Subrecent *and* Recent Deposits *of the valley plains of* Quetta, Pishin and the Dasht-i-Bedaolat; *with appendices on the* Chamans *of* Quetta; *and the* Artesian water supply *of* Quetta *and* Pishin: by R. D. OLDHAM, A.R.S.M., F.G.S., *Superintendent, Geological Survey of India* (with one Plate).

Occupying a position intermediate between the highly disturbed tertiary and pre-tertiary rocks of the surrounding hills and the undisturbed recent deposits of the valley plains of Quetta, Pishin and the Dasht-i-Bedaolat, come the beds which were described as gáj by Mr. Griesbach,[1] and subsequently classed as siwalik by Dr. Blanford.[2]

Siwalik they may be as regards their age, using the term siwalik for all upper tertiary beds ranging in age from miocene up to the latest pliocene, but they must not be confounded with the true, or what may be called marginal, siwaliks of the outer hills. The contrast is especially striking owing to the close proximity of the two types; in the area intervening between the Bolán and Harnai routes to Quetta the hills are formed of siwalik beds, which extend continuously to within a few miles of the Quetta plain, and, throughout this area, they maintain a very constant structure. At the base there is often a small thickness of clean grey or greenish sandstones, with a few strings of pebbles or thin bands of conglomerate, but, with this exception, they show everywhere that increase in average coarseness of texture from base to summit, which is one of the most constant features of the true siwaliks. Near the base of the section the series is essentially an argillaceous one, the prevailing rock being a red or brown earthy clay; above this the beds gradually get more sandy, till sandstone is the prevailing rock and in this pebbles appear and gradually increase in abundance and size, till the uppermost beds are almost entirely coarse conglomerates.

The siwaliks of the valley plains differ radically in structure from these. Where exposed on the northern terminations of the Chehiltan and Mashálak ranges, the bottom beds are composed of angular or sub-angular debris of the same cretaceous and lower tertiary rocks as form the summits of these ranges; they are in fact identical in structure, appearance, and doubtless in origin, with the talus and fan deposits, which are at the present day being formed along the margins of these ranges. These beds are succeeded, without the intervention of any well-defined zone of medium grained deposits, such as sandstone, by fine grained clays and sandy beds. Where they have been disturbed and elevated, these have been cut into a network of low hills, absolutely bare of vegetation, and showing most conspicuously the bright colouration of the material they are composed of. Elsewhere, however, these beds tail off to a horizontal dip and cover a large area in the valley plains, extending continuously across the valley at Baléli, and abutting against the foot of the ridge pierced by the Murghi pass, where the relation of the high dipping cretaceous limestone to the horizontal red clays is evidently one of original contact. This, taken with the nature of the bottom beds in the Chehiltan and Mashálak ranges, makes it clear that these

[1] Mem., Geol. Surv., Ind. XVIII, 18.
[2] Mem., Geol. Surv., Ind. XX, 115.

clays have been deposited since the elevation of the mountains bounding the valley plains of Quetta and Pishin.

The siwaliks of the hills, on the other hand, are as clearly shown to be older than the elevation of these hills, not only by their forming an integral part of them and their highest peaks, but by the parallelism of stratification between the lowest beds of the siwaliks, and of the beds on which they immediately rest in unconformable contact. There is certainly a considerable lithological resemblance between the clay of the valley siwaliks and the clay zone at the base of the siwaliks of the hills, and it might be held that these were originally continuous and had since been separated by the elevation of the hills. On this supposition the junction of the valley siwaliks with the cretaceous limestone near Baléli would be a great faulted boundary, the faulting being concealed by a small thickness of subsequent deposits at and near the surface; such a supposition is just barely possible were there not weighty reasons for rejecting it. The most important of these is the impossibility of accounting for the absence of the great thickness of sandstone and conglomerate, forming the upper portion of the siwaliks of the hills, which must formerly have extended over the area occupied by the valley plains, and whose complete removal is inexplicable if their stratigraphical position were that of conformable superposition on the clays of the valley siwaliks. On the other hand, their thickness, close up to the limits of the valleys, shows that, in their original extension, these conglomerates and sandstones must have spread far beyond the present limits, determined by disturbance and denudation, over the area now occupied by the valley Siwaliks, and, as these latter cannot be older, the only alternative is that they are newer than the siwaliks of the hills.

The conclusion is strengthened by a feature in the structure of the siwaliks of the hills. Instead of forming a single conformable system, they form two unconformable divisions, of which the older,—that which is referred to in the preceding passages,—was formed before the elevation of the hills and the great disturbance of the underlying beds; the other or newer, which is almost entirely composed of conglomerate, dating from a period when the older rocks had not only undergone nearly the whole of the disturbance they have been subjected to, but had been carved into deep valleys, and the present drainage system to a large extent already defined. The newer conglomerates rest with a marked unconformity on the eroded edges of the highly disturbed tertiary and cretaceous beds, as well as of the older group of the siwaliks. They can be seen in the Gandak or Sarakhúla valley, where their presence has been recorded by Dr. Blanford. They form part of the hills, east of Khánai, and an outlier of the same conglomerates forms the cap of a very conspicuous hill which rises above the railway line between Fuller's camp and the Bostán valley.

To the west of Khánai, the northern extension of the Bostán valley is bounded by a ridge whose surface is covered by a shingle of limestone and chert pebbles, evidently derived from the weathering of conglomerate beds. Owing to weathering of the beds and the absence of deep-cut stream gorges, no good exposures of rock *in situ* are seen in the conglomerate zone, but the contour of the hills, no less than the structure of the higher parts, shows that the dip of the beds is north-westerly, and

[1] Mem. Geol. Surv., Ind. XX. p. 185.

that these conglomerate beds graduate upwards, with a more gradual transition than in the Mashálak range, into the clay beds of the Pishin valley siwaliks. Now it seems natural enough to regard these conglomerate beds as closely related to those which unconformably cap the disturbed beds of the hills, east of Khánai and, as these are youngest beds of the siwaliks of the hills and the former the oldest beds of the siwaliks of the valleys, the relation between the two is evident.

It will be seen, from what follows, that these siwaliks of the valleys graduate upwards into the recent deposits of the valleys and that, in spite of local unconformities, the process of formation has been continuously going on in one part or other of the area under description. We have, consequently, another illustration of the two truths that are constantly being borne in on the geologist who works among the upper tertiary beds of extra peninsular India,—(1) that there is no real distinction or constant horizon of demarcation between the deposits of uppermost tertiary and of recent age, and (2) that in beds deposited subaërially in a region that has been undergoing disturbance and upheaval during the period of their accumulation, the stratigraphical value and signification of an unconformity is very different from what it has when found among beds of marine origin.

