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CHARLES HUTTON GREGORY, President,
in the Chair.

No. 1,214.—"On the Lagoons and Marshes of certain parts of the Shores of the Mediterranean." By D. T. ANSTED, M.A., F.R.S., For. Sec. G.S., F.R.G.S., &c., Honorary Member of the Institute of British Architects.

THERE are many important departments of Engineering in which considerations of Physical Geography and Geology enter largely and directly, and cannot safely be neglected. In subjects of this kind the observations of those who are not by profession Civil Engineers, but whose pursuits are in some measure analogous, have been too often and too directly appreciated by the Members of this Institution to admit of any doubt as to the reception of a Memoir treating on one of the most interesting among them. No apology need therefore be offered, for submitting the result of inquiries and observations made within the last three years, on the northern shores of the Mediterranean and the eastern coast of Corsica, with a view to determine the history of the lagoons, salt marshes, and swamps, that are there frequently accompanied by the worst forms of malaria, and of which there are so many examples. The Author is the more induced to direct attention to this subject, as he believes it to be certain, that a careful study of the mode in which the lagoons have been formed will in some cases suggest a simple method of sanitary improvement, and in others may point out in what way the marshy lands, now useless and poisonous, may be converted into cultivated fields, yielding luxuriant and profitable crops. He will endeavour to show that certain principles, based on the physical geography of these coasts, and dependent on their local geology, explain all the peculiarities of each separate case, and that a knowledge of these principles is indispensable for the effectual and economical removal of the evil, either by drainage, or by retaining the waters near a fixed level and uniformly salt. In justification for venturing to offer an opinion and advice, in a matter which may seem almost too exclusively engineering for a geologist to treat upon, it may be stated that the Author has from time to time had occasion to visit and examine professionally a number of instances of malarious coast connected with lagoons; that he is familiar, not only with those of the Mediterranean and of the Black Sea, but with others in the West Indies and in North America, and that he is acquainted

with the various engineering plans suggested, and the works carried on to improve them.

There is, perhaps, nowhere to be found a more instructive system of lagoons, salt marshes, and swamps, than that which has for its origin the Delta of the Rhone. This great river, which formerly emptied itself into the Mediterranean by a channel now called the Little Rhone, 35 miles west of its present embouchure, has been steadily advancing eastwards for a very long time, partly by natural causes, and partly in consequence of the construction of artificial works, consisting of embankments and canals, whose object has been to convey the flood-waters direct to the sea, and to leave large tracts of low flat land in a state fit for cultivation, free from the mischief of inundation. The river has now reached a limit towards the east, and a tongue of low land projects into the sea. Plates 13 and 14, which have been reduced from the recently published sheets of the French government maps, show the general form of the present delta and the principal channels by which the Rhone reaches the sea. The main delta is the Isle de la Camargue, between the main channel of the stream to the east, and the Petit Rhon or Little Rhone to the west. Many of the ancient channels are also marked.

The Rhone is a river exceedingly subject to floods, and it receives its large supply of water from three distinct sources. It drains the western flanks and spurs of the Dauphiny Alps by a number of considerable streams, and at length by the Durance, a torrent river conveying enormous quantities of detritus during flood seasons. It receives the Sâone after a long course from the north, and also the drainage of the eastern slopes of the Cevennes and the contiguous mountain ranges. Such a stream cannot fail to bring down a vast variety of detritus, much of which is deposited where the waters first enter the flat land. In this way is formed the delta. All the larger and coarser detritus is dropped at the upper part of the delta, but there remains a great overplus of sand and fine mud. Of this the less coarse part reaches the sea. On entering the low flat lands at the head of the delta, the rate of the stream diminishes, and there are a number of water channels. Originally these would shift each season, as they are known to do in similar cases where left to nature; but in the case of the Rhone, the channels are canalised, and the larger detritus entering them is made to fill up some hollow, and tend to the permanent elevation of the delta. The process of warping has been carried on from time immemorial, and is still pursued. In this way has been formed the large tract of the Camargue, the local name of the modern delta, parts of which, as has been said, are permanently reclaimed and cultivated, but a large portion consists of pools or sheets of shallow water nearly dry in summer. These pools are now filled with water entirely fresh or

slightly brackish, but originally they were occupied by salt water. Besides these pools, and between them and the sea, is a wide space occupied by salt water lagoons and salt marshes communicating still, more or less freely, with the sea.

The true delta of the Rhone is limited to the east by the gravel cliffs of the singular district called the Crau, and to the west by the western water-shed of the Vidourle, a river coming from the Cevennes, and only joining the Rhone at the very extremity of the delta. The total width thus limited is a little less than 40 miles. If a line be drawn from the mouth of the Vidourle to the east, passing the mediæval town of Aigues Mortes, almost all the country to the north side of this line will be found to be reclaimed and cultivated, while that to the south consists of lagoons, marshes, and sand-hills. Up to the thirteenth century of the Christian era, the sea appears to have reached this line in some places, as from Aigues Mortes Louis the IXth embarked, in 1249, to join the sixth crusade, and a galley of that period was found, in 1835, in the adjacent marshes, far within the present water-line of the dunes. This galley may now be seen in the Museum of the Louvre, in Paris.

Assuming, however, this ideal line as a kind of datum, the projecting accumulations of the Rhone detritus have for a very long time been deposited to the east of the Vidourle in two well-defined steps. That nearest the Vidourle and the ancient bed of the Rhone extends parallel to the datum, at a distance of about 7 miles to the south, and with a breadth of 23 miles; while the rest, nearest to the present mouth, extends double that distance, or 14 miles, with a breadth of about 17 miles. The extent of ground occupied by lagoons and marshes is, therefore, very much greater nearer the present than the ancient bed, and the delta is rapidly advancing in this part. Thus the tower of St. Louis, and some others built along the coast about six centuries ago, are now fully 2 miles within the delta. In other places, it is mentioned by Lyell (quoting French authorities) that the Tower of Tigneaux, erected in 1737, is now more than a mile distant from the shore, and that Psalmodi, an island in 815, is now 2 leagues from the shore. It is to be observed, that whilst the course of the Rhone has been for a long period receding towards the east, pseudo-deltas, extending far beyond the real delta, have been rapidly forming to the west.

