, four sinkings, to which I wish to direct particular attention, as they provide information of much geological interest and importance in connection with the formation of the plain, and its relation to the other rocks in the district. Of the four wells referred to, two of them were put down within the Borough of Napier, one in the immediate vicinity of Napier, at a spot locally known as the Western Spit, and the fourth one was sunk at the Greenmeadows, situated a mile or so on the Napier side of the Township of Taradale. (See topographical map of plain, "Trans.," vol. xx., p. 284.) The two Napier wells were successful ones, each having an excellent flow; whilst the other two—viz., the one at the Spit and the one at the Greenmeadows—were failures.

In certain places water is found in the vicinity of the Greenmeadows; but the spot selected for the sinking referred to here is within a few chains of the hills, which are composed of marl and limestones, and which hereabouts have had the more sloping portions fronting the plain slowly ground down by the back-wash at a time, not so long ago, when the sea covered this portion of the district. The sinking for water in this place has proved conclusively—so it seems to me—the limit of the artesian basin in this direction, as no trace of water was met with, and the characters of the beds passed through differ greatly from those that are found within the true artesian basin. During the process of sinking I visited this well, and from the workman in charge gleaned that after the first 24ft. had been passed, of which 10ft. were made up of shingle, there were 96ft. of a yellowish clay—pumiceous clay or loess—similar to that covering most of the Napier hills and district at the present time. This has evidently been washed from the surrounding hills as the plain was in process of formation. Following this clay was a succession of blue-clay beds, which continued as far as the sinking was carried—viz., 273ft.—except that at the depths of 140ft. and 181ft. 6in. respectively a bed of fine pumice-sand about 18in. in thickness was passed through. The appearance of these two pumice-bands is a very interesting geological find, as they give a clue to the relationship between the Kidnapper beds at the point and those which abut on the artesian basin to the north-west of the plain. Clay-marl beds containing one, two, and sometimes three pumice-bands are traceable over a large extent of coast and inland country (see "Trans.," vol. xx., p. 273), and

wherever met with it is observable that they are either overlain by limestones, with pumiceous clays atop of them, or by shingle, pumice, clay, and conglomerate beds corresponding to the Kidnapper pumice and conglomerate deposits, such as they appear to the south-west of what is known as the Black Reef. In my first paper on artesian wells I endeavoured to show, first, that there is a gradual slope in the water-bearing beds between Pakipaki and Napier; second, that the beds trough along their south-east and north-west edges, being deepest, or nearly so, midway between Taradale on the north-west and the place known as the Grange on the south-east; and, third, that the beds are recent, and have been formed by the filling-up of what was once a portion of the sea known as Hawke's Bay. The abandoned well at Greenmeadows, situated at the western end of what is locally known as Avenue Road, shows that the artesian beds die out in this direction as the hills are approached. According to the average depth of the wells at Taradale and at the Greenmeadows eastward of the well under notice, water should have been reached at the extreme depth of 125ft.; and, as none of the ordinary artesian beds was found except the overlying shingles, and perhaps a portion of the pumiceous clay which appears in the wells in Napier when approaching the hills, it would seem that hereabouts the upper deposits, which are the youngest of the plain-beds, overlap the true artesian beds and the blue marly-clay beds containing the pumice-bands, the artesian beds and the clay-marls being unconformable to each other.

Second Well, Western Spit, Napier.—The locality of this unsuccessful well is at the back of the hotel on what is locally known as the Western Spit. It was sunk with a view to supply the requirements of the South British Company, whose meat-freezing works are in the immediate vicinity; but after sinking to a depth of 328ft. the work was abandoned. I believe that in a former attempt to find water on the Spit side of Napier the pipes went down to a depth of 420ft., but no record as to the character of the beds passed through has been kept; otherwise inferences based upon ascertained facts might have been drawn as to the chances of finding an artesian water-supply on the Port side of the town. Unfortunately, I was absent from town when this well was being put down; but Mr. Garry, to whom I am so much indebted for valuable information in connection with the artesian wells on the Heretaunga Plains, has supplied me with all the information in his possession as to the beds passed through. He reports that at the depth of 328ft. hard limestone was struck, and that this circumstance caused the well to be abandoned. As far as can be gathered, the beds passed through are true water-bearing

