Earth Movements in the Delta of the Rhone.

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DELTA are essentially areas of instability. The very existence of a large delta is dependent on changes of level of the land, and not merely a general subsidence, but a special local sinking of the deltaic region in comparison with the surrounding land. Nor is this all, for there can be few deltas, if any, in which the general movement in a downward direction has not been interrupted at intervals by one in the opposite direction, and in which more or less extensive areas of upraised alluvium cannot be found. To this rule the delta of the Rhone is no exception, but there is no other instance in which the amount of this change can be measured, or the date fixed at which it took place, with so close a degree of accuracy as can be done for some of the changes which have taken place at the mouth of the Rhone.

Readers of NATURE may remember that this subject was referred to in articles on "Problems of the Rhone Delta", which appeared in the issues of July 4, 11, and 18, 1925. It was there pointed out that the geological work of M. G. Denizot had demonstrated an uplift of the land in the prehistoric past, by which the original alluvial deposit of the delta was raised to a level at which further accretion was brought to an end and an undulating land surface developed by denudation, a surface on which the Romans built their homes and monuments, and of which large areas are still in evidence, though a larger part has been buried under fresh deposits of alluvium formed at a later date. It was also pointed out that there was evidence of a subsidence of the land, amounting to about 5 metres, having taken place between the beginning of the eighth and the end of the ninth centuries. Since those articles were written, I have been able to collect a much larger volume of evidence bearing on the problems indicated in the earlier articles, and an epitome of the results, as they affect this question, of past changes of level, will probably be of interest.

The position of the mouth of the Rhone in Roman times can be fixed with certainty and a fairly close approach to precision from the maritime itinerary, first compiled in the first or second century of our era. It lay sixteen Roman miles from the port of Fossae Marianae, now represented by the seaside resort of Fos-sur-Mer, and this would bring it to the locality where is now the Grau de la Dent at the mouth of the Vieux Rhône, or channel occupied by the river during the seventeenth century, the existing sea coast being at this point almost coincident with the ancient shore line of pre-Roman and early Roman times. At Arles the channel of the Roman Rhone seems to have followed very closely the course of that in which it now flows, and local conditions preclude any wide departure from it. At about ten kilometres below Arles the channel can again be fixed within narrow limits; a spur of the gravels of the Crau puts an absolute bar on any course lying east of the present one, and within less than 3 kilometres to the

west comes a spread of the old pre-Roman land surface carved out of the upraised alluvium. Within these narrow limits the Roman Rhone must have flowed, but below this there is no certainty, except that it never flowed past Passon or by any of the channels below that point, which have been followed at various times from the twelfth century to the present day. The most likely interpretation is that it followed the general course of the present Aube de Bouic to near the shore of the Étang de Vaccarès, thence southwards to the east of Fiérouse and the ruins of the Abbey of St. Ulmet, and then to the same general course as was followed by the last 8 or 10 kilometres of the seventeenth century channel, which is still known as the Vieux Rhône. Measured along this course, the thirty Roman miles given in the itinerary as the distance by river from the mouth to Arles, would correspond very closely with the actual length of channel.

With the end of the Roman dominion the records become scanty and fragmentary, until the close of the twelfth century, when we find an entirely different state of things. The seaport of Fossae had disappeared, the entrance to the main channel of navigation was at the mouth of what is now the Étang de Galéjon, on the western shore of which there is a group of low hills, then known as Odor, and later as La Roque. Passing this a broad stretch of inland lagoons was traversed to the neighbourhood of Passon, where further progress was only possible along a single channel, narrow and barely deep enough to admit even those vessels of small tonnage by which the bulk of the sea traffic of those days was carried. This channel, known as the Grau de Passon, led into a wider and more open one coming down from Arles, and was the cause of constant anxiety to the council of that city, for fear that it might become blocked by obstacles to navigation. Though called a 'grau', which at the present day would suggest the mouth of a river, the condition in the twelfth century was different; it is clear from later history that the real river did not flow this way, and did not reach the so-called grau until after the thirteenth century had run its course. The channel was a passage between two lagoons, through which little or no current flowed, and the question arises of how it could have originated. It is certain that nothing of the sort existed in Roman times and that the track of vessels bound for Arles did not then run up the Étang de Galéjon, and through that channel which is crossed by the railway from Arles to Port St. Louis, immediately south of the station of La Porcellette. Here a small irrigation canal, deriving from the river, is all that remains to mark what was once the main channel of navigation from Arles to the sea, then for a while of the river itself, continuing ultimately as a distributory until it was artificially closed, somewhere about 1640, and ultimately converted into an irrigation canal. There is but one way in which a narrow channeling, as this did, between broader