Draining an unusually large proportion of mountain land, and therefore subject, in an unusual degree, to floods, the Rhone always conveys a large proportion of mud, but in freshets the quantity is enormous. Its stream also, as far as the head of the delta, is extremely rapid, and the delivery of water is large. Before the principal stream was embanked and confined it would, no doubt, shift from year to year, and in this way would fill up the breadth of the

delta; but now that this is prevented, the stream carries with it into the sea not only much water, but great quantities of sand and mud. Admiral Smyth records that, during the war with France at the beginning of this century, Sir Edward Pellew's ships anchored in the offing south-east of the Tour St. Louis, skimmed as much potable water as was wanted, "and at three-quarters of a mile from the shore the fresh run was about 3 feet deep." Although, therefore, the current of the river has been much diminished in rate in coming from Arles to St. Louis, over a dead level for 27 miles, there is still a considerable stream capable of carrying out to sea a large quantity of sand, silt, and mud.

It is only necessary to visit and travel over the Delta, and reach its sea limit, to understand clearly the mode of its formation. It would seem, however, that visits of this kind are very rare, as the Author can find no account of the Delta of the Rhone which gives the most distant idea of its present condition. Judging from the maps, it would seem to be a vast swamp, of which by far the largest part is covered with a sheet of water. In point of fact, however, a considerable part is cultivated; in other parts there are salt-works, here and there are tracts of sand covered with brushwood, juniper, and umbrella pine; while in the autumn it is perfectly easy to cross any part on horseback, and the water is nowhere more than about 3 feet in depth, with a hard bottom. A breed of almost wild cattle feeds on the pastures and brushwood, of which there is a large quantity.

The terminal line of the delta towards the sea consists of a long succession of sand-hills, a few feet above the mean level of the sea. Within this line, at a mean distance of about half a mile, though sometimes more and sometimes less, is another line nearly parallel to it, but more connected. This inner line is in places of considerable breadth, and admits of being fixed by vegetation. Within it there are generally pools of water, brackish at all times, but varying in saltness according to the season. These pools, as well as the outer lagoon, which is always salt, being entirely open to the sea, are all very shallow. The growth of the delta consists in the gradual closing up of the outer line of sand-dunes, so as to make it in time an almost continuous bank. During this time the innermost lagoon tends to fill up by warping, and the intervening one becomes less brackish as it is washed over, time after time, by fresh water. As soon as it becomes nearly complete, an outer line of detached hills begins to form, and thus each outer line in succession becomes an inner one, while each salt-water lagoon becomes first brackish, then fresh, and is ultimately filled up and reclaimed.

There can also be no serious doubt as to the origin of the sand-hills which form the first step in the enlargement of the delta. They are drifted by marine currents, and consist of part of the fine

detritus conveyed into the sea by the main stream. It is this distribution of the finer detritus on which the essential physical features of the delta depend. In the Gulf of Lyons the prevalent winds are south-east, and these produce a definite stream current sufficiently deep to convey sand, silt, and mud to a considerable distance. The deposit is kept up from the existing line of sand-hills by the drift that takes place seawards from time to time, when the inner lagoons become filled during and after freshets, and discharge their fresh water into the sea. The breadth of the interval appears to be a measure of this discharge.

In the various maps of the Delta of the Rhone, the Etang, or lagoon, of Valcares, is always a prominent feature. At the present time it covers about 25,000 acres, and is by far the largest sheet of water in the Delta. It is defended from the sea naturally, by an inner line of sand-hills, of the kind already described; but this is imperfect, and the water has remained brackish. It is now being reclaimed, and for this purpose a dyke or sea wall has been constructed which forms an effectual barrier. This barrier, however, is nothing more than a bank of loose sand, 6 feet above the mean level of the sea, obtained by cutting a trench on the inner side and throwing up the sand. This dyke, occasionally strengthened with a few fascines, is about 500 yards from the outer line of sand-hills. It is 16½ miles long, and was completed almost entirely in the course of one winter, at a cost of £20,000. It was built in 1857. The Author rode along this dyke for a considerable distance, and only observed a few places where the rains had partly injured it. The bed of the lagoon within it is formed partly of fine silica sand and hard mud, and partly of a vast accumulation of shells of cockle (*cardium edule*). Fresh-water lymneæ and land snails are mixed in some places with the shells of cardium.

Except for the magnitude of the works, the difficulty of washing away the salt in the bed of the lagoons, and the smallness of the local population of the Camargue, there would seem to be no reason why the whole of the inner lagoons should not be reclaimed or utilized. Some, indeed, are already in process of reclamation, like the Etang of Valcares, while others are used as evaporating pans to obtain salt, of which a large quantity is here made. The district is unhealthy, being subject to ague and intermittent fever; but the malaria, though serious, is by no means so fatal as in some parts of the Mediterranean.

As a proof of the small amount of change in the surface of the Camargue, by either marine irruptions or floods of fresh water, it may be mentioned that while riding across some of the wildest parts near the sea, the Author observed, among some tamarisk bushes, the whitened skull of a horse, which his companion remembered to have seen in the same place more than sixteen years.

Fragments of Roman brick and pottery are found lying among the sand that forms the bed of the inner pools, mixed with the delicate shells of freshwater and land molluscs.

The works projected and partly executed, to drain the lagoons of the Rhone delta, are very primitive and inexpensive. Sand-dykes, such as that already described, a few brick and stone locks to control the influx and efflux of the water, a few canals, and some windmills to lift the water, make up the whole.

It has been mentioned that the natural termination of the Rhone delta is the water-shed of the river Vidourle, a comparatively small stream, draining a portion of the eastern flanks of the Cevennes, and entering the delta after crossing the gravel, which corresponds with the gravel of the Crau on the eastern side of the Camargue. But although the delta proper cannot be considered as reaching further than this, the deposits brought down by the river affect the coast for a distance of nearly 50 miles to Cape Agde, beyond the extremity of the Etang or lagoon of Thau. Again as far as Port Vendres, where the Pyrenees project into the Mediterranean, the coast is a line of sand banks, enclosing lagoons; but these probably have been formed chiefly by the detritus brought down by the Herault, the Orbe, and other streams crossing the plains of Languedoc. The exact origin of these extensions of sand deposits and the history of the lagoons connected with them is not yet clearly made out.

The Vidourle, though a small stream, during freshets brings down both water and mud in considerable quantities. It is now received, for the purpose of warping, into the Etang de Repousset, which is nearly filled up.

If the physical geography and geology of the country now drained by the Rhone, of the delta of that great stream, and of the Gulf of Lyons, be considered, with a view to make out the history of the remarkable string of lagoons, which extend without break from the extremity of the present delta to the Pyrenees, the task will be easier than might at first appear. It will also be admitted, that this study will point out the remedy, as far as there can be any, of the sanitary evil thus occasioned. The Author will venture, therefore, to give in a few words an outline of this chapter in the history of Europe.

