THE SUBMARINE LEAKAGE OF ARTESIAN WATER.

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In a paper read at the Brisbane meeting of the Australasian Association for the Advancement of Science in January, 1895, I spoke of two kinds of leakage which might possibly affect the bibulous beds at the base of the Lower Cretaceous formation: First, a leakage into the sea—"Suppose the beds to dip seaward and beneath the sea, and either to rise to the ocean bed or to dip at a lower angle than the slope of the sea bed, there would be a leakage into the sea. And, again, suppose (what we believe to be actually the case) the outcrop of the beds to occur at gradually lower levels till it attains the sea level, there would be a leakage in the form of springs, or into river beds along the line." I then referred to evidence in favour of the first kind of leakage—into the sea—afterwards to be recapitulated, and in speaking of the second kind of leakage, as springs where the intake-beds had their outcrops at comparatively low levels, said:—"Nor is evidence of the second kind of leakage to hand. The outcrop of the Blythesdale Braystone, as it falls away from its highest altitude . . . down to the McIntyre River is not very conspicuously marked by springs." In discussing a paper on the subject by Mr. Walter Gibbons Cox, C.E., Mr. J. P. Thomson, President of the Queensland branch of the Royal Geographical Society of Australasia, endeavoured to show that the second kind of leakage is of considerable volume, in evidence of which he quoted Julian E. Tenison Woods' observations* on the occurrence of a

* "Australian Handbook," 1895 Edition.

line of groups of thermal and cold springs. Mr. Woods did not claim that the springs he referred to occurred at the outcrop of the water-bearing formation, and, as a matter of fact, they do not occur there more than elsewhere. Some, for instance, the largest of them all, that on the Einasleigh, well out of Palæozoic rocks. So far, however, as they are known to occur within the boundary lines of the Lower Cretaceous formation, they are, of course, natural artesian wells, but their output is insignificant compared with the intake of the bibulous beds near the base of the formation.

On the latter subject, as my colleague, Mr. Maitland, is now at work continuing the delimitation of the lowest Cretaceous beds between Hughenden and the Gulf, it may be well to record his identification of the Blythesdale beds (the lowest and most important of the intake beds) on the Flinders River and Porcupine Creek, with their base at 2600 feet and their top at 1900 feet above the sea level, and to quote a passage from a letter dated 9th June :—" The Upper Flinders cuts its way through the escarpmenta of the Blythesdale beds, which here are of such a character as to be admirably adapted for the absorption of and transmission of water, and, in crossing the outcrop, has eaten out a channel for itself, in some places 400 feet and 500 feet deep, and not more than 30 feet or 40 feet across—in some places not nearly so wide. Before entering the sandstone, &c., the Flinders is a fine running stream of considerable width ; down the canon by far the greater portion of the water has disappeared ; whilst at Hughenden I could scarcely believe I was crossing the same river." He adds :—" I am told on good authority that the heads of the Dutton and the Cambridge are formed of deep sandstone gorges, identical with those of the Upper Flinders."

In the paper before alluded to I pointed out that several large watercourses—*e.g.*, Blyth's, Bungil, Bungeworgorai, and Amby creeks, the Maranoa River, Hoganthulla Creek, the Warrego River, Birkhead Creek, Torrens Creek, and the eastern tributaries of the Thomson River, which cross the outcrop of the Blythesdale Braystone, while crossing that outcrop, absorb enormous quantities of water, and that the streams, except in flood time, cease to run beyond the outcrop. In the absence of measurements of the amount of water absorbed by these Queensland rivers, I quoted, as a parallel instance, Mr. H. C. Russell's calculations relating to the Darling. " The mean annual rainfall on the Darling River catchment for the past ten years has been 22.14 inches, and of this only 1½ per cent. or 0.33 inches of rain passes Bourke in the river. If 25 per cent. of it, which is equal to 5.53 inches of rain, passed away in this river, as it does in the Murray, there would be seventeen times as much water passing Bourke as now actually does pass. . . . And we ought, therefore, to have an underground water supply at least equal to sixteen times as much water as passes Bourke now. . . . That we do not find it in the Darling is to my mind proof that it passes away to underground drainage." To make Mr. Russell's argument clearer I ought to have had quoted this further passage :—" The Darling carries away only 1½ per cent. of the rainfall, while the Murray, a river existing under similar conditions of climate, wind, rain, and evaporation carries away 25 per cent. of the rainfall. The only difference I can see which seems to offer any clue to this great disparity . . . is in the extremely porous character of much of the Darling basin."