The siwaliks of the valleys graduate into the next type of deposit to be considered. In the Pishin valley the gently inclined siwaliks, which form the low range of hills lying between the head-quarters of the district and the broad Pishin plain, have a low westerly dip, which gradually flattens off to horizontal, and pass, with perfect transition, underneath a series of fine grained, distinctly stratified, alternating beds, mostly thin, and varying from fine clay to fine grained sand. Very good sections of these beds are exposed in the vertical sides of the numerous nullahs which ramify through them, and especially in the high cliffs which border the bed of the Lorah, and their distinctly stratified nature proclaims them to have been formed by aqueous action, while the absence of anything that could be called a coarse grained deposit, and the rarity of even slight traces of false bedding, show that they must have been deposited in still water. In these features the beds bear considerable resemblance to a lake deposit, and, so far as their appearance is concerned, they might well be of such an origin. It is, however, very improbable that, with so small a catchment area, a large lake could be formed in the dry climate which appears to have characterized Balúchistán throughout the recent period of geology, nor are there any beach terraces, such as one would expect to find had the Pishin valley ever been occupied by a lake. But, though it is improbable that a permanent accumulation of water occupied any portion of the Pishin valley during the recent period of geology, it is more than probable that, before the outlet was deepened by erosion and so allowed the streams to cut deep channels through the plain, large areas of it were subject to temporary flooding after every heavy fall of rain on the surrounding hills. The water, as it left the hills, would carry with it debris of every degree of coarseness, but as soon as its velocity was checked, all the larger particles would be deposited, and the depression would be filled with water, bearing only fine particles of mud and sand in suspension. These, after a while, would subside, and the water would dry up, by the combined effect of evaporation and percolation, but the next flood would bring down a fresh supply of material to be deposited in a thin layer on the top of what had gone before.

The process here described can be seen at work on many of the valley plains of the Balúchistán hills and, as the lowest-lying parts are most often flooded and consequently receive the largest addition of sediment, one of its most conspicuous effects is a diminution of the surface gradients, till they cease to be perceptible to the eye. Now, in the Pishin plain, there is a very conspicuous difference in the surface gradients of the area occupied by these stratified deposits and that occupied by the unstratified loess which will be described further on.

From the foot of the hills to the east of the plain,—if we except a narrow zone in the immediate neighbourhood of the hills,—there is no perceptible gradient over the whole area occupied by the stratified deposits, but, from their limit, the loess rises very perceptibly to the north and west, to the foot of the talus slopes of gravel. This loess slope marks that portion of the plain which lay too high to be flooded, while the rest is the lower-lying portion subject to more or less frequent inundation, in which the gradient of the surface would be less, owing to that more rapid deposition in the lower levels which has been referred to above. It might, of course, be urged that the present extent of the loess marks the encroachments made by the dry land on to a pre-existing lake before it was finally drained, but, as far as the Pishin plain is concerned, the sections in the tributaries from the north, which join the Pishin-Lorah near Alizai, conclusively disprove this hypothesis. Instead of the loess being found overlying stratified deposits, we find that there is a horizontal transition from one to the other. The exact limit of each is not very definite and, to a certain extent, they are found to intercalate with each other, a distance of a quarter of a mile at places even of a couple of hundred yards, being sufficient for the complete replacement of stratified by unstratified deposits, thus showing that, during a period of time represented by the gradual accumulation of over 30 feet of deposit, the horizontal limit between the area which was liable to flooding, and that which was not, remained much the same.

In the foregoing description I have only mentioned the stratified deposits in the Pishin plain, but it must not be supposed that they are confined to it. It has been a matter of convenience to take Pishin as the typical area, because there good sections have been exposed by the streams, and there, owing to the red colour imparted to them by the river wash from the siwaliks, they are more easily recognized. In the closed drainage areas of the Dasht-i-Bedaolat and Gwende Dasht similar accumulations are being formed, but as they are composed principally of rain wash from the loess, and consequently more uniform in texture, the stratification is more obscure, while the absence of good sections, and more especially the identity of colour, renders it more difficult to separate them from the true loess.[1]

As seen in the Quetta and Pishin plains the loess is usually of a pale grey or yellow colour, fine grained in texture, firm enough to allow it to stand in perpendicular cliff of 50 feet or more in height, porous and readily absorbing water and very slightly permeable owing to the minute size of the pores. When broken down with water the loess forms an impalpable slimy clay which, in drying, retains the shape im-

[1] The term loess is here used, in the sense which it has acquired, to designate a fine grained deposit not stratified, or only obscurely so, of Æolian origin, the sense in fact in which it is used by the Baron Von Richthofen in his work on China, and without reference to any consideration as to whether it is or is not the same in age or origin as the typical loess of the Rhine valley.

pressed on it when moist, and is used for the manufacture of bricks of fair quality. In the composition of the loess there is always a considerable proportion of carbonate of lime, so that it effervesces freely with acid, and this is distributed evenly through the mass in the shape of minute grains, which are doubtless dust derived from the surrounding limestone hills. The other ingredients are equally minute granules of quartz and of argillaceous matter, the last enabling it to be used as a brick earth while the large proportion of lime renders it very easy to overburn the bricks. Small calcareous concretions, or *kunkur* nodules, occur, but they appear to be rarer than in the loess of China, and I have not been able to detect the numerous vertical tubelets which are described by Von Richthofen. In all other respects, both of texture, composition, structure, and in the contour of its surface, it agrees perfectly with the descriptions of that observer.

There can be no doubt that this type of deposit is really of Æolian origin; not only is the occurrence of finely comminuted limestone, most unusual, if not almost impossible, in beds formed by water but the absence of stratification points to the same conclusion. Moreover, if deposited by water, it must either have been formed at the bottom of a deep lake or in an alluvial plain. The shape of the surface would not be inconsistent with the former mode of origin, but there are no traces of those shore line terraces which could not but have been found had such a lake existed. Were the loess, on the other hand, a subaërial alluvial deposit, we would find a plain sloping gently in the direction of the stream, but nearly horizontal in a direction transverse to that, or even higher in the centre than at the sides; such, however, is not the shape of the section across the Quetta or Dasht-i-Bedaolat plain, where the lowest point is always in the centre, and the ground slopes upwards on either side towards the hills. The most conclusive evidence, however, is to be found in the widespread distribution, in height, of similar deposit, and its occurrence, in small patches, on the tops of hills and other places where an alluvial origin is quite out of the question.