The Rhone and the Saône occupy a great fissure between the very ancient but low chain of the Cevennes, continued northward under many names, and of the Western or Dauphiny Alps. Geologically speaking, the great east and west mountain axis, of which the Pyrenees and the Alps are the western extremity, was turned aside, as it were, by the still older north and south mountain axis, of which the Cevennes is the representative. Hence the broad and, at one time, deep bay, now filled with the detritus brought down

by the Rhone and its tributaries, and hence, also, the trending southwards of the Mediterranean shore beyond the present delta of the river. By a subsequent and comparatively recent elevation, accompanied by a line of volcanic eruption, the main direction of the Cevennes is retained as far as the Cape of Agde, which is a basaltic headland, and part of an almost unbroken line of volcanic ejections, extending from the Auvergne district into Spain. Thus the physical features of the district involve not only the line of the axis of the Cevennes already alluded to, but the line of basaltic eruption parallel to and at a little distance to the west of it. The former terminates in the mountain of Cette, the latter at the Cape of Agde. Beyond the Cape of Agde, as has been already pointed out, is the drainage of the plains of Languedoc, and beyond the bed of the Rhone, towards the east, there is no stream of any importance till arriving at the Var, a distance of 140 miles.

The distribution of the detritus of the Rhone is thus clearly traceable, and it is easy to see that the alluvial and other flat lands between the Rhone and the Cape of Agde can only be due to this source, with the exception of the wash of the hill sides, and the mud conveyed by the small stream of the Lez passing Montpellier, and draining a total area of 125 square miles. The drainage area of the Rhone is estimated at 37,000 square miles.[1]

The geological boundary of the deposits beyond the delta consists at first of the tertiary deposits, near Montpellier, then of the jurassic (Oxford clay) rocks of the Gardéole, and finally of the basaltic rocks continued from Central France towards the south, and seen at the Cape of Agde.

From the lighthouse of Aigues Mortes, behind which is the lagoon of Repousset, now being reclaimed by warping, the whole extension of the sand-banks, lagoons, and marshes, between the hills at some distance inland and the sea, is due to the Rhone detritus conveyed by marine currents. Plate 14 shows the position of these lagoons, their form and their relation to the drainage of the land. Taken in conjunction with Plate 13, which is to the same scale, the relation of the great delta of the Rhone, and these subordinate or pseudo-deltas, each containing its lagoon, will also be clearly recognised. The formation may have commenced long ago, but the present lagoons are not, in all probability, of very great geological antiquity. They form an almost unbroken succession, being only interrupted at long intervals by artificial embankments, and traversed by canals. Between the bed of the Vidourle and the first lagoon is a wide space of 1,800 acres,

[1] This represents the estimated drainage area of the stream according to old authorities. The French geographers have recently given as the drainage area of the Rhone system in France alone 45,884 square miles.

of which about 1,000 acres are marsh and the rest salt pans; the whole being slightly below the level of the Mediterranean. Beyond this space is the lagoon of Mauguio, which has a water area of about 8,000 acres in summer. It is nearly 7 miles long, and in most places from a mile and a quarter to a mile and a half across. Its greatest depth below the mean level of the sea is 4 feet 7 inches, its mean depth 3 feet 5 inches, and its waters in summer are about 8 inches below the lowest mean level of the Mediterranean. It communicates with the sea, at present, by a single artificial cut called the Grau de Pérols, which is the outlet also for the adjacent lagoon to the west. The sand-bank which separates it from the sea is a mile and a half wide at the eastern extremity, but it narrows rapidly to three-quarters of a mile, and is reduced to 500 or 600 yards near the adjacent lagoon. Towards the land side there are extensive marshes. All the villages and towns near it are very unhealthy, and the value of life in them is very small. Besides the rain that falls on its surface, the lagoon and marshes of Mauguio receive the drainage of an area of about 78 square miles, conveyed over land but little elevated, by a number of streams, the longest of which has a course of 13 miles. There is a line of watershed between the feeders of the Mauguio and those of the river Lez, separating naturally the lagoon of Mauguio from that of Pérols to the west. A tongue of higher land approaches within 350 yards of the sand-bank, which is here only about 700 yards wide. It is observable that the little town of Pérols, built on this tongue of land, is far less unhealthy than the adjacent towns to the east and west; but this is, no doubt, owing to its being more elevated above the plain. A slight elevation above the plain, where there is no tendency to drift the malaria to the level of the town, is generally a safeguard; but mere elevation above the sea, as in funnel-shaped valleys, or on the slopes of hills up which the air is obliged to pass in advancing inland from the sea, is no safeguard. The former case is illustrated in the valleys of Corsica, which will hereafter be referred to, the latter in the condition of the town of Cagliari, in Sardinia.

The lagoon of Pérols, including that of Grec and the marshes immediately around, occupies in all about 3,300 acres. Of this the actual lagoon of Pérols occupies 1,925 acres, and that of Grec 500 acres, the two being only separated by an artificial canal: the remaining part of the larger area to the north, about 475 acres, consists of marsh-land, and of the smaller area to the south, about 500 acres, of salt marshes. The mean depth of water is only 14 inches, and the maximum depth 33 inches below the summer water level, which is 7 inches below the mean level of the Mediterranean. The lagoon of Grec is shallower than that of Pérols, its maximum depth in summer being only 20 inches below

the Mediterranean. The marshes round the lagoon of Pérols are 10 inches above the summer water level. There is very little drainage into these lagoons from the land.

Essentially the three lagoons of Mauguio, Pérols and Grec form but one, with only one natural outlet to the sea; but the line of sand-bank is not sufficiently complete to exclude the sea during storms. This natural outlet is towards the furthest extremity, measuring from the Rhone delta, which is the source of the drifted material that has enclosed the lagoons. The conditions are those least favourable for sanitary requirements, as the water in summer is more or less salt and very warm. It is also liable to be rendered almost fresh during the rainy season, by the influx of rain-water brought into it by torrents. After long evaporation the water becomes exceedingly salt in dry weather. The large area of marsh-lands, nearly 5,500 acres, at present left around the lagoons almost without drainage, fully accounts for the unhealthy state of the district. It is proposed to drain effectually all the marshes, and a large portion of the lagoons, so that in place of the present unhealthy waste, there will be about 8,800 acres of valuable cultivable lands, and a permanent lake of 6,750 acres in open and free communication with the sea. The estimated cost of these works is £53,400, and they would need a permanent expenditure of £2,560 per annum for keeping up the works. It is proposed to use wind-mills to lift the water.

