THE
GEOLOGICAL MAGAZINE.

NEW SERIES. DECADE V. VOL. V.

No. II.—FEBRUARY, 1908.

ORIGINAL ARTICLES.

I.—FLOWING WELLS AND SUB-SURFACE WATER IN KHARGA OASIS.

By HUGH JOHN LLEWELLYN BEADNELL, Assoc. R.S.M., F.G.S.

WITH the exception of an article written by me for Sir William Willcocks and published in his "Nile in 1904,"¹ and a reference to the relations of the Eocene and Cretaceous in the oasis of Kharga in a paper read before the Geological Society in 1905,² nothing has, I believe, been published on the water-supply and geology of this district since Dr. Ball's report in 1900.³

Since my first acquaintance with the Libyan desert oases, where from time immemorial a considerable population (at the present day exceeding 30,000) has flourished, the origin of the underlying artesian water, on which the very existence of the inhabitants depends, has always appealed to me as one of the most interesting problems of Egyptian geology. It was not, however, until two years ago, when I took up more or less continued residence in the oases, that I was able to pay special attention to the subject and make a commencement of attacking the problem by undertaking a detailed study of the geology and water-supply of a definite district, the northern part of Kharga oasis.

Before proceeding to a description of the actual district in question it may be well to briefly remark on the chief characteristics of the surrounding country as a whole, a more detailed account of which I hope shortly to give in a separate publication.

The Libyan desert is the easternmost and most inhospitable portion of the Sahara, or Great Desert of Africa. On the north and east its boundaries are clearly defined by the Mediterranean Sea and the highly cultivated valley of the Nile; on the south it is bounded by the Darfur and Kordofan regions of the Egyptian Sudan; south-eastwards its limits may be regarded as coterminous with the elevated

¹ "The Oases and the Geology of the Nile Valley," being Chapter 5 of "The Nile in 1904," by Sir William Willcocks, K.C.M.G., Cairo, 1904.

² "The Relations of the Eocene and Cretaceous Systems in the Esna-Aswan Reach of the Nile Valley": Quart. Journ. Geol. Soc., vol. lxi (1905), pp. 667-678.

³ "Kharga Oasis: its topography and geology": Egypt. Geol. Surv. Report, Cairo, 1900.

district of Tibesti, while on the east it stretches to the outlying oases of Fezzan and Tripoli. Its area is approximately equivalent to that of the British Isles.

Except for a narrow belt fringing the Mediterranean the region is practically rainless, so that unlike the more elevated deserts on the other side of the Nile, where the rains are of sufficiently frequent occurrence to maintain a water-supply in the isolated water-holes and valley springs, and to allow of the growth of a fairly permanent though scanty herbage in the more favoured areas, the greater portion of the Libyan desert is quite devoid of vegetation, and is uninhabited even by nomad tribes. The extreme barrenness of the region as a whole, however, is in great measure counterbalanced by a number of isolated highly fertile oases, in which there is a permanent resident population.

The chief groups of oases are the Siwan on the north, that of Kufra on the west, and the Egyptian, including the four large oases of Baharia, Farafra, Dakla, and Kharga, on the east.

The Egyptian oases occupy extensive depressions cut down nearly to sea-level through the generally horizontal rocks forming the Libyan desert plateaux. These depressions owe their origin in great measure to the differential effect of subaerial denudation acting on rock masses of varying hardness and composition. Variation in the original conditions of deposition has resulted in a preponderant development in some areas of soft argillaceous beds, and subsequent folding has raised these beds in some districts and depressed them in others. Wherever during the general denudation of the country these soft deposits have become exposed, weathering has proceeded at an increased rate and gradually produced deep and broad depressions separated by elevated plateaux.

Geological Sequence in Northern Kharga.

The geological succession (excluding Pleistocene and Recent superficial deposits) in the northern part of the oasis of Kharga, determined by actual measurement of the different stages exposed on the floor and in the cliffs of the depression, and from numerous bores put down within the last two years, is as follows:—

		Average thickness in metres.	
LOWER EOCENE	{	Lower Libyan...	1. Plateau Limestone ... 115
		Passage Beds ...	2. Esna Shales and Marls ... 55
	{	Danian	3. White Chalk } 70
			4. Ash-grey Shales } 30
UPPER CRETACEOUS	{	Campanian (Nubian Series)	5. Exogyra Beds 70
			6. Phosphate Series... .. 50
	{		7. Red Shales 45
			8. Surface-water sandstones ... 75
			9. Impermeable Grey Shales ... 120
			10. Artesian-water Sandstones ...
			630

See Map, Fig. 1, p. 51. The numbers 1–10 correspond with section (Fig. 2) given on p. 55.