In none of these beds have I found any fossils; the siwaliks and stratified beds of Pishin have not been very closely searched, but I have spent some time trying to find remains of shells in the loess. So far, all that has been found are some fresh-water shells, of the same species as are now living, in mud dug from some of the swamps in the valley. I was also shown a specimen of black clayey matter containing fragments of shells in a whitened and extremely friable condition said to have come from a depth of 60 feet in the artesian[1] boring put down in the Residency compound. The shells had been too much broken up by the boring tool to be determined with certainty, but there is no reason for doubting that they were fresh-water shells of existing species. The matrix was undubitably a swamp deposit, and apparently quite local in its extent, for it does not appear to have been met with in any of the other borings put down close by.

Of true fine grained alluvial deposits formed by overflow of streams, as opposed to those formed in temporary stagnant accumulation of flood waters, there is little to be seen in the area under consideration. The streams all flow in narrow channels, cut below the general surface of the plain, and in the bottom of these

[1] The specimen was not seen by me till after the boring had been completed; no proper record of this well was kept, and the determination of the depth from which the specimen came depends merely on the memory of the driller in charge.

there are occasional stretches of alluvial land, but beyond this nothing. Coarse-grained gravel deposits are however abundant and conspicuous in the broad talus fans, which spread out from the mouth of every valley, as it leaves the hills. They are the often-described "fans" or "*Cones de déjection*," formed of water-borne debris of various degrees of coarseness, the actual slope of the surface depending on a variety of circumstances, the principal of which are the volume of water which pours down in flood time and the average size of the debris carried; it varies from about 300 feet to 600 feet per mile, slopes higher than this being found, but, I believe, in every case these are due to disturbance subsequent to formation. In the actual channels usually followed by the streams the gravel is tolerably clean and easily permeable, but over the greater area of the fan, where its surface is not now washed by the streams, the stones are mixed with a varying proportion of wind-borne dust, which may even completely obscure the underlying gravel and form a surface of pure loess. Sometimes, as on the north-east of the Quetta plain, the smooth glacis slope of the fan is separated from the hills by a region where the slope is steeper and where the gravels have been cut into an undulating surface intersected by valleys. The distinction of surface is very marked, and is difficult to account for unless we suppose that part of the fan has undergone disturbance, by which its surface has been thrown into a steeper slope than that at which the gravel is naturally deposited, and, in consequence, the water flowing off has been able to cut it into hill and vale.

Besides the gravels of the glacis slope or "Dháman," the streams push long tongues of gravel over the loess area and, as the streams from time to time have altered their courses over the fans, the direction of these tongues has varied accordingly and they have been successively covered up by the gradual accumulation of loess. One of these underground tongues of gravel formed by the Hanna stream can be traced near Sherdil, two miles from the edge of the gravel fan, where an area of some acres of ground is riddled with karéz shafts, some of which, lying along a well-defined line, have struck gravel, while others have found nothing but loess.

These stream deposits have been only cursorily described as they present no important features of interest or novelty so far as their structure or mode of occurrence is concerned. Economically, however, they are most important, for it is to the tongues of gravel that we must look for a supply of artesian water, while in the fans themselves is a source of water-supply which, when tapped by the karez, is a most important element in the agricultural economy of these valleys and of all the drier parts of Central Asia.

A digression regarding the theory of the karez.—As the theory of the karez is a matter on which much misconception is prevalent, it will be well to treat of it briefly. The ordinary explanation is that an "underground spring" having been discovered, a series of shafts connected by tunnels is made, by which the water is brought out to the surface. This idea of an underground spring is extremely prevalent and owes its origin to the description of the natives who have frequently told me that the water entered their karezes from springs. I have scrambled through the underground passages of some of these karezes to investigate the matter and have found, as might be expected, that the description is a natural but misleading one. In a few cases the karez does appear to derive its supply from what may without great impropriety be called an underground spring. Such are the karezes between Kuchlák and Baléli which are driven through impervious siwalik clays up to the foot of a limestone ridge; it is not from the siwalik clays that they could derive any supply of water, so it is probable that there are here springs issuing from the solid rock. A still more striking instance is a short karez at Karáni driven, not into either of the fans which lie to the north and south of the village but towards the hill where there is no stream valley of any size, yet this is not only the shortest but one of the most abundant karezes I have seen: here, too, it seems probable that the water is supplied by a spring issuing from the solid rock. Such cases are, however, very exceptional, and, as a rule, the explanation, both of the real facts and of the origin of the misconception regarding the action of the karezes, is very different.

As the karezes are never lined in any way, it is impossible to drive them through incoherent material charged with water; it would moreover be unnecessary to do so as, if an incoherent bed of sand or gravel charged with water were once struck, the supply would amply satisfy the desires of the karez-diggers. The karezes, then, after they enter ground charged with water, can only be driven through stuff which is rendered coherent by a greater or less admixture of cementing material. But this cementing material not only renders the ground firm enough to form the sides and roof of the tunnel, but lessens the permeability of the ground and, what we are more concerned with, makes it irregularly permeable. When the karez is driven through such a deposit, the water will first of all drain away at those spots, where it is most permeable, very probably washing out the fine-grained matrix and forming a small channel penetrating to a greater or less distance from the sides of the tunnel. Into this channel water will percolate and, instead of oozing from the sides, enter the karez principally at certain defined spots, giving rise to what are called springs. The origin of the commonly held idea is thus natural and easily explained, but to call these "underground springs" is a misnomer and as misleading as it would be to apply the same name to an ordinary surface well.

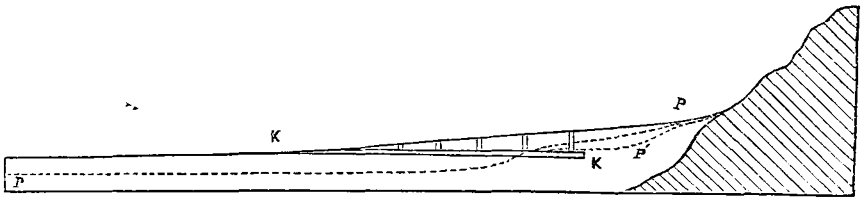

Fig. 1.—Diagram to illustrate the theory of the karez.