The river Lez enters the sea by an artificial channel, separating the lagoon of Pérols from that which next succeeds to the west. The whole system of lagoons and marshes between the Vidourle and the Lez may be traced to the fact, that the natural discharge of the land-waters into the sea being intermittent, long intervals elapsing between any sweeping currents, the sand and mud drifted from the mouth of the Rhone have been enabled to form sand-banks, which the occasional torrents have failed to remove. Thus have been established numerous pools and lagoons, into which at first the sea could enter freely, and which could readily discharge their surplus waters; but which in time have become closed, leaving only one imperfect outlet often choked up. Between the Vidourle and the Lez, the total area of the land draining into the lagoons is about 125 square miles. The Lez, although not draining a large area, has to drain a multitude of small valleys, and thus, though generally small, it is liable to sudden and heavy floods. It is formed by two principal branches uniting close to the outlet. They are called respectively the Lez and the Masson. Of each the total length of course is about 25 miles. The total drainage area is, as already stated, 125 square miles. In a climate where the rain-fall is at all equally distributed, such a stream could hardly be regarded as important; but in this part of the south of France,

owing to a combination of causes, the showers are sometimes exceedingly heavy. As an example of this, it may be mentioned that, on one occasion, in the month of October, 1868, the Author measured a rainfall of 7 inches within twenty-four hours, almost the whole fall being, in fact, within fifteen hours.[1] The Lez may thus now and then be subject to enormous floods of water, conveying large quantities of detritus into the sea. All this must be distributed by marine currents; but in the intervals between two rainy seasons several months may elapse without any rain, and the amount of mud and sand drifted along the coast is amply sufficient to close the channel for the time. These are conditions that can hardly fail to result in the formation of a lagoon, and the lagoons of Mauguio and Pérols, near the mouth of the Lez, are examples which admirably illustrate this view. It is probable that as the Lez is now canalised, there will be little difficulty in carrying into execution the proposed works, and restoring the healthiness of the surrounding country, by draining the marshes, and opening the lagoon of Mauguio into permanent communication with the sea.

Beyond the Lez to the west are three connected lagoons, before reaching the great lagoon of Thau, into which they open. The total length of coast enclosing these three lakes is 13½ miles, and the total area of water 11,280 acres. They are called respectively the Etangs of Villeneuve, Vic, and Frontignan, the passage from the latter to the lagoon of Thau being called 'les Eaux Blanches.' All these waters are very shallow, the deepest parts not exceeding 40 inches below the Mediterranean. Of the different sheets of water, that nearest the Lez (Villeneuve) occupies about 3,000 acres; the next (Vic) about 4,820 acres, including the marshes; the next (Frontignan) 2,730 acres, and the Eaux Blanches about 730 acres.

These lagoons receive the drainage of a tract of land amounting to about 33 square miles, between the range of hills called the Gardéole and the sea. This range comes to an end in a kind of peninsula, stretching into the lagoon of Thau as far as Balaruc, where are some celebrated hot springs. The mountain of Cette is of the same formation geologically, and is a detached hill of the same line of elevation. For the reasons already assigned, this area of drainage, although small, is fully sufficient to justify the group of lagoons between the plains and the present coast line.

The lagoon of Thau is a sheet of salt water 11½ miles long, and in most parts more than 3 miles broad; its total water area being about 20,000 acres. It has no natural outlet to the sea, except by a narrow neck, extending beyond the extreme southern extremity, but there is an artificial channel kept open at Cette. The shores

[1] This was at Villeneuvette, near Clermont, in the valley of the Hérault.

are not remarkably unhealthy, owing to the fact that the water is generally kept at the same level, and the degree of saltness is almost uniform throughout at all seasons. It is not surrounded by marshes. Beyond the lagoon is a coast line of about $3\frac{1}{2}$ miles to the Cape of Agde, within which are about 300 acres of pond and marsh. The headland, on which is the lighthouse of Agde, is volcanic in its origin, and is part of the extensive tract of basaltic rock, extending southwards from the Auvergne country and the Vivarais. The eastern side of the high ground, thus determined, drains into the lagoon of Thau. The total drainage area supplying it with water is nearly 120 square miles, chiefly consisting of a strip of land near the lagoon about 6 miles in width, but part of it rising into considerable hills, and extending some distance to the east of the lagoon.

It must not be lost sight of, that these large sheets of shallow water, surrounded by marsh, are liable to a sensible increase in their volume merely by the quantity of rain that falls on their surface during the heavy rains that sometimes occur. Thus, in the case of a rain like that in the month of October last, the mere surface fall, without any addition from drainage, would add one-fourth to the volume of water contained in some of the basins. Unless, therefore, the means for removing surplus water are unusually complete, the result could not fail to be very troublesome, for such showers run off the land rapidly, and are difficult to guide. The drainage of a system of lagoons of the kind now under consideration, if carried on without recognition of the history of its formation and its mode of growth, as well as of the conditions to which it is now subject, can hardly be expected to be a successful operation; and it is notorious that, in countries where the rainfall is much smaller, and the maximum fall in twenty-four hours not half that of the plains of Languedoc, very extensive works have failed, owing to the impossibility of removing the incoming torrents, after heavy rain, with sufficient rapidity.

The works already carried on in the district appear to be to a great extent in a right direction. They consist of a series of canals, connected with open cuts, the water to be lifted at certain places by windmills. These are intended to drain a part of the lagoons and the whole of the marshes. The rest of the lagoons will be put in free communication with the sea. The artificial channels made for the passage of the waters of the Lez into the sea, and those for introducing the sea into some of the lagoons at will, are already in operation. They are constructed with a view to permanence, and are very efficacious.[1] There seems no reason why, if the principal

[1] These are executed according to the plans and under the superintendence of M. Régy, the Chief Engineer of the Ponts et Chaussées, resident at Montpellier. This gentleman's plans for the whole drainage of the system of lagoons are prepared; and the printed statement appended to them (for a copy of which the Author is indebted

streams can be made to convey their waters direct to the sea when this is required, or to deposit their detritus in still water before they reach the sea, when warping is necessary, there should not be a permanent improvement in the general condition of the coast. The work, however, is on a very large scale and needs to be carried through with caution. The annexed tabular statement will give some idea of its nature in the district now under consideration. It refers to the whole of the lagoon and marsh lands of the delta of the Rhone, and the coast to the west, affected by the deposits brought down by the Rhone, and distributed by the currents of the Gulf of Lyons:—