Mr. Thomson, in discussing Mr. Cox's paper, pointed out that recent measurements* show that not 1½ but 6 per cent. of the annual rainfall on the total effective catchment area of the Darling above Bourke (which is 20 inches instead of 22.14 inches†) passes Bourke in the course of the year. Assuming the accuracy of those figures, I do not see that Mr. Russell's argument is impaired. The rainfall is distributed in three ways : One portion sinks into the earth, not to return except through springs or submarine leakage ; a second portion is evaporated ; and a third is carried off by the watercourses which drain the surface. Whatever figure we assume or ascertain for the amount drained by the watercourses, the remainder of the rainfall must be divided between evaporation and absorption. Even if 6 per cent. of the rainfall is carried off as drainage by the Darling valley, the remaining 94 per cent. will surely leave enough both for absorption and evaporation.

* Annual Report of the Chief Engineer for Water Conservation, New South Wales, for 1891.

† Mr. Russell informs me that in 1891 the rainfall over the Darling area was 27.27 inches.

But, says Mr. Thomson, "When it is taken into consideration that the climate of the Bourke district is one of the hottest and driest in the country, it will not, I presume, be difficult to imagine that an enormous volume of the somewhat scanty rainfall must be lost by evaporation as compared with the rather small quantity discharged by the river . . . In the case of our rocks and soils there is rapid evaporation under favourable atmospheric conditions, owing to high temperature produced by internal as well as external heat." What, in this case, evaporation through the agency of "internal" heat means, is that water penetrating the soil may reach a portion of the earth's crust where the heat is great enough to convert it into vapour, and that the vapour may rise through superincumbent strata, and escape at the surface. There could, however, be no such escape, as the vapour would be condensed on reaching the cooler strata near the surface, and, in the form of water, would gravitate inward, retracing the steps of its outward course.

Mr. Thomson does not, however, seriously dwell on the possibility of evaporation by means of internal heat, although from subsequent remarks he seems to see an analogy between the crust of the earth and the moleskins which form the outer integument of many Australians, but passes on to the subject of evaporation by means of solar heat. He asserts that at the Enoggera Reservoir the water evaporates at the rate of a quarter of an inch per day, "and in the central regions of Australia it has been estimated, by a series of experiments and reliable observations elsewhere, that the process of evaporation goes on, under favourable conditions, at the rate of 1 inch per day."* "Just imagine," he adds, "what this means in regions where the annual rainfall is not greater than from 10 inches to 12 inches!" It means, no doubt, that a rainfall spread out in a thin sheet on a non-absorbent clay soil, which does not slope sufficiently to permit of rapid drainage, will be dissipated by evaporation in a few days or weeks, and nobody can deny that

*In a letter dated 22nd July, 1896, Mr. Russell says: "I have, for a number of years, measured the actual evaporation in the Western districts. The greatest recorded evaporation in a year in our hottest country is 5ft. 5in., and this from a tank 4ft. in diameter and 3ft. deep, kept full or nearly so—a condition in which sun and wind have more effect than they have in ordinary reservoirs.

these conditions exist over a large portion of the western interior of Queensland—that portion, in fact, where modern artesian wells are now pouring out enormous volumes of water. I was present at a meeting of the Geographical Society on 29th May last, when Mr. Thomson expressed the opinion that evaporation (through internal and external heat) was sufficient to account for the whole of the rainfall not carried off by drainage. It *must*, indeed, if the same conditions of impermeable soil and excessive solar heat observed in portions of the Western interior apply to the outer edge of the artesian basin, where the water is absorbed. But if these conditions apply, Mr. Thomson's argument proves too much ; for it proves, to those who believe that rainfall is the first cause of artesian water, that there is *no* artesian water in the West. It is easier to imagine that the conditions do not apply.