beds, and correspond in general characters to those found within the artesian basin of the Heretaunga Plain. But, although the beds to the north and south of Scinde Island are almost identical in character, they belong to two distinct basins of deposition, being separated from each other by a ridge of rocks running from the lowest of the Napier limestones in the direction of the Greenmeadows and the Quarantine Station. This will be evident from what has already been stated as to the dip of the beds between the Greenmeadows and Napier in a south-east direction. From a careful study of the beds between Petane and Napier I am inclined to the opinion that water may be expected within certain areas of what is a very limited district; but it may be that the formation of the basin is such as to debar the possibility of flowing wells, like those which are so common on the Heretaunga Plain. The area composing the basin of the inner harbour, as far as Petane, appears to have no connection with any body of fresh water except the Esk River, which in its lower reaches passes over beds corresponding to the Kidnapper pumice and conglomerate beds. The road from Napier to Petane is a shingle-deposit like that between Napier and the Kidnappers. This deposit separates what is known as the inner harbour from the ocean proper; the inner harbour on the Petane side representing an area corresponding to the Heretaunga Plain. Through this shingle-band water percolates to and from the ocean and the inner harbour, according to the state of the tide. The shingle has a depth reaching in places to as much as 100ft., but it is curious that not far from the place where the abandoned well is situated there is a spring of fresh water of good quality, and during the driest season the supply is fairly plentiful at a depth of a few feet in the shingle. This fresh-water supply cannot be from shingle drainage, as no fresh water is found elsewhere along the Spit; besides, the dip of the shingle is not in the direction of the fresh-water spring. Possibly this fresh water may point to the existence of a break in the beds below the shingle, through which the water passes, and reaches to the height which may be expected should a well be put down in this place. It is observed that in places on the Heretaunga Plain, and even in Napier, the artesian water has forced itself to the surface, in small quantity, up the outside of the tube-bore; and the saturated salt-water shingle-beds would act somewhat like a tube-bore to the fresh water of less specific gravity as it rises towards the surface. Personally, I do not feel satisfied with the results of the tests for artesian water on the Western Spit. The beds are certainly similar to those met with on the Heretaunga Plain, and more particularly to those presently to be described; and, although, as previously pointed out, the wells belong to two



To illustrate Paper by H. Hill.

separate basins, there is no reason to suppose that the water-beds are absent in the one whilst being present in the other. Possibly the places hitherto selected for sinking were too near the hills. On the south side of Napier the rule holds good, for the water-bearing beds are lost as the hills are approached. For my part I should very much like to see another attempt made to put down a well on the Western Spit by what is known as the "shelling-out process."

A test-well at this place would settle once and for all whether artesian water is obtainable or not on the Port side of Napier, and such knowledge would go far towards encouraging the establishment of manufactures in close proximity to Napier and to the seaboard. It seems to me that public bodies like Borough Councils, Harbour Boards, and County Councils might expend a portion of their funds in less useful ways than testing for a good water-supply in places where the community as a whole is likely to be benefited; and I, for one, shall rejoice to see the day when public bodies like those named will recognize that the co-operative principle in providing for the common weal is not only the cheapest, but the one most likely to lead to the rapid development of production and of industries among communities.

Third and Fourth Wells, Napier.—The two wells to which reference will now be made are situated in Munro Street, Napier, on what was until eight years ago a portion of dead water known as the "Napier Swamp." The first of these two wells is located some distance from the south-eastern boundary of Clive Square, and the second well is just 14 chains further away from the same boundary in a south-east direction. Clive Square is at the foot of the limestone hills forming the so-called Scinde Island, about midway between the north-east and south-west ends, so that the sinking of these two wells in a straight line from the hills is of value as showing the inclination of the water-bearing beds, whether towards the limestones or away from them. The value, however, is much enhanced by the fact that 19 chains further away from the hills, along the same street, and exactly at the junction of Munro and Hastings Streets, another well was put down three years ago, so that in the same straight line extending from the foot of the Napier Hills in their central part there are three artesian wells, the exact depth of each being known, and the geological characters of the beds in the two wells under notice being also known for each foot and portion of a foot passed through during the process of sinking. These two wells were authorised to be put down by the Napier Borough authorities to provide for the growing requirements of the town, and they differ from any of the other wells in this district in their having a much larger tube-bore,