Description of the Surface.	Length of Coast in Miles.	Total Area (in Acres) of Lagoon and Marsh.	Approximate Area in Square Miles, draining into the Section.
Delta of the Rhone between the Crau and the ancient bed of the Vidourle	40[1]	50,000[2]	37,000[3]
Ponds and marshes between the Vidourle and the canal of Lunel	¾	1,800	40
Basin of Mauguio between the canal and the extremity of the lagoon of Mauguio, chiefly marsh land	¾	2,700	80
Lagoon of Mauguio	7	8,080	
Lagoon of Pérols, from the lagoon of Mauguio to the river Lez, including the Etang de Grec, being the part of the Lagoon of Pérols south of the Canal des Etangs	2¼	3,340	125
Lagoon of Villeneuve, or Arnel between the river Lez and the lagoon of Vic, and the lagoon of Maguelonne or Prevost, being the part to the south of the canal	3½	3,000	
Lagoon of Vic, and various basins and salt-marshes between it and the lagoon of Frontignan	3½	4,820	
Lagoon of Frontignan, and salt-marshes, &c., adjoining	3½	2,730	
Basin of Eaux Blanches, between the lagoons of Frontignan and Thau	2½	730	
Lagoon of Thau (including lagoon of Eaux Blanches), to the outlet at the south end	11½	20,000	120
Pools and marshes between the Grau de Thau and Cap d'Agde	3½	300	..
	78¾	47,500	365

indebted to the kindness of M. Régy,) has supplied many of the details in this account of the lagoons. Plate 14, Fig. 2, has been prepared from a rough tracing which the Author was permitted to take from M. Régy's unpublished plan. *Vide* Ann. des Ponts et Chaussées, 4e série, Tome V. p. 209.

[1] This is not the total length of coast line, which is nearly 60 miles, but the width of the delta in longitude. The miles are British statute miles throughout.

[2] The total area of the "Ile de la Camargue," according to a Report by M. Garella in 1829, is 73,000 hectares, or about 180,000 acres. The part now covered with water is roughly estimated as above.

[3] *Vide* note, p. 293.

After passing the Cape of Agde, there are on the coast to the south a number of small lagoons and several streams entering the Mediterranean. There is, however, no system of lagoons resembling that just described. The reason is to be found in the nature of the streams, which are sufficiently powerful to preserve an open communication all the year round, and to prevent the formation of sand-banks. These banks, by enclosing a part of the winter flow, soon form a permanent lagoon in or near the mouth of the stream. The rivers are sufficiently near each other to prevent any considerable amount of drainage area entering the sea between them.

The Author desires next to direct attention to another group of lagoons accompanied by malaria; occupying a somewhat different position, as not being connected with the delta of a first-class river, but capable of being explained without much difficulty by reference to the geology, or rather to the physical geography, of the district. He refers to the lagoons on the eastern side of the island of Corsica, and chiefly to the lagoon of Biguglia, the largest of all, and that whose drainage would more than anything else improve the sanitary condition of the island. The map, Plate 15, taken from the old French government map, as being the best authority at present available, represents the coast as it was half a century ago. It has since undergone some change.

Corsica has a backbone of mountains, which range nearer the western than the eastern side. Spurs from these mountains approach the eastern shore, but leave a belt of plains about 60 miles long and 3 miles or 4 miles wide. Between these spurs rivers come down and traverse the plains to enter the sea. Of such streams there are three of some importance, and a large number which are rather torrents than rivers, bringing down water only during the rainy season, and either dry, or nearly so, during summer. The Golo is one of the principal streams, and that farthest to the north: the Tavignano is of about the same magnitude, and the Orbo is smaller. There are systems of lagoons dependent on each. Between these principal streams are the beds of several torrents, always dry in summer.

The Golo enters the Mediterranean about 15 miles south of the town of Bastia, after a course of 50 miles, draining about 320 square miles of country. It brings into the plains, and carries into the sea, a large quantity of detritus, which is distributed by the prevailing currents along the coast to the north. The whole of the plains near the present embouchure are composed of gravel and detritus brought down at some former time, now occupying a plain nearly 4 square miles in extent, between the river and the commencement of the great lagoon which next succeeds. This lagoon extends for about $7\frac{3}{4}$ miles in length, parallel to the coast,

with a maximum breadth of about 2,000 yards, but an average breadth of about 1,000 yards for a distance of 6 miles. Beyond this is a passage or canal $1\frac{1}{2}$ mile long, and about 80 yards wide, open to the sea at its farthest extremity to the north, the communication being kept open artificially. The total water area is about 4,750 acres. The depth of water is very small. The maximum depth in the open lagoon is 4 feet 6 inches, but at one place in the canal it is 10 feet. The mean depth is about $33\frac{1}{2}$ inches.

This lagoon is at present shut off from the sea by a sand-bank, 900 yards wide at the southern extremity, near the river Golo, gradually diminishing to 400 yards at the other end. The height is in most parts about 8 feet or 9 feet above the Mediterranean, but there are two low parts over which, during great storms, the waves can at present wash. These are about 300 yards wide. The level of the water in the lagoon is generally a little below that of the Mediterranean, but after heavy rains it is higher, and during summer much lower. The water in summer is very brackish, but during winter and spring it is nearly fresh everywhere. It passes, indeed, at different seasons through almost all possible stages of saltness, besides varying in depth to an extent amounting to almost half the mean depth.

The drainage area supplying water to the lagoon is large. It amounts in all to about 70 square miles, being at the rate of 68 acres of lagoon for each square mile of drainage area. This proportion is unfavourable when compared with the whole system of lagoons on the coast of Languedoc, already described, where there are about 130 acres to the square mile. Deducting, however, the lagoon of Thau, where the proportion is exceptionally large (167 acres to the square mile), the general average of the rest is about 100 acres to the square mile, and this agrees nearly with the cases of the separate lagoons.

It is evident that the difficulty or facility of draining and keeping dry a lagoon must depend partly on the proportion of drainage area to the area to be drained, and partly on the distribution and amount of the rainfall. It is hardly requisite to point out the necessity of considering both these matters before attempting to calculate the cost of draining operations, or, indeed, the possibility, in an economic sense, of executing them. It is clear that, so far as the proportion of areas is concerned, the drainage of the lagoon of Biguglia would render the work much more troublesome and dangerous than that of any of the lagoons of the Rhone delta. Before, however, considering how far the meteorological conditions might modify the case, it is advisable to inquire into the method in which the drainage is distributed, and whether, by a study of the physical features of the district, the matter may not admit of great simplification.