For the Eocene limestone, which everywhere caps the plateau between the oasis and the Nile Valley and also the northern bounding

FIG. 1.

wall of the depression, I have adopted the convenient term of "Plateau Limestone." Between it and the White Chalk of the Upper Cretaceous come the Esna Shales and Marls, which, as I have shown in a former paper, are to be regarded as passage beds between the Cretaceous and Eocene systems.¹ It is true that in the lower layers fossils with typical Cretaceous affinities occur, but on the other hand forms of equally pronounced Eocene character are found in the upper bands. Lithologically there is nothing to distinguish one part of the band from another; typically it is made up of laminated shales, which by increase of carbonate of lime pass insensibly both upwards and downwards into the limestones above and below. The total thickness of the stage varies greatly in different parts of the oasis; this variation was regarded by Ball² as indicating an unconformity between the Eocene and Cretaceous, whereas it is due solely to the fact that varying thicknesses of the upper and lower portions become in places so markedly calcareous as to be indistinguishable from the limestones above and below. In some cases practically the whole, as a band of laminated shale, has disappeared, and then the Cretaceous limestones merge directly into those of the Eocene above.

Although the shales below the White Chalk differ little in colour from the Esna Shales above or from the shales of the *Exogyra* series below, I have retained Zittel's term "ash-grey shales"—though ash-grey is by no means their usual tint—to avoid the possibility of confusion. They are grouped most naturally with the White Chalk, which nearly everywhere forms a marked band at their summit; other less conspicuous bands of chalk or chalky marl sometimes occur intercalated in the shales on a lower horizon.

With regard to the *Exogyra* beds, it is only necessary to remark here that they are almost everywhere marked by hard bands made up of the shells of fossil oysters. Below comes a group of shales containing a number of prominent intercalated bands composed of fish-bones, coprolites, and phosphatic nodules; the series is so well marked in northern Kharga that it is difficult to understand how it had until recently escaped notice, yet that such was the case is evident, as Ball makes no mention of the beds in his report nor are they shown in the published sections. Considering the great development of phosphatic beds in the neighbouring oasis of Dakhla, the extension and thickness of which had been fully mapped and reported on by me in 1898,³ it was no surprise to find similar beds in Kharga when I made a casual examination of the succession at one or two points in the early months of 1905. Since then I have traced the beds over a large area of northern Kharga, and found them to consist as a rule of an upper brown coloured series, individual beds of which in places exceed two metres in thickness, and a lower division consisting of three or four bands of harder and lighter-coloured rock, in which the nodules are sometimes cemented by iron pyrites. These bone-beds mark the

¹ Op. cit.: Q.J.G.S., vol. lxi (1905), p. 675.

² Op. cit., p. 94.

³ "Dakhla Oasis: its topography and geology": Egypt. Geol. Surv. Report, Cairo, 1901.

invasion of the area by the Cretaceous sea, the underlying shales and sandstones being as far as known devoid of all fossil remains except vegetable impressions and silicified wood, having in all probability been accumulated in an immense inland lake.

Underlying the phosphates is a great thickness of an almost homogeneous red or purple shale, below which occurs the first water-bearing sandstone; this will presently be described in detail. Between this sandstone, which for purposes of easy reference I have designated the "surface-water sandstone," and the underground sandstone from which the flowing wells of the oasis derive their water, is a 75 metre band of grey shale or clay; it is this bed which forms the confining and impervious cover, and prevents the water in the beds below from reaching the surface except when provided with such means of escape as artificial boreholes. To all intents and purposes these shales are impermeable, at any rate over the district in question, and may therefore be referred to as the "impermeable grey shales." The upper layers of this division are visible on the floor of the depression in some parts of the oasis, notably in the Bellaida district west of Jebel Têr, and in the neighbourhood of Ain Mukta to the east of the same range. Their thickness has been determined from the results of about twenty bores put down on the area about midway between Jebel Têr and Jebel Ghennima near the eastern scarp of the depression.¹

The Longitudinal Monoclinical Flexure.

