The Dinosaurs of Tendaguru.

By F. W. H. MIGEOD.

THE expedition sent out by the British Museum in 1924 to Tanganyika Territory to explore the dinosaur remains at Tendaguru broke down in the following year on the death of Mr. W. E. Cutler, the leader, in August 1925.

I was appointed leader in his place, and work was resumed on my arrival in November of the same year. Although the rainy season was coming on I decided to begin at once, and was glad to find that the rains were not heavy enough to be a serious impediment. Occasionally a digging might be flooded if the possibility of drainage was not very good; in which case it had to be baled out. I reckon that in this region continuous work all the year round is possible, and when I left to return to England in November last, I made arrangements for the digging to be continued in my absence. This naturally ensures a much bigger output in the twelve months.

FIG. 1.—Excavating a small dinosaur at Tendaguru.

Nevertheless, prospecting is limited to the dry season. One has only to walk about the country in the neighbourhood of Tendaguru hill after the grass is burnt to see how vast is this graveyard of dinosaurs. There is an area of perhaps three miles width east and west and ten miles north and south where they may be found. Denudation in the course of ages has removed the many strata of rock that ages piled up on their remains immediately after their extinction; and once again these bones lie close to the surface. Most of the damage to them has been done in quite recent years through the penetration of the roots of plants and trees. At the present day they lie at an average level of 700 ft. above the sea, and fragments on the surface commonly, though by no means always, give an indication of where bones may be dug for. Yet further, the stratum is not always an indication, for the dinosaurs I collected lay in several different kinds of ground, as in clays of more than one kind, some stratified and some much contorted, in loose sand and in harder sand rock.

Exploration in the twelve months under review was made in thirteen different sites round Tendaguru hill, and the yield of fairly complete dinosaurs was considerable. There is possibly enough material partly to reconstruct some two dozen skeletons representing a considerable number of different species, and work has been begun on them in the Natural History Museum at South Kensington.

Some of the specimens are naturally more interesting than others. My first dinosaur excavated was a small one (Fig. 1), but near it lay the skeleton of another which eventually required eighty carriers to take it down to the port of Lindi for final packing and shipment. This one when examined may prove to be a brontosaurus. As an indication of its size I may mention that the scapulæ were 48 inches long by 28 inches at the widest part. The greater part of the body had lain on a bank, but a small stream of the distant age, of course, when that dinosaur lived and died, flowed by and had disturbed the remains on one side, some of the bones showing strongly the destructive action of this water. The pelvis, dorsal vertebræ, and upper-limb bones were mostly clear of this stream, though at no great height above it; but mixed with the lower bones were numerous river-worn pebbles, and in the case of one rib two smooth pebbles were tightly jammed under it, causing it to bend and of course break, which could only have taken place after the flesh was decomposed.

Another skeleton, that of a slender animal perhaps forty feet long, was interesting from the fact that the tail when excavated lay out on the ground complete. It was fifteen feet in length, and near the body it had been pressed down into the mud some two feet deep. It had not been completely severed, but two vertebræ nearest the pelvis were hanging vertically, there were two or three at the bottom, and one or two nearly vertical again, the upper one joining the unbroken part of the tail. It was as if at death, or shortly after, some other huge dinosaur had set its foot on the tail in passing and pressed that part of it down into the mud. The dimensions of some of the bones of this dinosaur were: femur 51 inches, scapula 44½ inches, humerus 33 inches. The fore part of the body was on a slightly lower level than the hind part and tail, and the head and neck, which were displaced, were in such a position as if it had died in drinking or trying to drink water. The body lay generally on a very dark-brown clay which I found nowhere else, and a feature, unique so far as my own excavations were concerned, was that, enclosing the bones, was a green matrix which did not exist apart from the bones (Fig. 3).

Of the sites which I worked two were cuttings into hillsides, and accordingly progress was slower here than on the flat. The hillside excavation that was especially interesting in its results was the one which I made into the side of Tendaguru hill itself. This hill stands on the top of the deposits, and represents a piece of old land left rising up like an island, and undenuded comparatively. By getting well into the lower slopes I hoped to reach bones that had not been attacked by the roots of plants and trees. Two strata of bones revealed themselves here. The upper, in the greenish-grey clay, held some bones of large size belonging to a four-footed dinosaur with the fore limbs longer than the hind ones apparently, and which was possibly a brachiosaurus. A femur in excellent preservation measured 67 inches and weighed nearly 4 cwt. when plastered and ready for removal (Fig. 2). A humerus measured 60 inches with the ends incomplete. This grey stratum rested on another of sand, and here, at the meeting of the two strata, other bones, of an apparently different type of dinosaur, were found. On this lower level and near these latter bones lay a tree trunk 26 feet

FIG. 3.—Tail of a dinosaur in the foreground.

long, with peat adhering, and other finds on this lower level were numerous bi-valve shells of small size, and traces of lignite, as well as impressions of leaves.

One of my sites furnished, in a space of 88 feet by 64 feet, a vast accumulation of bones which may prove to represent as many as twenty dinosaurs; and beyond these limits there were indications of many more. There was here what had the appearance almost of a battle-ground. We may figure to ourselves a region suffering a process of desiccation such as is going on in lands bordering on the southern Sahara at the present day, and coming on again in the Tendaguru region too. All living things flocked to the remaining

FIG. 2.—A femur 67 in. long, plastered and ready for removal.

pools of water for vegetation to eat and such water to drink as was left in the bed of a dried-up river; and they perished miserably one on the top of the other. A subsequent good rainy season could not help them as all was over. Sand swept over them and covered their remains, and the brief annual flow of the river in later years buried them in mud and sand. Here, as a matter of fact, there was very little clay. The deposit was principally sand, varying from a hardish yellow sandstone to loose and clean white sand.