The whole drainage area of the Biguglia district may be con-

sidered as distributed into three parts, which will be best understood by referring to the map, Plate 15, but which may be thus described. By far the largest part is that nearest the Golo, and extending thence to the water-shed of the small river Bevinco, the largest of the various streams and torrents that carry water into the lagoon. The Bevinco is a permanent stream of some importance, having a length of course of 12 miles, and draining a district of about 30 square miles. Before the sand-bank now enclosing the lagoon of Biguglia had reached the point opposite the Bevinco, this stream must have entered the sea by a passage now choked up, but across which the waves occasionally break in stormy weather. There can be no doubt that, until the closing up of this channel, the sea entered the part of the lagoon to the south, and preserved it permanently salt. Now, however, that the waters of this stream are thrown into the lagoon, they accumulate in the wide expanse to the south, and can only be discharged slowly by the outlet artificially kept open more than a mile to the north. There is a small drainage area of about 7 square miles draining into the part of the lagoon to the north of the Bevinco, and into the channel beyond, and this forms the third division of the lagoon. The whole drainage area is, therefore, thus distributed:—

—	Area in Acres.	Drainage area in Square Miles.	Proportion of Acres of Lagoon to Square Miles of Drainage
1. Southern and principal part	4,000	30	1 to 130
2. River Bevinco	..	32	..
3. Northern extremity and channel	350	7	1 to 50

Of these the former part is the old lagoon, which had been gradually increasing in length, diminishing, as usual, in breadth, from the time when the delta of the Golo first began to be distributed. The third part was probably a small lagoon, added when the waters of the Bevinco could no longer escape to the sea. The complete and modern lagoon of Biguglia dates only from the time when the channel of the Bevinco was closed.

It is evident that the enclosure of the waters of the Bevinco, which, till a comparatively recent period, entered the sea at the point where there is now a low break in the sand-bank opposite the mouth of the stream, has not only been the cause of the completion of the lagoon of Biguglia in its present form, but also of the extreme unhealthiness of the surrounding country. In a report recently submitted to the "Ponts et Chaussées," by M. Duponchel, Ingenieur Ordinaire, on the subject of the Etang, it is pointed out that the average mortality for the ten years, 1857 to

1866, for five communes near Bastia, not under the influence of the lagoon, was 19 per thousand, whereas, in four communes near the lagoon, it amounted to 39 per thousand, and close to the spot was 44¼ per thousand. It is a case extremely similar to that of the Lez, on the coast of Languedoc, which, however, being a larger stream, and draining three times the area, has been able to keep a clear channel, and requires but little assistance for this purpose. The Bevinco diminishes to a mere thread of water during extreme dry weather, and at this time the encroachments of the sand drifting from the Golo are sufficient to close it entirely. In autumn and winter the rains produce torrents which, since the closing of the channel, have been spread over the whole lagoon of Biguglia, instead of making their way direct to the sea.

Under these circumstances the first measure of improvement must be a restoration of the Bevinco to its former channel, a removal of all possibility of its waters entering the Biguglia, and thus the placing of the main lagoon in a position entirely analogous to that of the various lagoons on the coast of Languedoc. It cannot be doubted that in this manner the actual drainage of the Biguglia, which would probably be necessary to render the coast healthy, is removed from the class of works practically impossible, which has been up to this time the opinion of the French Engineers. In the report above referred to, dated August, 1869, it is proposed for the first time to canalize the Bevinco, as suggested by the Author in 1867. By preventing the influx of all the waters now entering the lagoon from the torrents that at present discharge into it, and conducting these streams by a system of catchwater drains, partly into the Golo and partly into the Bevinco, the remaining surface drainage, and the rain falling on the lagoon, would be easily kept under control; and the lake once drained, the noxious exhalations and malaria, to which it is now subjected, would be carried away by vegetation, and by a succession of forcing crops.

The history of the coast of Corsica illustrates very clearly the view here taken. Up to the middle of the seventeenth century the coast was at least moderately healthy, and there was then a town of some importance (Mariana), on the north side of the Golo, on the shores of the lagoon. The lagoon was then no doubt open entirely to the sea. This town of Mariana was the seat of the bishopric of an extensive and rich diocese. Its ruins remain, but the neighbourhood is not now habitable in summer. The closing of the lagoon and the shutting in of the waters of the Bevinco were probably rapid, and the consequence has been the retention, in the lagoon, of the large quantities of decaying organic matter which is brought in by the Bevinco and the various torrents. The total absence of the circulation of the water during summer,

when the heat and evaporation are greatest, and the high temperature of so large a sheet of very shallow water, produce a rapid growth of confervoid vegetation on the water, and this is drifted in enormous sheets to the inner shore, where it accumulates and rots. The smell arising from the lake is then very offensive, and a mist hovers over the surface. The smell and miasma are drifted up the valleys by the prevalent south-easterly winds, and thus not only the plains adjacent to the lagoons, but the greater part of the eastern side of the island becomes poisoned. In all the valleys the villages are unhealthy, and the town of Bastia itself suffers severely. The death-rate of the communes north of Bastia, entirely removed from the influence of the lagoon, is only from $16\frac{3}{4}$ to 18 per thousand. In the town of Bastia it is nearly 22.

Unfortunately for Corsica the conditions of the Golo are repeated, though in a less mischievous manner, at the mouth of the Tavignano, the Orbo, and the other principal streams. Near the Tavignano is the lagoon of Diana, now closed and unhealthy, but formerly open and healthy. Occupying precisely the same position between the lagoon and the river, as is the case with the mediæval town of Mariana, there was, in the time of the Roman occupation of Corsica, another town, Aleria, of which, also, ruins exist, but which has long ceased to be habitable. The lagoon of Diana is, however, deeper than that of the Biguglia, and requires different treatment. Beyond the Tavignano, and between that stream and the Orbo, is another large lagoon, the Urbino, besides smaller sheets of water, and still more to the south is the lagoon of Palo. The succession of so many lagoons and marshes on the 60 miles of coast that bound the eastern plains of Corsica, have checked all progress, and rendered these plains barren wastes, although they are marvellously rich in soil, and formerly yielded enormous crops. To restore the coast to its ancient condition of health, would probably render the valleys perfectly healthy, and enable the population of Corsica to double itself in a short time. The measures required for this improvement must, it is believed, have strict reference to the physical conditions that have caused the malaria.

The statistics of rainfall on the Corsican coast are not satisfactory. The observations range over only a short period, and though detailed they refer only to one station in the town of Bastia. They appear to prove, however, that the climate is, as might have been expected, more insular than that of the coast of Languedoc, the total amount of rainfall being distributed over a longer period of days, and the showers being less heavy. During the three years, 1861-1863, the mean total fall was about 24 inches, of which 10 inches fell in October and November, the rest being distributed over the winter and spring months. The maximum fall in twenty-four hours was a little more than 2 inches; the maximum weekly fall nearly 4 inches; the maximum monthly fall 12 inches. In

the report already referred to, it is stated that a heavier rainfall than seven centimètres ($2\frac{3}{4}$ inches) in twenty-four hours, has not been known even in exceptional storms. A large proportion of the heavier showers would naturally reach the lagoon, for the distance is small, and the ground falls with tolerable rapidity: but the hill sides are everywhere covered with vegetation. The drainage of the mountains is, of course, discharged by the large rivers.