being 6in. in diameter, whilst the largest up to this time were wells of a 3in. bore; so that the sectional areas are as 36 to 9, or 4 to 1. The mode of putting down these wells was entirely different from that formerly adopted in this district. I have been particular to locate these wells, as they are of special importance, for they show in the clearest manner the troughing of the water-bearing beds in the direction indicated by me three years ago. The first well—that is, the one nearest the hills—was sunk to the depth of 156ft. before the water-bearing basin was reached. The beds passed through in this well were as follows: Shingle, 58½ft.; fine white limestone, 1ft.; pale-blue shingle, interbedded with 2ft. of hard brown clay, 18ft.; blue clay, with shells, 22ft.; fine blue sand, with thin clay-bands, 9ft.; blue clays, with sand-and-shell band, 6ft.; fine blue sand, with shells, 3ft.; rather coarse blue sands, in places full of shells, 30ft.; clay, with thin sand-bands containing bits of water-logged wood, 8ft.; shingle, the water-bearing bed. When water was struck the artesian well at the railway works, some distance away, diminished the height of its flow about 20ft.; but this was only temporary, as the pressure again returned, and I understand that the flow at the railway well now shows no appreciable diminution. The characters of the beds passed through were very similar, except that in the first well, after passing through 58½ft. of shingle, 1ft. of fine white-limestone sand was met with. This was followed by 16ft. of blue shingle, about the middle of which was a hard pumiceous clay-band, nearly a foot in thickness. In the second well (see section, Plate XXXI., fig. 1) no limestone-sand band appeared, nor was there any pumiceous clay; but some of the pebbles brought up were of limestone similar to the Napier limestone. Below the shingle were alternate beds of blue clays and blue sands. When passing through the blue sands in each well fresh water appeared, and at times it rose in the pipe to within a few feet of the surface. Fresh water in these beds may be the result of percolation from the true water-bearing basin, as the beds run out towards the Scinde Island limestones. It has been explained that the first well put down in Munro Street was 156ft. in depth; the second well, which is 14 chains further from the hills, is just 40ft. deeper, or 196ft.; whilst the well at the junction of Munro and Hastings Streets, to which reference has already been made, is 230ft. in depth: so that the evidence is complete for the following statements:—

1. That the artesian beds die out towards the Napier hills just as they do towards the hills at the Greenmeadows.

2. That the beds dip apparently to the south-east at the rate of between 2ft. and 3ft. to the chain, which corresponds to a dip of little more than 2°.

The flow of water from each well is at the rate of 270 gallons a minute, or, say, 16,000 gallons an hour, or 384,000 gallons a day. Thus, these two wells, representing the work of a forty-horse-power engine, supply more than three-quarters of a million gallons of water daily, of exceptional purity and suitability for domestic purposes. The cost of sinking the two wells, including £64 for boring-tools and £30 for bonuses, amounted to £534 16s. 7d., which at 7 per cent. interest represents an annual outlay of less than £38, and for which the town is supplied with more than 280 millions of gallons of water ready for use. The water as it rises to the surface exerts a pressure of about 13lb. to the square inch, corresponding to a rise, when allowance is made for friction, of about 30ft. above sea-level. The head-pressure exerted on the water at the bottom of the well, which is 196ft. in depth, in order to raise it 30ft. above sea-level, is equal to about seven atmospheres on each square inch. This will show how very necessary it is when sinking a well to insist upon pipes being used of the very best description, as in the case of the well just mentioned the pressure upon the lowest section of the pipes amounts to over 100lb. to each square inch. With such a pressure it is easy to understand why so many artesian wells begin to diminish their supply of water after the lapse of a few years, as they become choked by the rotting portions of the pipe towards the bottom of the well.

But the sinking of the two wells in Munro Street has not merely given information as to the dip and general character of the beds overlying the true water-bearing bed: by the "shelling-out process," which was adopted in sinking, interesting information has been brought to light as to the age of the overlying beds. This has come about by the discovery in the blue-clay sands of a large number of very small shells in an excellent state of preservation. The common cockle-shell and a whelk had been the only shells noticed in previous sinkings, but it is now known that shells are common in most of the beds passed through during the process of sinking, except, perhaps, in the clay-sandy bed which immediately overlies the water-basin. In this bed much vegetable matter is met with, but no trace of shells as far as I have been able to discover, and I am inclined to the opinion that the clay-sandy bed which rests upon the water-bearing basin is of fresh-water origin, and, if not unconformable to the overlying beds, at least represents a change in the area of deposition to which reference will presently be made. The following is a list of the more important shells found in the beds during the process of sinking the wells. They were referred by me to Professor Hutton, of the Canterbury College, who kindly sent me the names of the different specimens received by him:—

GASTEROPODA: *Amphibola avellana*, Chem.; *Trophon ambiguus*, Phil.; *Trophon duodecimus*, Gray; *Trophon plebeius*, Hutton; *Cominella lucida*, Phil.; *Clathurella sinclairi*, Smith; *Turbonilla neozelanica*, Hutton; *Odostomia lactea*, Angas; *Potamopyrgus corolla*, Gould; *Pantipodus*, Gray; *Trochus tiaratus*, Q. and G.; *Cantharidus tenebrosus*, Adams; *Monodonta æthiops*, *Acmea flammea*, Q. and G.; *Conus neozelanicus*.