Although over the Libyan desert as a whole the general dip of the different sedimentary deposits is steadily northwards, we find considerable local variations, especially in the oasis-depressions. In northern Kharga there is a difference of level of over 200 metres between the same beds on either side of the depression, the dip being in fact eastwards, as will be seen from the accompanying section across the oasis from the summit of Jebel Tarif to the top of the eastern plateau in the neighbourhood of El Dêr. The dip appears to markedly decrease, if not die out altogether, on either side, and the structure of the area might therefore be regarded as a simple monocline were it not for the dominant line of disturbance which runs in a north and south direction along the centre of the oasis parallel to the longer axis of the depression. This line of folding and faulting is most marked in Jebel Têr, a hill range bounded by faults and formed of beds let down through a vertical distance of over a hundred metres. Southwards the line of disturbance—in some places a fault, in others a monoclinical fold—can be traced past Jebel Tarwan, Nadura, and Kharga village to the conspicuous highly inclined beds of Gorn el Gennah, and thence passed the old ruined temple known as Qasr el Ghuâta, immediately

¹ The localities referred to in this paper are shown on the accompanying map, p. 51, the topography of which is based on the maps of the Survey Departmental Report. The scale (1 : 500,000) is of course too small to show each division of the Eocene and Cretaceous, and the boundaries of such as are indicated must only be taken as approximate. On the Survey maps the names of the two prominent outliers of the plateau on the east side of the depression have their names reversed; the most northerly is Jebel el Ghennima, the other to the south Jebel Um el Ghennaim.

south of which the White Chalk is let down some 300 metres on to the floor-level of the oasis, it and the underlying shales being bent into an almost symmetrical oval basin or centroclinal fold. In all probability the isolated eminences near Bulâq, Gala, and Girm Meshim mark the prolongation of the line of fault southwards, and it may quite possibly continue throughout the depression.

The difference in level on either side of the line of disturbance is as a rule very marked, the floor of the depression on the downthrow side being very considerably lower than that on the west or upthrow side. As might be expected, the line of partial or complete fracture directly affects the water-supply, and one of the most noteworthy features of the country south of Jebel Têr is the grouping of all the most important wells near but on the upthrow side of the fault, in spite of the ground on this side being at a considerably higher level. Probably the sandstones rise gently to the west, in which case the underground flow in this neighbourhood may be from west to east, which would account for the best yields being obtained from bores put down near but to the west of the fault; on the other side, although the actual surface level is lower, the water-bearing sandstones occur at a deeper level, and possibly the line of fracture in great measure cuts off the supply.¹

Ball reported that the most striking evidence of faulting in the oasis was between Jebel Têr and Jebel Tarif, but although the possibility of this fault being connected with and causing the tilted strata of the Gorn el Gennah is referred to, he finally appears to have abandoned this view, as his map shows the fault as extending over only a comparatively short distance lying midway between Jebel Têr and Jebel Tarif and running in a N.N.E. and S.S.W. direction. This misplacing of the line of fracture led Ball to believe that the majority of the wells were on the east or downthrow side of the fault, whereas, as I have shown, they are in reality on the opposite or west side, the actual line of flexure passing almost direct from Jebel Têr through the Gorn el Gennah.

Surface-water Sandstone.

The stratigraphical position of the beds of this division will be seen by reference to the section. They have an average thickness of 45 metres, and consist almost entirely of sandstones of varying degrees of coarseness, often highly ferruginous, and containing occasional beds of aluminium and magnesium sulphates. Bands of shale are met with here and there, but as a rule are confined to the upper and lower portions of the series. Members of the group outcrop on the nearly level floor of the oasis over large areas to the east of the line of disturbance, while to the west, where, as I have shown, the general elevation of the beds is higher, they form the foothills of Jebel Tarif, Jebel Têr, and the high cliffs which rise to the north of Um el Dabâdib and Ain Lebekha. Probably the sandstones which form the surface of the desert between Kharga and Dakhla and cover large areas to the south of these oases, also belong to this group.

¹ Op. cit., pp. 95-97.

FIG. 2.—Kharga Oasis: detailed section across the Depression through Jebel Târ, C.W.E. Headquarters, and El Dér.

The sandstones of this series form the highest water-bearing horizon in the oasis, and one quite distinct from the artesian-water sandstone, the two being separated by a thick impervious series of dense grey shales. In the district round headquarters the water is as a rule met with at a depth of from five to six metres below the ground surface, is not under pressure, and does not rise appreciably in boreholes, so that to become available for irrigation it has to be lifted by power. An ordinary borehole or small pit is, however, useless, as the inflow of water through the pores of the sandstone is too slow to yield a pumping supply; in a large pit a number of small fissures are usually struck, and it is through these that most of the water is obtained. Provided a sufficiently large collecting tank is excavated—say 5×4 metres and sunk to from one to one and a half metres below the standing water-level—a supply sufficient to yield a continual discharge of eight gallons a minute (or 11,500 gallons per day of twenty-four hours) can usually be obtained. In especially favourable localities a pit of the dimensions given above will yield 15 or even 20 gallons per minute, and the pumping capacity can as a rule be still further increased by deepening. The extent to which this supply can be drawn on without appreciably lowering the water-level has not, of course, yet been determined, though in one pit alongside Bore No. 2, where a 'sakia' has been working more or less continuously for over a year, the water-level has not appreciably changed.