The rainfall statistics of the neighbourhood of Montpellier, and the coast of the Mediterranean near the delta of the Rhone, prove that the records of a few years not only fail to give a fair average, but that even a good average, if obtained, is of little value by itself, in inquiries that have any practical bearing. Throughout this part of Europe, the seasons recur in cycles of many years, and the rainfall, after being moderate and regular for a number of successive years, changes altogether its character, becoming for several years not only more excessive, but characterized by storms of tropical magnitude and rapidity. Allusion has already been made to a shower or succession of showers, during the month of October last, in this district, when in a period of twenty-four hours as much as 7 inches of rain fell. Such showers, though not common, are characteristic of the climate in this respect, and they are important as introducing elements of difficulty in drainage works which it would be unwise to neglect.

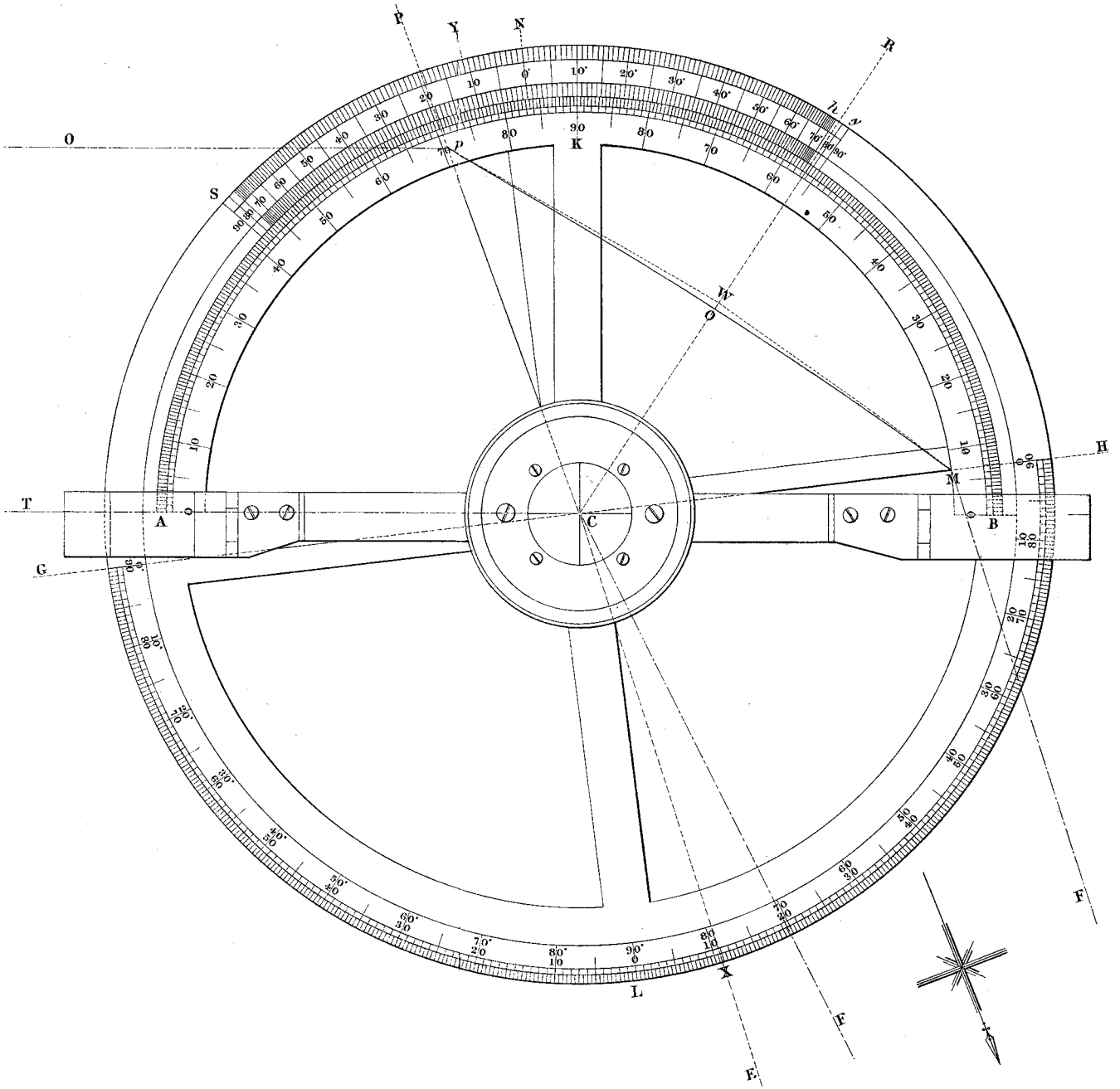
Over the delta of the Rhone itself, the rainfall appears to be about one-fifth less than the fall at and near Montpellier. For fourteen years before 1868, there had been a succession of wet seasons, the mean annual fall amounting to 40 inches; but previously there had been dry seasons, when the quantity of rain was much less. After the dry summer of 1868, a very heavy rain, which had taken place within a fortnight, had not produced much effect on the waters of the lagoon of Valcares, though its influence was seen in the countless swarms of gnats darkening the air during the day throughout the delta.

The following Table of the rain statistics of the town of Montpellier are interesting, but must not be regarded as sufficient to justify any general conclusions from the average:—

——	Jan. to March.	April to June.	July to Sept.	October to Dec.	Total.
	Inches.	Inches.	Inches.	Inches.	Inches.
1857	11·81	5·16	16·34	15·75	49·06
1858	9·68	2·95	3·38	9·37	25·38
1859	4·96	6·69	1·50	6·77	19·92
1860	10·43	8·20	6·89	14·05	39·57
1861	12·64	7·40	3·50	9·57	33·11
1862	8·23	5·27	11·53	26·11	51·14
1863	5·43	5·59	7·83	14·72	33·57
1864	8·74	2·28	1·50	28·31	40·83
Means	9·00	5 44	6·56	15·58	36·58

LIGHTHOUSE APPARATUS AND LANTERNS.

Mr ALAN BREBNER'S REFRACTION PROTRACTOR, FOR GLASS WITH REFRACTIVE INDEX OF 1·51.



ALAN BREBNER, DELT

Minutes of Proceedings of The Institution of Civil Engineers, Vol. XXVIII. Session 1868-69.