At the January meeting Mr. Thomson gave "some remarkable examples of the atmospheric condition of Central Australia," in order to emphasize his remarks on the adequacy of evaporation for disposing of that portion of the rainfall not carried off by drainage. He is reported to have said : "In one of his exploring expeditions my esteemed colleague and predecessor in office, the Hon. A. C. Gregory, had several hard guttapercha drinking mugs with him. They were left in camp one day on top of the table. When the explorers returned in the evening the mugs had disappeared, the only trace of them remaining being a liquid glutinous substance on the spot where the mugs had been left. On another occasion Mr. Gregory was camped about a quarter of a mile from a creek, and it was necessary to swim it. When returning to camp Mr. Gregory wore a thick pair of heavy moleskin trousers, and in swimming the creek with them on they were, of course, completely saturated ; but after walking into camp the whole of the water absorbed had evaporated absolutely, and the trousers were quite dry." The heat on the date of the drinking-cup incident may have been 128 deg., and as guttapercha will melt at 115 deg., I have no doubt that Mr. Gregory contented himself afterwards with pannikins of more difficult fusible material. As for the moleskins, they may have been thick and heavy when they left the shop, but no one who knows Mr. Gregory's active habits can doubt that by the time they had been in use for a few months they were not much thicker than those worn by the average bushman. A well-known mercer in this city informs me that twenty-five folds of the thickest moleskin go to an inch, and it need be no matter for surprise that a film of water supported by a textile fabric one-twenty-fifth of an inch thick should be rapidly dissipated into vapour between the fervour of the explorer within and the ardour of the sun without. It may even be remembered that history records how, in a much colder climate, a party of invaders, after swimming a river which enviously interposed between them and certain rich lands and fat beeves, "danced themselves dry to the pibroch's sound," notwithstanding the considerable quantity of water carried to the English shore in the voluminous accordeon-pleated garment which they preferred to moleskins or corduroys.

Mr. Thomson, at the January meeting, suggested that the disappearance of river water in crossing the bibulous beds, which are now recognised as the principal intake beds of artesian water in the West, might be imaginary, and it is needless to repeat that this disappearance is an observed fact, which can be attested by any dweller in those regions. He cited the bodily disappearance of rivers of which Monsieur E. A. Martel gives many examples in his work, "Les Abimes." There is, however, no analogy between the disappearance of European rivers in the caverns of limestone strata, and the soakage of water into the sandstone and conglomerate beds of the Australian interior, among which the occurrence of elongated caverns is a physical impossibility. No thick beds of limestone crop out at the base of the Cretaceous formation; and if they did, and if the rivers were engulfed by elongated caverns, the artesian water would be found only where the borer had the good fortune to strike the course of such underground channels. As the system of boring pursued is (within the defined limits of the Cretaceous formation) what is known in mining language as "blind stabbing," there would be a hundred unsuccessful for one successful bore if the artesian water ran in narrow underground channels instead of being almost everywhere present within the area represented by the outcrop of the Lower Cretaceous. Underground rivers have nothing to do with the case. Mr. Thomson further (January) remarked that "the whole central basin is nowhere greatly elevated above sea level. . . . and it must be remembered that the levels are so low that it would be difficult, if not altogether impossible, for water to circulate along these by gravitation." I should have thought that the low levels of the surface of the interior, implying still lower levels for the strata in which artesian water is actually met with, coupled with the fact of the high altitudes at which the strata crop out, afforded, on the contrary, the most favourable conditions possible for the circulation of water.

I can only reiterate the observed fact that numerous important rivers disappear on crossing the outcrop of the lowest beds of the Lower Cretaceous formation. There is nothing in the world to lead us to doubt that the water is absorbed by these strata, and carried down by them beneath the impermeable clay shales, which underlie the soil of the interior. That it is so distributed is demonstrated by the bores themselves. The inference follows naturally that if, every wet season, these beds are prepared to absorb a great portion of the rainfall, they must have been emptied, to a corresponding extent, of the water absorbed during previous wet seasons. In other words, if they are full, they can hold no more. The bores and springs combined do not give out a tithe of the water absorbed every wet season, and, as the water does not escape by land, and can hardly be supposed to find a hiding-place in the centre of the earth, the only alternative is that it must escape where the absorbing strata crop out beneath the floor of the ocean. "But," says Mr. Thomson (January): "In support of the theory of leakage it has been stated that the capacity of the water-bearing beds can only be rendered efficient and adequate by the subterranean channels that communicate with the sea; that, in fact, the quantity of water drained off by these compensating or accommodating arteries is about equal to that absorbed by the bibulous rocks. And upon this hypothesis we must conceive that there is an absolutely inexhaustive underground reservoir of artesian water *intra muros* with an outflow so nicely regulated that its capacity is *in equilibrio* and adequate to receive and contain the whole body of water greedily absorbed during periods of rainfall and flood, and that, moreover, the waters of this reservoir never reach sea level, even during times of prolonged drought, as evidenced by the constant and undiminished overflow of our artesian wells. Were cause and effect so easily explained, we should have before us one of the most remarkable examples of natural phenomenon with which students of the century have had to deal—one of the most interesting dynamical problems of the age. It would, indeed, be a remarkable natural process by which an artesian reservoir would never fall to the level of the sea, even during long periods of intense dryness, when there could be no local supply with which to replenish an ever decreasing store." The conception of such a condition of equilibrium is entirely Mr. Thomson's own. It is not difficult to understand that when more fluid is poured into a receptacle than it will hold it runs over, and there is nothing unnatural in the fact that after a heavy wet season, when the absorbent strata have been filled to their utmost capacity, the rivers run longer than usual over the Western interior. Fluctuations in the artesian wells will be looked for by all who admit that the first cause of the supply is the periodical rainfall. To show that I regarded such fluctuation as inevitable, I may quote from the paper read in January, 1895, at the meeting of the Australasian Association :—"The loss of water by the Darling River, and probably a similar loss of water by the Western Queensland rivers, proves that the water-bearing strata must leak into the sea, and hence that unless the strata be periodically replenished the sea level would ultimately become the level to which the water would rise. A drought sufficiently long to bring about this result would, no doubt, have, for a prior result the destruction of the greater part of the land fauna of this part of Australia, including the *genus homo*. Far short of this, however, we can conceive of the temporary diminution or cessation of the flow of some at least, of our artesian wells."