Having stated what is not, it is now necessary to describe what is, the correct explanation of a karez. In fig. 1 a diagrammatic section of one of the gravel slopes is represented; the dotted line *p.p.* represents the limit of permanent saturation, that is the limit below which the gravels are always charged with water even in the driest season. Such a limit exists everywhere, but the form of its contour depends on a variety of conditions, such as the rainfall, discharge of streams at the head of the fan, permeability of the gravels, etc., which need not here be considered in detail. Now, if the karez *k.k.* is driven into this slope, that portion of it which lies below the line *p.p.* will drain the sub-soil of its water and discharge this at the outlet.

It will be seen from this that in its nature and mode of action the karez is only a sub-soil drain; in both cases the object is to bring water which lies underground to the surface, the only difference being that in the one case it is desired to obtain the use, and in the other to get rid, of the water.

From the nature of the case these karezes are affected by the rainfall in a marked manner,—a single dry season, and still more a succession of years of deficient rainfall, causes a diminution in the discharge of the karez. Last year (1890) the falling off of water-supply was very widespread and, so far as the diminished discharge was only due to the dryness of the season, was not altogether an unmixed evil, for it led to an energetic cleaning out and in some cases lengthening of the karez which will improve its ultimate capacity. In a new karez, however, the failure may be due to another cause, which is more serious, as it permanently affects the supply of water, and may make this fall so low as to lead to the abandonment of the karez.

When the karez *k.k.* in fig. 1 is first made, water will flow freely into it from the surrounding gravels in all that portion which lies within the original limit of permanent saturation. But, after it is completed, a new outlet is provided for the sub-soil water, the limit of permanent saturation will adapt itself to the new conditions, and ultimately settle down with a profile which may be represented by the line *p. p'. p.* The subsequent history of the karez will now depend on the relative importance of the causes which led to the sub-soil water originally maintaining its level along *p.p.p.* If the gravels were tolerably permeable and a considerable supply of water was constantly percolating through them, the karez will settle down to a fair or abundant discharge. If, on the other hand, the amount of water percolating was very small and the level of permanent saturation kept up by the impermeability of the gravels, the ultimate conditions of the karez will be one of very small discharge.

I do not know to what extent this cause of failing supply of water has acted, or is acting, but there can be no doubt that, except in the case of old-established karezes, it must to a greater or less extent be at work. I made many attempts to collect information which would bear on this point, but was baffled by ignorance, reluctance to impart the information, or an inability, real or pretended, to understand the points regarding which information was desired. I was unable even to arrive at a trustworthy conclusion as to whether the reputed diminution of supply was as common, or as extensive, as was complained of, and this, when we consider how many reasons the proprietors have for complaining of a failure of water-supply and the absence of any inducement to acknowledge an increased discharge, is not to be wondered at.

As might be expected in a country where water is so valuable and apparently so mysteriously capricious in its occurrence, a class of men has arisen which pretends to a special knowledge of the underground distribution of water and to them the planning of new karezes appears to be principally entrusted. I have not met any of these men, but so far as I can gather they seem in some cases to possess a certain amount of knowledge, partly inherited, partly the result of observation, of the subject they profess. This is doubtless mixed up with a good deal of superstition, but as their directions are received with the same implicit belief as their rulers grant to the dictum of any self-styled "expert," the shaft, sunk on the spot indicated, is carried down till it reaches water, whereby the reality of his knowledge is proved.

Meanwhile he takes care to conceal the knowledge—if he possesses it—that there was no special virtue in the spot selected, and that there are many other places where a shaft would be equally certain to strike water, if given the same chance. Should water not be found, his employer is probably informed—for there is a close resemblance between the various species of the genus expert—that he did not go deep enough, or that though water was not found just there "the indications are very favourable," he is recommended to try some other place near by, and, if his patience or capital be exhausted before water is obtained, the expert, following the example of his kind, takes himself off to another country where his ignorance has not been exposed, there to find that ready credence which mankind is prone to yield to a plausible assertion of knowledge and, with better luck, repair his damaged reputation.

The amount of labour spent on some of these karezes, and the depth of their numerous shafts, is astounding; they are frequently miles in length and the shafts near their heads are said to be in some cases 150 feet deep. This is doubtless an extreme case, but, when examining the Quetta plain, I found that in many cases the shafts at the head of those which drain from the hills, east of the valley, could not be plumbed with the 70-feet line I carried with me. These must have taken many years and cost large sums to excavate, but it is probable that the whole was not made at once, and that they were gradually lengthened at their upper ends, where they are deepest out of the profits derived from the water which the original shorter channel yielded.

The Chamans or Artesian Springs of Quetta.

Among the most remarkable features of the Quetta plain are the numerous *chamans* or *chinnas*. The first of these words meaning a grassy spot, the second a spring, their nature is at once indicated. Riding across the naked plain, bare of vegetation where it is lying fallow or after the crops have been reaped, one suddenly comes on a green spot and water. Sometimes these are mere marshy spots, from which a small driblet of water may trickle away, but more commonly there is a pool, and not infrequently a strong spring of clear water issues from the soil.

There is a very conspicuous instance of this to be seen on the western bank of the Lorah just where it is crossed by the military road from Quetta to the Gháziáband pass. Here a strong spring of clear water with a discharge of several thousand gallons per hour issues from the scarped face of loess, as if from a rock. So too, about two miles from Quetta on the road to Sariáb, in one of these springs a short way west of the road, the water can be seen issuing with some force from the bottom of the pool. To the west of Quetta there is a series of these springs, draining one into the other and finally forming a considerable body of water, which has cut for itself a valley of some 20 feet depth in the loess. The great bulk of this water issues from the lowest of the springs, a pool of 20 feet diameter with a level bottom about 2 feet from the surface: this bottom is not, however, solid, but a very mobile quicksand kept in constant motion and surging to and fro by the action of a stream of water which is constantly forcing its way upwards from below. In 1888 a plummet was sunk into this, by Mr. P. Duncan, Executive Engineer, North-Western Railway, to a depth of over 100 feet before it was stopped, most probably by the friction of the sand on the sounding-line. From this it was evident that the water came from a considerable depth through a well-defined channel, and the nature of the spring stood confessed as a natural artesian well.

These springs vary considerably in size; from some there is a copious discharge of water, others again barely moisten a small patch of a few feet across, while yet another category is formed by those which, though they now have but a small discharge, show, by the sand heaped up over their orifices, that the water once issued with sufficient force to carry it up from below, the flow having since been checked by the falling in of the sides of the channel through which it flowed, by the heaping up of sand on the surface, or by both causes combined.