Unfortunately the quality of this water, at any rate in the headquarters area,¹ is not uniform, in some places being quite sweet while in others, only a few hundred metres distant, it is highly ferruginous and more or less charged with salts. For instance, the water of a pit put down at a point 570 metres E.S.E. of headquarters was found on analysis to contain 63 grains of dissolved solids per gallon, the salts consisting of iron, potash, and soda, with traces of lime and magnesia, mostly in the form of sulphates and chlorides.² The utilisation of this water for purposes of irrigation would, at the rate of three gallons a minute per acre, mean an annual deposition of over three tons of sulphate of potash and common salt on each acre of land, an amount which would of course spell ruin to its agricultural value in a very short time.

In many parts of the oasis, however, perfectly sweet water is obtainable from the sandstones of this series, and that this source, as an auxiliary to the artesian supplies obtained from deep borings, was taken full advantage of by the ancients, is testified by the wonderful systems of underground aqueducts which penetrate the sandstones in many parts of the oasis, but more especially in the districts round Um el Dabādib, Ain Lebekha, and Qasr Gyb. They were especially applicable to districts where the bulk of the sandstones, as in the first two localities mentioned, form extensive hills above the general level of the neighbouring cultivable ground. The method was probably

¹ The headquarters of the Corporation of Western Egypt, Ltd.; the area over which the boring operations referred to in this paper extend is shown on the accompanying map (Fig. 1, p. 51) by a dotted line.

² For the analyses quoted in this paper I am indebted to Mr. William Garsed, formerly of the Oasis Headquarters Staff.

introduced into the oases from Persia, where underground aqueducts or 'kareez,' for the transference of water from one locality to another, have from an early date been extensively employed. The immense amount of time and labour which must have been expended can hardly be realised without actually exploring the excavations themselves, but it may be remarked that at Um el Dabādib the two main carrying channels, with their subsidiary branches, measure several kilometres in length, and are cut almost throughout in hard sandstone rock, the tunnels being moreover connected at frequent intervals with the ground surface above by vertical air shafts, likewise excavated in the solid rock; one of the latter which I descended measured 130 feet in depth.

It is difficult to believe that the supplies of water obtained from these sandstones were commensurate with the time and labour involved in the construction of the necessary collecting tunnels, but that enough water was obtained to enable fairly large colonies to exist is evident from the traces of former villages and cultivated areas. After the withdrawal of the Romans these outlying districts were abandoned and the subterranean aqueducts gradually silted up. Some few years ago one of the main tunnels at Um el Dabādib was completely cleaned out, and when I visited the place in 1905 the discharge at the mouth of the aqueduct was about 30 or 35 gallons a minute.¹

(To be concluded in the March Number.)

II.—NOTES ON THE GEOLOGY OF BASUTOLAND.

By the Rev. S. S. DORNAN.

THE rocks composing Basutoland belong to the Stormberg Series of the Karroo System. They cover a much larger area than Basutoland, extending into the Orange River Colony on the west and north, on the south and east into Cape Colony and Natal, and, I am informed, across the Vaal into the Transvaal. The area is thus not less than 45,000 square miles. The whole of that part of the Orange River Colony known as "the Conquered Territory," east of a line drawn from Thaba 'Nehu to Vrede, is occupied by the whole or portions of these rocks.

The average thickness of the rocks is as follows:—

		Designation.			Thickness of feet.
Recent and superficial accumulations		...	...	...	20-40
Stormberg Series.	(1) Volcanic Beds	...	...	...	600-4000
	(2) Cave Sandstone	...	...	...	150-400
	(3) Red Beds...	...	...	...	300-500
	(4) Molteno Beds (base not seen)	...	...	...	600 exposed.

¹ Ball visited the locality in 1898 before the tunnel described above had been cleaned out, and is responsible for the rather fantastic theory that it led to another inhabited oasis to the north of the escarpment (op. cit., pp. 31 and 76). The same writer further remarks (p. 82): "It is worthy of note that, with the exception of the Roman work near Ain Um Dabadib and a line of bricked manholes near Gennah, no traces of underground watercourses, such as occur so abundantly in Baharia Oasis, are to be seen in Kharga." As a matter of fact, however, there is hardly a district in northern Kharga where extensive underground aqueducts do not occur, and they far exceed in magnitude anything found in the oasis of Baharia.