Since this was written fluctuations have been observed in the pressure and output of a few of the artesian wells. Some have even ceased, and after a time have recommenced to flow. The only possible intermittent source of artesian water is the rainfall; but a series of observations on the fluctuations of pressure and output in the wells, only initiated by the Government within the last twelve months, must be carried out for some years before we can arrive at the relations between the rainfall and the activity of the wells. It must be mentioned, by way of caution, that some of the wells obviously owe their stoppage to faults in tubing, and others to the caving-in of the strata. The observations are rendered necessary by the fact that strata in which the grains or granules are massed together with varying and unknown degrees of compactness must conduct water (owing to friction) at a rate different from what would be the rate in the theoretical open tube. It may take one, two, five, twenty, or a hundred years for a given drought to affect any particular bore; but if corresponding curves can be established by observation between rainfall on the one hand, and the output of the bores on the other, we shall have a law by which we can predict in any given year what will be the flow of the bores—barring, of course, such accidents as decay of tubing, filling up with deposited mineral matter, and caving-in of the strata. It is now well known to borers that the nearer they are to the edge or intake of the basin, the less will be the chance of a heavy supply, and the greater will be the chance of an intermittent supply, the obvious explanation being that the head of water in these cases is apt to fall to or below the level of the bore. At the January meeting Mr. Thomson advanced an argument against the submarine leakage, which I am able to quote verbatim :—" I am strongly of opinion that the pressure of the higher specific gravity waters of the ocean would prevent any remarkable leakage at anything like considerable depths." At the May meeting, when I was present, Mr. Thomson further expounded and Mr. Gregory confirmed this view. Given a sufficiently elevated " head " of fresh water, connected by a tube with the salt water of the ocean, an equilibrium, depending on the slight difference between the specific gravities of fresh and salt water, would inevitably be established. This is one of the simplest axioms of hydrostatics. If, instead of salt water, the ocean were filled with glue of a tenacity sufficient to protect the submarine outlet of the strata from the pressure due to the head of water at the outcrop, then we could understand how the strata could fail to be periodically emptied, and prepared to receive further contributions from the rainfall ; but on no other supposition is such a failure imaginable. But we know that the strata do annually imbibe an almost incalculably large amount of water; therefore they are partially emptied before the periodical rains set in; and therefore the depths of the ocean are no more filled up with glue than they are with rose water.

At the May meeting of the Geographical Society, Messrs. Gregory and Thomson said they had seen no direct evidence of submarine leakage of artesian water. No more have I, as the depths of the sea are inaccessible. I have not seen it, but I believe in it, on evidence similar to that on which I believe in the existence of Fiji, of which Mr. Thomson and others have furnished us with credible information. Granting that there may be another explanation of the fresh water bubbling up through the salt water of the Australian Bight, there is (besides the disappearance of inland rivers) some direct evidence pointing in the same direction. For instance, I have lately been informed by a thoroughly reliable shipmaster, that there is a spot far out in the Gulf of Carpentaria where almost fresh water can be taken up in a bucket, and that by no means when there is any reason to suspect that local rains or flood-waters from the Gulf country have anything to do with it. Here, at least, there are not, as in the Australian Bight, any Tertiary rocks, which may be suspected of exuding the fresh water; and the Normanton bore, practically on the edge of the Gulf, and sunk from a level of about 30 feet above it, struck the artesian water at a depth of 1983 feet (say 1950 feet below sea level), "when the drill got out of blue shale into sandstone," and entered the underlying granite at 2291 feet, and there is no ground of assuming that this is the lowest part of the basin.