spreads of water could have originated, and that is a general subsidence of the country and submergence of the lower levels; the narrow passage was across the strip of higher ground, known as the Plan du Bourg, which may be described as the backbone of the country east of the Rhone. Besides the Grau de Passon, at least one other channel was opened across this barrier, but neither it nor any

The depth of the channel at some time not later than the end of the fourteenth century was such that the bottom stood at about 2.75 metres below mean sea-level, and in the twelfth century would probably have been somewhat, though not materially, below this. Adding these two together, we have proof of a change of level amounting to nearly 6 metres in all, for, taking the shallowest part of the channel, where

the solid land rose to its highest level along the depression, we find that a spot which up to the fifth century had stood about 3 metres above sea-level, in the twelfth lay about the same height below it, and this could only come about through a change in the relative height of land and sea, which may be described as a sinking of the land, or a rise of the sea, level, according to the point of view. Four years ago this figure seemed excessive for the town of Arles, where remains of Roman structures on the banks of the Rhone show that here also there has been a change of level, which appeared to have amounted to about 5 metres, but not more than that. In October last, however, when visiting Arles, I found the river standing at an unusually low level, and was able to examine the remains on the western bank more thoroughly than had previously been possible, with the result that the amount of change since Roman days must be raised to a figure of quite 6 metres, or possibly more. From this must be deducted an allowance for subsidence which took place in the eighteenth century of from a half to a whole metre, so that the evidence at Arles and at Passon confirm each other in showing that the eastern delta along the present course of the Rhone stood somewhere about 6 metres lower in the twelfth than it did in the earlier centuries of our era. Subsidence of this amount, in a region of such low-lying land and such low relief, must have had one

FIG. 1.—Map of the eastern delta showing the main channel of navigation between Arles and the sea in Roman and in early medieval times. The change from one to the other took place in the eighth century A.D.; the eastern channel became blocked by the advance of the river about the end of the fourteenth century. The course of the Roman Rhone across the Camargue has not yet been worked out in detail; that shown on the map is merely approximate.

other, if such there were, was as deep or convenient for navigation.

Here, then, we have a definite means of measuring the amount of subsidence which took place. In Roman times the ground level of the bed of this channel must have stood above the flood level of the Rhone, and at the present day the flood waters of the Rhone near Passon reach a height of about 2.75 metres, from which we may conclude that the bottom of the channel must originally have been about 3 metres above the mean sea-level of Roman times.

result, that large areas of the lower levels would permanently sink below the level of the sea, and, as a further consequence, there would come into being a large area of shallow waters through which the river could extend its new delta with great rapidity. These new lands so formed gave rise to a number of disputes over their ownership, and from the evidence recorded and the maps which were made to illustrate the claims of one party or another, it has been possible to reconstruct the main outlines, and in some cases even the details, of the geography

of the country as it stood after the subsidence was complete, but before the river had re-established itself in its former territory. The result, however, has only been attained after a considerable search among the ancient records; made possible by the care which is taken in France of their archives and the unfailing courtesy of the archivists in charge.