The most extensive of those belonging to the last category that I am acquainted with lies west of Quetta and covers about a couple of acres of marshy ground. Yet this is not a marsh of the type which is usually seen in the low-lying parts of valleys, where the level of permanent saturation rises to the surface, but it is distinctly raised above the level of the surrounding country, and on all sides water drains away in small driblets into the lower level of the loess plain. Between this and Quetta there is a very perfect little chaman, a low conical mound of about 20 yards in diameter, and rising some 4 or 5 feet above the level of the plain, at its apex, is a small pool of clear water and the whole recalls, on a very small scale, the description of the Hawaian volcanoes. Nor is the resemblance merely one of form, for there can be no doubt that just as these volcanoes have been built up of material poured out from the crater, so this has been built up of material brought from below by the water, which for some reason no longer issues with the force it used to.

Whatever may be the underground structure of the Quetta plain, the existence of water under pressure has been amply proved by the numerous successful artesian wells that have been sunk, but it still remains to be seen how the defined channels through the overlying deposits could have been formed before the "chamans" have been accounted for. In the case of those from which there is a copious discharge of water, it is conceivable that the channel might be kept open during the gradual accumulation of the loess, as any dust settling over the spring could be washed away as fast as it was deposited. In those far more numerous cases where there is little or no discharge such an explanation is not admissible, as there is no flow sufficient to keep the channel open against the continuous raising of the surface of the plain, and, in course of time, all these are certainly doomed to extinction; it might be urged that this is so, that these chamans which have so small a discharge were once copious springs, whose flow has been gradually reduced as the level of the surface was raised by the deposit of loess, and that the chamans, once much more abundant than they now are, have steadily diminished in number, as one after the other became obliterated by the same cause. The first objection to this is that, taking into consideration the great proportion of these springs whose condition is such that they would be obliterated by a very small increment to the thickness of the loess, small, that is to say, in proportion to the total thickness that has been deposited, and supposing that their destruction went on at the same rate throughout, the original number of the springs would have to be inconceivably great.

The most serious objection, however, is that the hypothesis is not a real explanation of the difficulty; as long as the water-bearing stratum formed the surface of the ground artesian conditions could not arise, and it is only after it had become covered up by a considerable thickness of fresh deposits that water could accumulate under pressure. Let us assume that only half the present cover was sufficient to produce artesian conditions, it is almost as difficult to understand how well defined vertical channels could have been made through 50 feet, of so necessarily homogeneous a deposit as the loess, as through 100 feet, and so we are landed once more in the same perplexity as before. Were it possible to suppose that these chamans marked the sites of old rock springs, whose flow had preserved an open channel through the gradually accumulating deposit in the valley, a natural explanation would be available, but the numerous borings put down at Quetta leave no doubt that such is not the case, that water under pressure exists below an extensive area, but that only locally and along defined channels does it obtain access to the surface.

The problem then is this, we have a permeable bed or beds containing water under sufficient pressure to make it flow at the surface as soon as it is afforded an outlet; we have overlying this a thickness of 100 feet or more of deposit homogeneous and practically impervious, except for certain defined channels reaching down to the water-bearing bed which can only have been formed after a considerable portion, if not to all intents and purposes the whole, of the deposit they penetrate had been accumulated. To account for these channels by natural causes seems impossible and the only resource lies in the hypothesis that they are the work of man, that the chamans in fact are in their origin artificial not natural artesian wells.

The idea, startling as it is, is not so absurd as it seems at first sight, the experience of the last two years has shown that the simplest and rudest appliances would suffice to put down a bore-hole through the fine-grained loess, and there are not wanting indications that the Quetta valley was once occupied by a race more civilised and energetic than the present indolent and apathetic inhabitants.

Scattered over the Quetta and adjoining plains there are a number of artificial mounds, varying in size, of which the largest and most conspicuous is the Miri, or citadel of Quetta. Owing to the earth from these being valued as a manure, some of them have been deeply dug into and they can be seen to be entirely of artificial origin and gradual growth; they are composed of innumerable layers of ashes and rubbish, mixed with earth, and have grown in size partly by the addition of material with deliberate intention of raising their height, but principally by the unintentional, steady raising of the level which goes on in every thickly populated locality through the constant bringing in of fresh materials for repairs to existing and the erection of new buildings. Originally they were probably the refuge forts for a race to whom the use of metals was unknown, but in their later stages they were occupied by a race which was not only possessed of the art of pottery, but made and used well-formed and well-baked bricks of a large size. Besides this, during the excavations made in the Quetta mound, Greek coins and a statue of Hercules were discovered, which show that the people who owned this fort 2,000 years ago had intercourse with the Western world. There is no great difficulty in supposing that this people possessed the art of boring for water, the difficulty is to understand how the art became lost, but an explanation may be found in the long period of anarchy and internecine warfare which the country is known to have gone through.

The explanation mooted here has at least the advantage of accounting for the facts; it accounts for the existence of well-defined channels through the otherwise homogeneously impervious loess, and it also accounts for the differences in discharge from the different chamans. I have said that to bore down through the loess to the gravel beds is a task which can be accomplished with the simplest of appliances, but once the gravel is struck, to carry the borehole further would require appliances which we cannot suppose were at the disposal of these ancient inhabitants of the Quetta plain. Consequently the discharge from a borehole would depend on the nature of the first gravel bed struck. If the gravel were so mixed up with loess as to be quite or almost impervious, there would be no discharge, the well would soon fall in and become obliterated; if, on the other hand, the stuff struck immediately below the loess were freely permeable, the water would issue in large volumes carrying with it quantities of sand, as actually happened in the case of some of these chamans. Between each of these extremes every gradation might occur, as the greater or less degree of permeability of the water-bearing beds where struck, and the hydrostatic pressure of the water contained in it, admitted of larger or smaller discharge into and from the borehole.

Examples of both extremes of discharge can be found among the artesian borings put down during the last two years in Quetta. Two of these, put down by hand-power without any casing and carried only as far as the water-bearing bed, were sunk in the Residency Surgeon's compound; the first of these yielded a moderate flow of water, quite sufficient to keep the borehole clear, the second struck the gravel where it was less pervious and failed to give any discharge. The history of the pioneer well, that at the Railway station, is different. This was put down by steam-power with all the appliances which modern ingenuity has perfected. When the gravels were struck there was only a moderate discharge, but the well was carried on till, at a depth of 140 feet, a freely permeable bed was struck, from which the water commenced to flow, bringing with it large quantities of sand, till ultimately the well attained a discharge of 20,000 gallons per hour. Had this freely permeable band immediately underlaid the loess, the water, when first struck, would have issued with force, carrying up with it sand and loess washed from the sides of its channel, and doubtless ultimately have settled down to a copious spring of water similar to those referred to above.