Though this site did not furnish any bones of outstanding size, the biggest femur being 55 inches and biggest humerus 40 inches, it was interesting to find bones of quite young dinosaurs, one pair of femora measuring only 14 inches.

The position of the bones inclines one to the opinion that the dinosaurs here did not all lay themselves down to die in peace. There was much trampling by reptiles weighing several tons on others already dying or dead, which would cause some breakage of bones. There were bones which seemed to show breakage at or immediately after death, and while the muscles were still operative, one being a femur. Other bones, too, seemed to show fractures made during lifetime which healed without being set. The difference between these fractures and the clean ones made after fossilisation and due to earth tremors or stresses or to the recent action of vegetation, are readily apparent.

The dinosaur field of Tendaguru is by no means yet worked out. One might almost say it has only been scratched. That future work will yield many duplicates of the species already found is only to be expected, but it would be a serious scientific loss to the world if the area were exploited on lines of only taking certain bones and abandoning all others to perish from exposure simply because no immediate use can be made of the output. To cover up the bones again is not the same thing as leaving them untouched. In the circumstances, in view of the already considerable output, the preparation of which will take the British Museum some years, future field work at Tendaguru will be of a limited nature, and be carried on only in places where there is reason to believe in a possibility of different species being found.

Interionic Forces in a Completely Dissociated Electrolyte.[1]

By H. HARTLEY, C.B.E., F.R.S.

ONE aspect of the solution problem which has lately come into prominence is the effect of the forces acting between electrically charged ions. Faraday was much impressed by what he called "the enormous electric power of each particle or atom of matter," that is, the large size of the ionic charge. Helmholtz in his Faraday Lecture gave a calculation showing that the attractive force between the electrical charges associated with equivalent quantities of oxygen and hydrogen is 71,000 billion times greater than the gravitational attraction between these masses. It would seem obvious that such forces as these must affect the behaviour of ions. However, the difficulties in the way of a mathematical analysis of the effects of the electrical forces between ions in solution were considerable, and the problem was not attacked successfully until thirty years later.

Sutherland in 1907 was the first to suggest that electrolytes were completely ionised at all concentrations and that the interionic forces were in part responsible for the change in equivalent conductivity with concentration. In 1909, Bjerrum found that the molecular colour of chromium solutions was independent of dilution in the absence of complex ions, and explained his results on the basis of complete dissociation. He pointed out that the old difficulty with regard to the Mass Law would be removed if the interionic forces were entirely responsible for the variation of the equivalent conductivity and of the molecular freezing-point depression with dilution, as there would be no question of any equilibrium between ions and molecules.

The theory was supported by the additive properties of solutions of electrolytes and by the small change in the heat of neutralisation of strong acids and bases with dilution. In 1912, Milner succeeded in calculating the freezing-point depression of an electrolyte at different concentrations on the assumption of complete dissociation, by taking into account the change in potential energy of the ions on dilution. He pointed out that as a result of the electrical forces between them they would be so distributed that on an average unlike ions would be closer together than like ions, and that consequently work must be done in separating them on dilution. His results showed that in dilute solutions the change in the freezing-point depression with dilution could be ascribed entirely to the effect of interionic forces with a completely dissociated electrolyte.

In 1922, Debye and Hückel attacked the problem by fresh methods, starting from the same assumption of complete dissociation. By taking into account the unequal distribution of the ions, they were able to calculate approximately the freezing-point depression of salts of different valency types in very dilute aqueous solutions, although the calculated and observed values diverged at higher concentrations. But a matter of more immediate interest to us is their treatment of the conductivity problem on the basis of complete dissociation. They start from the same point of view as that of Milner, namely, that owing to the electrical forces between the ions there will be an excess of ions of opposite charge in the immediate neighbourhood of any single ion, as in the structure of a crystal of sodium chloride. Owing to the finite time which is necessary for the redistribution of the ions to take place round an ion that is in motion, there will always be an excess of ions of opposite sign in its rear, and hence it will be subject to a retardation when moving in an electric field. Further, as ions of opposite sign are moving in opposite directions and as both are supposed to carry with them a certain amount of solvent, the viscous resistance to the motion of the ions will be greater than if the solvent were at rest. Thus both these effects act in such a way as to reduce the speed of the ions. Assuming that at infinite dilution the ionic mobilities obey Stokes's equation, Debye and Hückel arrive at the expression

$$\frac{\lambda_o - \lambda_c}{\lambda_o} = \left(\frac{K_1}{D^{\frac{3}{2}}}w_1 + \frac{K_2}{D^{\frac{1}{2}}}w_2 b\right)\sqrt{\nu m},$$

where the term $\frac{K_1}{D^{\frac{3}{2}}}w_1$ represents the fall in conductivity due to the electrical retardation and $\frac{K_2}{D^{\frac{1}{2}}}w_2 b$ that due to the electrophoresis of the solvent.

K_1 and K_2 are universal constants for all solvents at the same temperature.
D is the dielectric constant of the solvent.
w_1 and w_2 are valency factors.
b is the average radius of the ions.
ν is the number of ions per molecule.
m is the molecular concentration of electrolyte.

[1] Extract from the presidential address on "The Ionic Theory of Electrolytic Solutions," delivered at Oxford to the Science Masters' Association on Jan. 4.