The date at which this subsidence took place is as important and interesting as the amount, and so far as the eastern delta no new evidence has appeared beyond that referred to in the earlier article. At the beginning of the eighth century the port of Fossae Marianae—which by this time had dropped the second word of its title—was still a mart of importance, a port of destination for sea-borne commerce and, presumably, of transshipment into river-going craft. Its character was still the same as in Roman times, and we may conclude that the subsidence had either not yet commenced or, at any rate, had not gone far enough to affect the status of Fossae. From the middle of the ninth century we find the Passon channel in full use, and nothing more is heard of Fossae as a seaport, for it had been superseded by Arles, which had become a port of destination for the overseas commerce of those times. The bulk, if not the whole, of the change of level must have taken place between the commencement of the eighth and the latter half of the ninth century, and in the eastern delta the limit cannot be more closely drawn, but if we turn to the western delta we find that it also underwent a change of level comparable in amount with that which affected the eastern, and a charter of the year 788, conveying a grant of land to the Abbey of Psalmodi, shows that the subsidence, if not complete, was at any rate far advanced at that date. As the grant out of the customs of Fossae, made to the Abbey of Corbie in 716, shows that the subsidence had not yet made much progress, the two together put the bulk of the movement as having taken place within the limits of the eighth century, though doubtless overlapping it at either end, and this brief period of rapid change of level came between two much longer periods of little or no change.

Interesting as this would be in itself, it is by no means the whole story, for the maps of the eighteenth century make it clear that the latter part of that period saw a renewal of downward displacement of the level of the land, of shorter duration in time than that of the eighth century, and smaller in amount; the total change of level having been no more than a metre in all, and possibly less. More interesting, however, than this, is the distinct suggestion of a change of level, not very different in amount from that of the eighth century,

having taken place somewhere about a thousand years before our era. The "Ora maritima" of Avienus, after describing the course of the Rhone from its source in the mountains, says that it enters a great marsh and mere, known in ancient times as Accion, and then, resuming its character as a river, gives off a branch towards the west. On this follows immediately the mention of the bifurcation of the river and of Arles, from which it is easy to fix the position of the lake Accion. Hereabouts it is known that there was a great spread of water in the Middle Ages which has largely been silted up, disappearing finally when the canal from Aiguesmortes to Beaucaire was constructed. This drained away the permanent standing water, and all that is

FIG. 2.—Map of the seaward portion of the eastern delta, as it was from the ninth to the thirteenth century. The representation is necessarily approximate and somewhat diagrammatic; the actual outline must have been more intricate, and many small islands, not shown, must have existed, but nothing is represented for which there is not some authority, and nothing of material importance is likely to be missing. B, T, G, L, sites of the Tours de Bolovard (1469), Timpan (1606), St. Genest (1656), and St. Louis (1736), built by the town of Arles to guard the channels successively adopted by the Rhone.

left to preserve the memory of a lake which had been important enough to be shown on a portolan map of Petrus Vesconte, is a tract of marshy ground, lying east of Bellegarde. Though occupying the same position, this medieval lake cannot be accepted as a continuation, but must rather be regarded as a successor of that mentioned by Avienus, though not by the Roman geographers of the first century or by later writers, even those contemporaneous with Avienus himself. In this there is nothing either of contradiction or inconsistency, for the "Ora maritima", though composed in the fifth century, was avowedly based on an ancient record, which modern scholarship has recognised as a Greek 'periplus' of about 600 B.C., revised in part and at intervals of later date. It is to this period that the lake Accion must be referred, which

had dwindled, in later Roman times, to a condition not unlike that of the marshes of Bellegarde before they were drained in the eighteenth century. History, in fact, seems to have repeated itself twice in this period, and the great spread of water which may be inferred as having been originated by the eighth-century subsidence, was preceded by a similar one, resulting from a subsidence, not greatly

FIG. 3.—Variations, during the last 3000 years, in the height of the Rhone delta above sea-level.

differing in magnitude, at somewhere about 1000 B.C. In both cases succeeding centuries saw the lake gradually diminishing as it became filled up and narrowed by the alluvial deposits of the Rhone.