Such is what appears to me the only feasible explanation of the chamans of the Quetta plain. That there are difficulties in the way I do not deny. It is hard to believe that the present race of inhabitants ever possessed the art of sinking artesian wells and we must look to their predecessors, a people who must have differed in character and may have been the same as those who built the "ghorbastas" of Sarawán, those extensive and carefully planned masonry works which have attracted the attention of more than one traveller, which also, like the artesian wells of Quetta, were intended to increase the agricultural capabilities of the land.

The restriction of these artesian springs to the Quetta plain, with the possible exception of one near Bostán, and their absence over the Pishin plain and Dasht-i-Bedaolat agrees very closely with the probable limitation of the area in which artesian water exists a a depth at which it would be accessible. At Bostán easily accessible artesian water is known to exist, but the area over which it is likely to be found is very small and the pressure in the solitary boring put down was barely sufficient to make it flow at the surface. Under these circumstances it may be that one or two failures discouraged further attempts, or it may be that the pressure and flow of water was so small that boreholes, which once existed, have since fallen in. It must also be remembered that the sinking of these bore-holes with the primitive appliances available would be a work of time; the art may have originated or been most energetically carried on in the Quetta plain and, before the full capabilities of the other valley plains were developed, an irruption of barbarians destroyed at once the civilisation and the skill which had given birth to these undertakings.

This is, of course, a matter of conjecture impossible to substantiate, what is certain is that the chamans of the Quetta plain are essentially artesian wells, that the water rises by well-defined channels through a homogeneous and impervious cover from an underlying pervious bed, in which it exists under pressure, and that the bulk, if not the whole, of this cover must have been deposited before the passages were opened between the water below and the air above. These passages may have been opened by natural causes, but the most probable explanation, taking all things into consideration, is that they were made, with the deliberate intention, by a race the very memory of whom has now been forgotten.

On the mode of occurrence and probable distribution of artesian water in the valley plains of Quetta, Pishin, and the Dasht-i-Bedaolat.

In an attempt to decide whether artesian water exists under any particular spot, the first thing is to arrive at a definite conclusion as to the structure of the ground, and the cause of the pressure which makes the water rise to the surface when tapped by a borehole. The ordinary text-book explanation of an artesian well being inadequate and altogether inapplicable to the Quetta plain, it will be necessary, in the first place, to consider this question and then proceed to the application of the conclusion arrived at.

In the case of the Quetta wells the ordinary popular explanation is that the pressure comes from the surrounding hills, but a very slight consideration will show that there can be no continuity between the highly-disturbed ancient and indurated rocks of the hills, and the soft, nearly horizontal deposits of the plain which are still in process of formation, and consequently it is impossible in a general way that the pressure of the subterraneous water in the latter can be due to the greater vertical elevation of the former. There is, however, a particular circumstance of structure in which the pressure of the artesian water might come from the surrounding hills. If we suppose a subterraneous spring to issue in a patch of coarse-grained permeable deposits, *t. t.* in plate 1, fig. 1, such as one of the minor talus fans, and this patch of permeable deposits to be subsequently covered up and sealed by the deposit of fine-grained impermeable beds, *L. L.* of the same figure, there would be a small area in which a boring would be able to obtain artesian water, whose pressure would really be directly due to the water which soaked into the surrounding hills at a higher level. Such conditions are probably very exceptional, but the possibility of their occurrence must be borne in mind.

A more rational explanation of the pressure is that illustrated by the diagram section, fig. 2. This figure is analogous to the ordinary text-book explanation of an artesian well, on what may be called the basin theory, and in the case of the Quetta plain, such conditions do indubitably exist to a large extent. The rock basins in which the recent deposits of the Quetta and neighbouring plains have been formed are due to "earth warping," as it has been called, that is, to an elevation of the outlet of the drainage at a rate greater than the stream was able to cut downwards whence the velocity of the current was checked and deposits accumulated over a large part of the basin so formed; the first deposits being coarse-grained permeable stream gravels and sands which were afterwards covered up by fine-grained deposits. The exact proportion of the valley so underlaid by a floor of permeable grained deposits would depend on the rate of elevation of the outlet, and the original contour of the ground, none of which are now determinable with accuracy; broadly speaking, the floor of coarse-grained stream deposits will be continuous over the original main and tributary valleys, while the fine-grained deposits will be to some indeterminable extent in direct contact with the underlying rock on what were originally the spurs.

But though there is doubtless such a continuous floor of gravels, and though it is to this only that we can look for artesian water in the central parts of the valley plains, it by no means follows that this is the source of the artesian water that has so far been obtained, and a study of the records of the wells put down, as yet leads to a different conclusion.

The first artesian well in Quetta was put down in the summer of 1889. The next well in order of time to be sunk was that in the compound of the Political Agent, Quetta and Pishin, which also struck water and was followed by a number of others, particulars of which, so far as they are available, are given in the appendix. If all these wells have been sunk to a layer of porous deposit, which lies directly on the rocky floor of the valley and is overlaid by the finer deposits, we would hardly expect to find great differences in the depth at which they struck water, as the upper surface of the coarse deposits would be smoothed off to a fairly uniform slope by the action of the streams. But if we remember the tongues of stream deposits which are thrust forward from the main body of the fans over the surface of the fine grained loess, we can arrive at a simple and intelligible explanation. On this hypothesis the deep wells would penetrate the older tongues which, when the stream broke away from its course, became covered up by fine-grained deposits, till, at a later period, the stream again took a course approximating to its older one and formed the tongue from which the shallower wells derive their water. The conditions here indicated are graphically explained in the diagram section, fig. 3, which indicates a condition as favourable for the production of artesian wells as that in fig. 2, and is more in accordance with the facts at present known.