My colleague, Mr. A. Gibb Maitland, read before this Society on the 17th April last the first instalment of a paper on "Extra-Australian Artesian Basins," in which he demonstrated that the principal artesian water-basins of the world "are not," as he says, "disposed in the shape of these ideal basins, sections of which have done duty for many years in geological manuals." "Both on the coastal and the great interior regions" [of America], says Mr. Maitland, "the water-carrying beds are so arranged that there is only one side of a synclinal trough, the higher rim differing in altitude from the lower, in the former case by not less than 1500 feet, and in the latter by an amount varying from 3000ft. to 5000ft. The strata thus present abundant facilities for the escape of the water absorbed by the strata on the catchment area to the west. In the interior, a continuous discharge is actually visible in many places along the eastern margin of the basin. In the case of the Tertiary beds of the Llano Estacado, north of the Canadian River, this leakage supplies many of the rivers flowing from the great plains. The discharge from the Cretaceous Dakota Sandstones is well seen in the valleys of the Missouri, the Big Sioux, the James, and the Vermillion rivers, where the water rises through the glacial drift in the form of powerful artesian springs. . . . No discharge from the water-bearing strata of the gulf and Atlantic border regions is witnessed from the portions of the strata which crop out beneath the sea; but that such must be the case may be inferred from the fact that the pressure on the coastal deep wells is not nearly so great as it ought to be were the water confined in a sealed basin. The hydrostatic pressure of the body of water stored in the inland portion of the strata has a tendency to force the fresh water outwards, and thus cause a permanent seaward flow. This water flows with a velocity due to the difference of level between the intake and the level of discharge, less the frictional resistance of the rock through which it flows." Mr. Maitland adds: "I am not aware of any observations having been made as to the salinity of the water along the sea bottom, but it appears to me that there must be a difference in the salinity in those localities where a continuous discharge of inland waters takes place." No doubt there is, but it would take such an extended series of observations to prove it that we can scarcely hope for its accomplishment within the present century.

The May meeting of the Geographical Society had for its chief object to allow Mr. Gregory an opportunity of discussing Mr. Cox's paper, and Mr. Thomson, as President, added some remarks before declaring the discussion closed. As the "Proceedings" have not yet been published, I can only speak from recollection of what took place while I was present. Both speakers agreed in everything, and among others that they had never witnessed the alleged submarine leakage, and this statement must pass unchallenged. Both gave equally indisputable instances of high temperature and rapid evaporation in the West. Mr. Gregory treated the Western interior, as it seemed to me, as if it were a homogenous mass of porous rock in place of having a subsoil of water-tight clay-shales, and insisted on the impossibility of water sinking beyond the reach of evaporation. He insisted again on the impossibility of fresh water rising up through an ocean of salt water. Finally, he produced a small map of Australia, on which he had drawn a red line round the heads of the Darling, Thomson, Diamantina, and Georgina, and described this line as one along which an anticlinal axis of Palæozoic rocks comes to the surface, interrupting the continuity of the Cretaceous formation. Such statements receive no support from any geological map ever published. The fact is that Palæozoic rocks only crop up along a small portion of the line in question, and that when they do crop up no synclinal axis coincides with the line ; on the contrary, where Palæozoic rocks underlie the line they present the upturned edges of strata disposed at such angles as to prove that they were thrown into anticlinal and synclinal folds, whose axes for the most part cross the divide at right angles. Mr. Thomson summed up by saying that a few facts, such as Mr. Gregory had brought forward, were worth more than all the theories which had ever been invented. I am still under the impression that the facts accumulated on the spot are on the other side, and that Mr. Gregory's "facts" are fancies only.

The question at issue is no longer whether the water which, when tapped by bores, issues in artesian wells, occurs in porous strata lying underneath impermeable strata. The bores themselves have settled that, and the outcrops of the strata have been to some extent mapped, and found at altitudes sufficient to give a "head" capable of forcing the water to the surface in the lowlands of the West. These outcrops, moreover, have been detected in the act of absorbing, year by year, more than water enough to supply the wells and springs. The question is, whether the strata form a sealed basin, or crop out beneath the ocean in such a manner as to give rise to a circulation of the underground water. A mass of evidence has been accumulated to prove that, as the strata are periodically filled up with water, they must first have lost a certain amount by leakage. In the case of Australia the only possible escape is beneath the ocean, and although we cannot observe this leakage with the bodily eye, we may believe in it, as we believe in many things we cannot see. A powerful confirmation of this view is supplied by the fact that some important artesian basins elsewhere leak out on land, while the rest have the physical conditions which must inevitably lead to submarine leakage.