Accepting this interpretation we may draw a graph of the level at which the delta stood, relative to the present level of the sea, for the period during which there is any historical record. The result is an instructive and interesting one, for we see that, while the change has been always downward, uninterrupted by any appreciable upward movement during the last three thousand years, it has not been slow and continuous, but limited to three periods during which the change was more or less rapid, separated by much more prolonged periods during which no change took place, or only to an inappreciable extent.

It is natural to inquire whether these changes were localised in the delta of the Rhone, or formed part of a widespread change in the level of the Mediterranean. It is scarcely possible that a change of 20 feet at Passon would not have extended so far as Fos, only ten miles away, and this may well be the explanation of the fact that an important and prosperous town, such as was Fossae Marianae in its prime, has left no remains of buildings adequate to its former importance, the site of the docks, warehouses, and public buildings having sunk beneath the sea. Farther afield, however, the evidence becomes contradictory and unconvincing; on one hand there is the existence, at several places along the coast, of Roman constructions, which archæologists have described as the remains of piers, harbours, and fish-stews, but the interpretation is a matter of opinion and open to argument; on the other hand, there are structures which must originally have been built above sea-level, and are now partially submerged, but none of these gives positive proof of more than a very few feet of change, though they are not inconsistent with movement of larger amount. The question calls for fuller investigation, and until this has been carried out it is impossible to assert that the changes of level which can be recognised in the deltas were not localised to that region; for the present they cannot with safety be regarded as having any bearing on the question of whether there has been a widespread change in the relative level of land and sea, affecting simultaneously and as the result of a common cause any large fraction of the Mediterranean, to say nothing of the Atlantic Ocean as well.

Diet and the Teeth.¹

IN the course of Prof. E. Mellanby's researches on rickets in dogs, which led to the discovery of the antirachitic vitamin, now known as vitamin D, it was noticed that defects in calcification were not confined to the long bones, but occurred also in the jaws and teeth of animals maintained on defective diets. Mrs. Mellanby followed up this point, and during the last decade has published numerous papers upon the influence of the diet upon the teeth, and also upon the relationship between dental structure and disease. A detailed account of this work is in preparation, and is being published in three parts: the present volume is the first of the series and is being followed by Part II., upon dental structure in other animals than the dog, and upon the production of dental disease, and by Part III., upon the structure of human teeth and the relationship between structure and caries.

The dog was selected as the experimental animal of choice, since wide variations of dental structure can be readily produced: it is, moreover, omnivorous, like man, and can be readily kept in health under strict laboratory conditions; it is easy to handle, and its teeth can be readily examined at

any time. Like man also it shows a deciduous and permanent dentition.

The report describes in detail the various points to which attention was paid in each of the experimental animals; notes were made of the general health as well as of the condition of the mouth; macroscopic examination of the teeth and radiographs of the jaws and teeth during life were followed by microscopic examination of the teeth and related structures post-mortem, special attention being directed to the large carnassials in the upper and lower jaws. The various grades of calcification are best studied in photomicrographs of ground sections of the teeth, of which numerous excellent reproductions are included in the report; at the same time enlarged photographs of the crowns readily show up deficiencies in calcification of the enamel.

The standard basal diet used throughout had the following composition: cooked cereal 100-200 gm., separated milk powder 10-30 gm., raw 'lean' meat 10-20 gm., oil or fat 10 c.c., orange juice 3-5 c.c., brewer's yeast 5-10 gm., and sodium chloride 1-4 gm. If 3 c.c. of the oil consists of cod-liver oil, perfect health and perfect dental structure are observed, indicating that the diet is now adequate. Small quantities of fat-soluble vitamin occur in the milk

¹ Medical Research Council. Special Report Series No. 140: Diet and the Teeth, an Experimental Study. Part I: Dental Structure in Dogs. By May Mellanby. Pp. 308+109 plates. (London: H.M. Stationery Office, 1929.) 17s. 6d. net.