The only alternative hypothesis is the improbable, though not impossible, one that these wells have all been sunk on to lines of talus debris, and derive their water from a subterraneous spring, as is represented in fig. 1. Besides its inherent improbability, the nature of the gravel and sand brought up from the borings, so far as I saw it, does not favour this hypothesis. The pebbles were all more or less rounded and, especially the fine gravels, showed such signs of the action of running water that it is difficult to believe that they were not deposited by a running stream;

a supposition strengthened by the alternation of coarse and fine-grained material exhibited by the boring put down in the compound of the office of the Superintending Engineer, Sind-Pishin Railway. The question would soon be settled by a single boring carried down through the shallow water belt to the solid rock, or to the fine-grained impervious beds which should be found, if the explanation I regard as the more probable is the true one.

It would be too much to expect private enterprise to go to this expense, but seeing that nearly all the wells sunk, or being sunk, are Government wells, it does not seem too much to ask that one should so be driven on, even after water has been obtained, and if two or three others were sunk in properly selected spots in the neighbourhood of Quetta and driven as deep as possible, unless previously stopped by rock, a satisfactory conclusion regarding the true conditions of these wells will be arrived at. Nor would this be of merely theoretical interest—that bug-bear of the so-called "practical man"—but the knowledge so obtained, by enabling us to predict with some approach to certainty the probable result of boring for water at any spot, would result in a more economical expenditure and a prevention of the waste of money which will be inevitable if the principle followed is that of putting down a boring wherever it is thought that water would be desirable, irrespective of any considerations of the possibility of success.

In the meanwhile, it is impossible to determine with certainty the exact conditions under which the artesian water of the Quetta plain occurs, but the evidence available is so far in favour of the hypothesis I have suggested, illustrated by fig. 3, that I shall adopt this as the best working hypothesis available, and in the portion of this report which is devoted to a determination of the areas over which artesian water probably exists, shall base my conclusions principally upon it.

The Gwende Dasht and Dasht-i-Bedaolat have been least fully examined of any of these plains. They are both areas of closed drainage, both are remarkably level and characterized by an absence of large fans on their margins, the fine-grained deposits of the plains often extending right up to the foot of the hills. This absence of fans is due to the absence of any large streams draining on to the plains, and such small streams as do issue from the hills cannot extend far over the plain owing to the flatness of the surface. The recent deposits of both these plains seem, as far as could be judged when merely travelling along the road, to consist entirely of wind-blown loess, which has in many places a distinctly reddish tinge when wet. The lowest parts of these plains are, however, regularly flooded after heavy rain, and it is probable that there finely stratified deposits are formed, though, from the nature of the case, no sections can be observed.

The conditions here are altogether adverse to the occurrence of artesian water. The thickness of the loess is probably very great, and the coarse-grained beds which underlie it, have been cut off by its extension from any but a very small accession of surface-water at the margin of the plain. The very gentle surface gradients prevent the formation of long tongues of gravel extending into the plain, and the conditions of deposit to which the low surface gradients are due, have probably continued through the accumulation of some hundreds of feet of loess. The only part where there is any promise of success is in the extreme north-west corner of the Dasht-i-Bedaolat, where a larger stream than usual enters the valley, and there is a well-marked, though not very large, fan; a boring sunk a couple of miles from the edge of this might find water, but I cannot regard the prospect as promising.

The watershed separating the Dasht-i-Bedaolat from the Quetta plain is formed by great fan-shaped accumulation of loess and gravel. This does not appear to me to be altogether a slope of deposit, but largely due to a warping of the surface in consequence of differential movements of elevation. However this may be, on crossing the watershed we enter a valley plain, which differs most markedly from the Dasht in the abundance of well-defined and extensive gravel fans, and in the distinctly noticeable slope of the surface towards the centre of the plain. The valleys of the streams within the hills are in many cases larger than those which drain on to the Dasht, and this, combined with the surface slope, enables them to send long tongues of gravel out into the plain. To this circumstance appears to be due the prevalence of artesian conditions in the centre portion of the Quetta plain, as evidenced not only by the successful artesian wells which have been sunk, but also by the numerous "chamans," or artesian springs, which are scattered over an area of seven miles from north to south, and three miles from east to west, in the central part of the valley. Over all this area, which includes the whole of the civil station and the western half of the cantonment of Quetta, water may be bored for with a probability of success; failure is, of course, possible in the sense that at any one particular spot the boring may miss the gravel tongues, and fail to find water at a depth which would make it worth while boring for.

To the north, along a sinuous line with a general east and west trend, about a mile south of Baléli, the red siwalik clays crop out at the surface and form a plain, rising slightly above the level of the loess, from which some low hills rise to heights varying up to about 40 feet. North of Baléli these siwaliks range right across the valley and abut against the hills on the east. Owing to the structure of these beds, artesian water probably exists under all this area, but at so great a depth as to make its extraction unprofitable.

About Kuchlák a strip of loess separates the siwaliks from the limestone hills to the east, and at its southern end is the fan at the mouth of the Murghi pass. Near this artesian water might be obtained, but it is doubtful, as the stream and fan both appear to be too small to produce the necessary conditions. A borehole was put down at Kuchlák village in 1890, but without success; failure, however, was only what should have been looked for here, as it is too far north to be supplied by the Murghi pass stream, and there is no other stream capable of producing the necessary conditions.

To the north of Kuchlák the siwaliks again extend across the valley and probably abut against the hills, though, at the surface, they are covered by talus. East of Bostán there is a large fan, whose southern margin runs on to the siwaliks, doubtless overlying them, and in this direction the chance of finding water is very problematical. On the northern slopes of the fan the conditions are different; here it tails off into loess, in which the presence of artesian water has been proved by the successful well sunk near the railway station. The area over which artesian water may be expected to occur, lies northwards from the village of Kasim Khán and east of the line of railway, but to the west of a line drawn from the village of Kasim Khán to the railway station, success is problematical, while north of the line of railway it appears to be impossible.

The Pishin plain is more extensive than any of the others and has not as yet been fully explored. All the eastern part of it is composed of finely stratified deposits, and over this area if artesian water exists at all, it is probably only at such a depth that it would not pay to bore for it. Along the northern and eastern margins of the plain, unstratified loess like that of the Quetta valley comes in, and there are several large fans of gravel. The resemblance in these respects suggests the possibility of a similar occurrence of artesian conditions, and I would suggest that experimental borings should be put down at about three miles from the edge of the Gulistán fan, in a south-easterly direction from the village, and at a similar distance south of the edge of the gravel fan at Alizai on the north of the plain.