LAMELLIBRANCHIATA: *Tellina glabrella*, Des.; *T. subovata*, Sowerby; *Venus stutchburyi*, Gray; *V. mesodesma*, Q. and G.; *Tapes intermedia*, Q. and G.; *Kellia citrina*, Hutton; *Nucula lacunosa*, Hutton.

I believe that all these shells are to be found to-day, if not in the immediate vicinity of Napier, certainly on some portion of the coast-line of New Zealand. They belong to animals which frequent tidal mud-flats like those of our inner harbour, or comparatively shallow waters in quiet bays and coves. The shells named above are found extending from a depth of 112ft. to 175ft. below the present sea-level, and there is every appearance of the animals which once occupied the shells having lived in the sands and sandy clays where the shells are now found. Similar deposits to those in which the shells were found are scattered over the whole of the district included within the artesian basin—varying in thickness, but, on the whole, maintaining their general characteristics. I am informed by Mr. Hamilton, our secretary, that the animals which occupy shells of the kinds named do not now live at such great depths as those where the shells were found during the process of sinking; hence it must be inferred either that the animals have modified themselves to altered conditions since the beds overlying the artesian basin were deposited, or that these beds have been deposited on what was a subsiding area.

Before deciding this question it will be necessary to see what information may be gathered from the rocks surrounding the Heretaunga Plain, which represents the area referred to. At one time, not so long ago considered as a geological period, the Kidnapper beds were united to the Redcliffe-Taradale beds. Between them that portion of the plain now intervenes which is the very centre of the artesian basin. The Kidnapper beds dip N.W., whilst the Redcliffe beds dip S.E., so that a syncline, extending for about ten miles, is formed between these two conglomerate and pumice series. The limestone range behind this series runs south-west, forming bold scarps behind Havelock, in the Tukituki Valley. The least observant must have noticed the peculiar slope of these limestones as seen from Napier. These rocks dip N.W., at a fairly high angle under the Heretaunga Plain, the tilt being as if the rocks had suddenly snapped away from the

limestones covering the hills farther to the south-east, and had fallen towards, and were about to slip underneath, the plain. At Napier the general dip of the limestones is N.W., just as at Havelock; whilst the limestones to the south-west of Redcliffe dip S.E. and form with the Havelock limestones.

Here, then, on the north-west and south-east sides of the plain, are deposits of enormous water-carrying capacity passing under the plain, forming a longitudinal trough, open towards the ocean, and overlain by a series of beds that have been deposited on a subsiding area. That the Heretaunga Plain, the Kidnapper conglomerates, and the area around Pakipaki have been disturbed by earth-movements, even within the memory of living evidence, is beyond question. In the great earthquake of 1853, which was felt over the larger portion of the colony, I am informed by our ex-president, the Rev. William Colenso, F.R.S., that the Ngaruroro River overflowed its banks at Waitangi, near Clive, and the ground showed a rift 10in. to 12in. wide, running north-west and south-east across the plain, through which rift a lambent flame flickered for some time. A similar phenomenon was noticed by the Maoris who then dwelt on the west of the inner harbour, and so frightened were they at the unusual event that they quitted the locality. Disturbances were also noticed at Pakipaki, and the land in some places was raised several feet in height. It was during this earthquake that the Kidnapper conglomerates were riven and torn in many places. These rifts may still be seen, and they can even be distinguished by an observer standing on the Napier hills by the circumstance of the conglomerates falling in sections towards the north-west, and by the greater slope of the north-west side of each rift than of the south-east side. Here, then, the evidence seems clear that the Heretaunga Plain has been built up on an area of subsidence, and, such being the case, it is easy to account for the appearance of shells—shallow-water shells—at comparatively great depths, together with bits of wood, raupo, and even resin from the rimu-tree. The beds overlying the true water-bearing beds overlap limestones and conglomerates, and it is to this circumstance that the flowing wells are due, as the water in the underground basin is unable to find an outlet, except by percolation where the beds thin out underneath the ocean. As to the age of the artesian and overlying beds, it will have been inferred that they follow in succession the upper shingle-deposits belonging to the Kidnapper beds. No single extinct shell has been found among those brought up with the sands from the wells, as enumerated above. Curiously, all the shells are represented in the rocks forming what is known as the Wanganui system, an upper division of the Pliocene formation, a list of fossils from which appears in

a paper by Professor Hutton, "Trans.," vol. xviii., p. 336. That they are Post-tertiary I think there can be no doubt, the shingle-spit running from the Kidnappers to Tangoio forming the youngest deposit of the series in this district.

The following section (Plate XXXI., fig. 1) represents well No. 2, Munro Street, Napier, as put down between the 10th May and the 1st August, 1888, at a cost of £281 9s. 11d.