It will be seen from the foregoing that the area over which water may be bored or with a prospect of success is much smaller than the expectations of those whose hopes have been raised by the successes at Quetta would lead them to suppose. It must of course be borne in mind that the conclusions have been based entirely on an hypothesis which is not the only possible, though the most probable one. But this is of the less importance as we are concerned principally with those areas over which water can be obtained at a moderate depth, deep borings being inadmissible from their expense where the water is required for agricultural purposes and only justifiable where special circumstances necessitate the procuring of a supply of water at whatever price it may cost. The area over which water can be obtained by borings of moderate depth would not be increased, but rather diminished from that described in this report, were any other hypothesis adopted than that on which I have based my conclusions.

SECTIONS OF BORE HOLES AT QUETTA AND BOSTÁN.

1. Well at Railway station—
   - 120 feet loess.
   - 20 feet gravel, underlaid by quicksand.
   - Discharge 20,000 gallons per hour; hydrostatic head 50 feet.
2. Well in Political Agent's compound—
   - 115 feet loess.
   - 8½ feet shingle with a little artesian water.
   - 2 feet loess.
   - Gravel, an abundant discharge of water.
3. Well in Loco. Superintendent's compound—
   - 92½ feet loess.
   - 3½ feet gravel with artesian water.
4. Well in Executive Engineer's (Railway) compound—
   - 90¾ feet loess.
   - 10 feet gravel, from which water just flowed at surface.
   - 10 feet loess.
   - 20 feet coarse sand and gravel, with an abundant discharge of water.
5. Well at Gymkhana—
   - 77 feet loess.
   - 10 feet "hard sandy stuff".
   - 8 feet "indurated sandy lumps".
   - 35 feet "clay with nodules".
   - 3 feet quick sand.
   - 12 feet hard clay.
   - Quicksand with water.

6. Artesian well at Bostán, as deter.nined from specimens preserved—
   10—20 feet pale yellow unctuous clay containing fine grains of silica and effernescing freely with acids. LOESS.
   20—30 feet the same, but not so fine grained.
   30—40 feet finer than 10—20 feet.
   40—60 feet very like 20—30 feet.
   60—80 feet the same with some pieces of calcareous rock, (kunkur).
   80—90 feet same as 10—60 feet.
   100 feet irregular small pebbles of pale grey limestone.
   180 feet still in gravel, discharge of water 2,500 gallons per hour.
   230 feet or thereabouts, entered as siwalik clays.

GEOLOGICAL SURVEY OF INDIA DEPARTMENT.

TRI-MONTHLY NOTES.

No. 10.—ENDING 31ST JANUARY 1892.

Director's Office, Calcutta, 31st January 1892.

The staff of the Survey is distributed as follows :—

Lower Burma.—THEO. W. HUGHES, A.R.S.M., Superintendent.
P. N. BOSE, B.SC., 2nd grade Deputy Superintendent.

Upper Burma.—C. L. GRIESBACH, C.I.E., Superintendent.
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Sub-Assistant Kishen Sing.

Madras.—T. H. HOLLAND, A.R.C.S., Assistant Superintendent.

Head Quarters, Calcutta.—The Director; and R. D. OLDHAM, A.R.S.M., Superintendent.

Mr. Hughes and his party continue at the tin exploration in Tenasserim: Mr. Griesbach accompanied the north-east Burma Column, and afterwards joined the Irrawadi Column in quest of reported ruby occurrences. Dr. Noetling is attached to the Northern Column in the Amber and Jade country. Mr. Datta is engaged in surveying the country south of Yenangyoung. Mr. LaTouche, with Sub-Assistant Kishen Sing, has taken up the survey of the south-east Takht-i-Suleiman

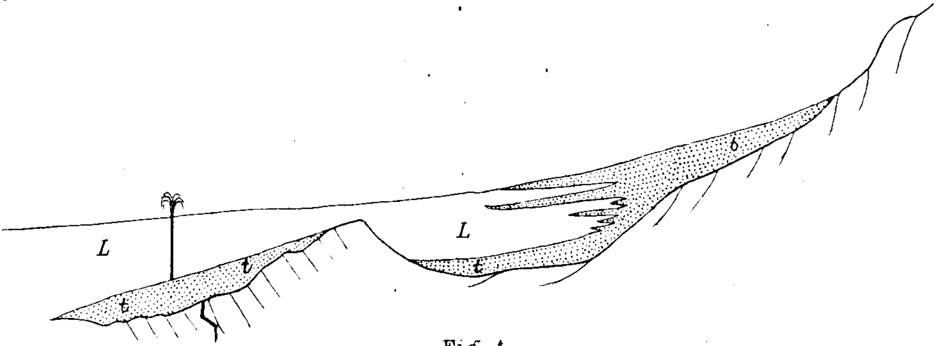

Fig 1.

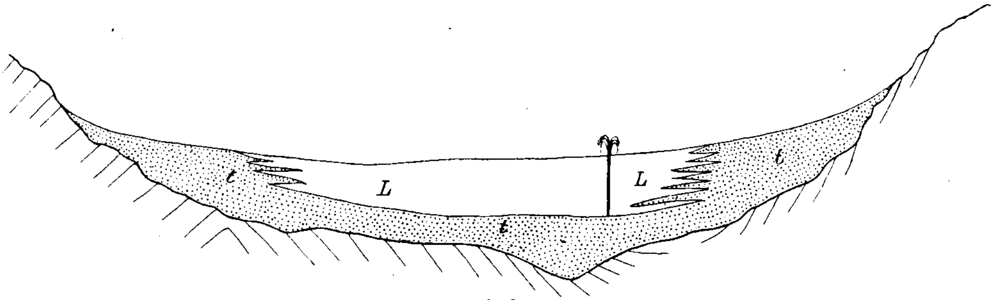

Fig 2.

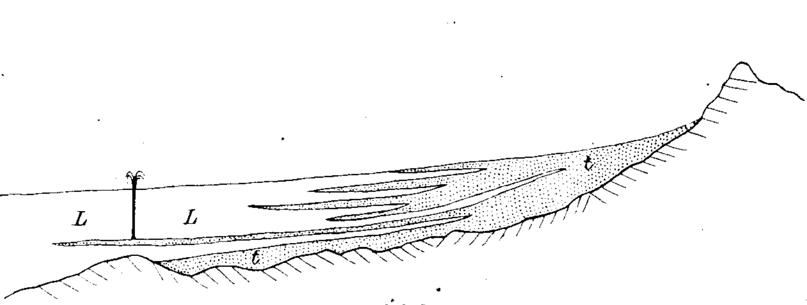

Fig 3.

To illustrate possible conditions of occurrence of artesian water.

L. L. fine-grained loess. t. t. permeable gravels.