KELL, BROS LITHRS

At Carcassonne, the mean of the ten years 1849--1858 was 29·88 inches: the position of this town explains the difference. The following details of the rainfall in Bastia for the three years of corresponding observation are interesting:—

——	Jan. to March.	April to June.	July to Sept.	October to Dec.	Total.
	Inches.	Inches.	Inches.	Inches.	Inches.
1861	..	..	..	5·67	20·12
1862	6·53	4·41	2·95	15·83	29·72
1863	..	..	..	12·21	22·84

They indicate a much smaller rainfall generally, but a considerably larger proportion during the winter months. This appears to correspond with general experience.

Besides the marshes connected with, and almost forming part of the lagoons, and the lagoons directly derived from river deltas, there are others in the extended plains of Languedoc, on the coast of Provence, and on the islands of the western Mediterranean, off the coast of Spain. There are also extensive groups of lagoons at the head of the Adriatic, connected with the delta of the Po, and others in the eastern Mediterranean, and on the western shores of the Black Sea near the mouths of the Danube. In each case there is something special, and each must be dealt with on its own merits, and after a careful consideration of the physical geography of the district. But a large proportion of the lagoons must certainly be referred to the cause pointed out, the drifting of transported material by marine currents along lines of coast, where the natural drainage of the land has not the strength to sweep a clear channel through the silt accumulating in front of it. Under such circumstances a careful study of the physical conditions of the surrounding country, and a knowledge of the history of the formation of the lagoon, as derived from observation, should precede any attempt to remedy the evil attendant on malaria, if that has already been prevalent. This is the case whatever be the proposed remedy, whether by draining the lagoons and reclaiming the land if that be practicable, or if not, by opening the lagoons to the sea by permanent canals, and locks capable of being kept clear of obstruction from the constantly advancing sands. In observations of this kind, a knowledge of the general physical geography and meteorology of the district seems to be absolutely indispensable, and an acquaintance with the local geology extremely useful.

The practical bearings of the facts and inferences submitted in this communication may be thus briefly summarised:—

First. That the malarious lagoons and marshes, of which there are so many examples on various shores, are the result of the

interception of waters coming off small tracts of land, or of small and torrential streams, by banks of drifted sand and mud, proceeding from larger rivers, carrying out to some distance a large quantity of detritus which is distributed by marine currents.

Secondly. That a study of the existing physical geography of each district affected by malaria, combined with a knowledge of its geology, is sufficient to explain the conditions, and to determine the history of the operations that have terminated in the formation of the malarious marshes and lagoons.

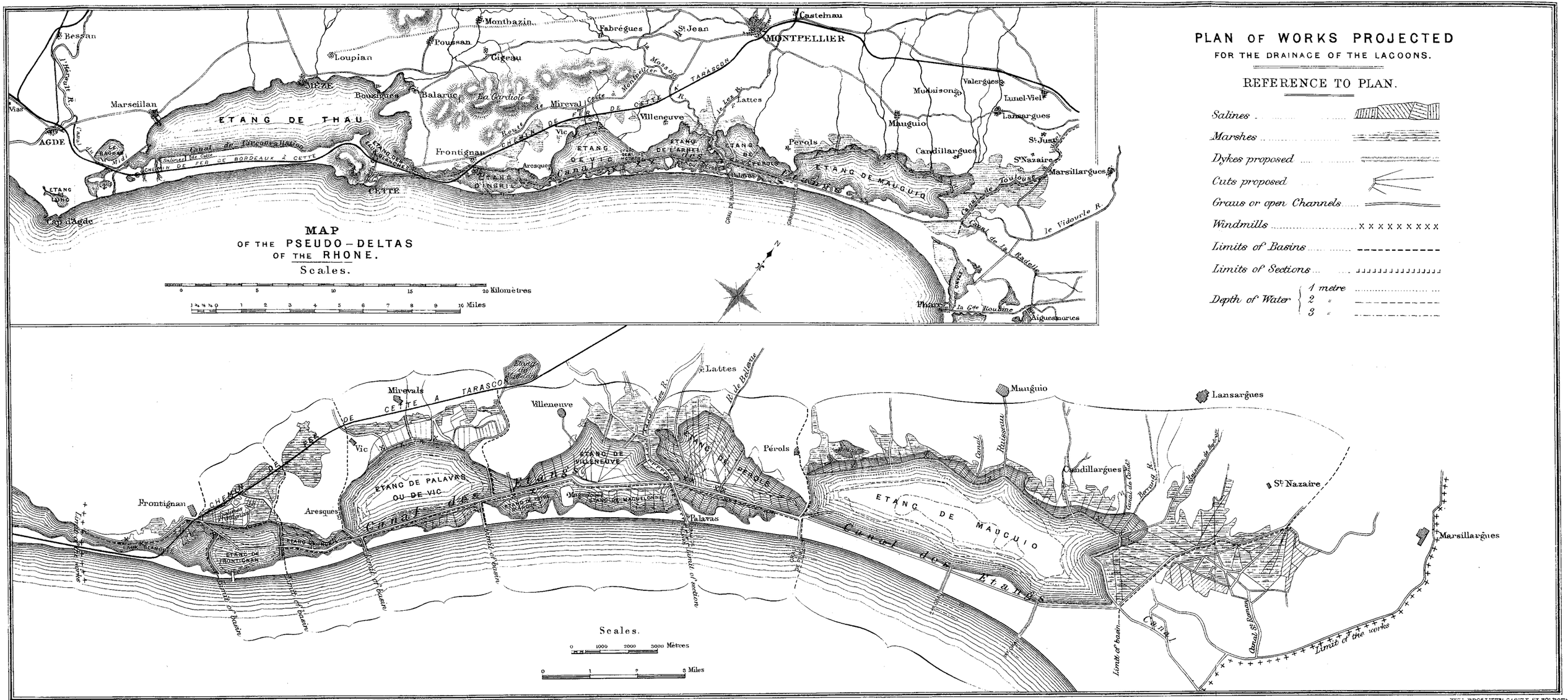
Thirdly. That the removal of malaria, whether to be effected by complete drainage or by partial drainage, accompanied by the keeping certain lagoons in free communication with the sea, can only be hoped for by engineering operations, based on the special history of the case under consideration, as determined by a knowledge of the physical geography and geology of the district.

Fourthly. That, in certain cases where small torrential streams have been kept back from the sea by the rapid accumulation of drifted sand, the drainage of the marshes and lagoons may be rendered comparatively easy by keeping open a permanent channel for such streams.

Fifthly. That the principle of breaking up the large drainage areas which supply water to the lagoons into smaller areas, each of which admits of separate treatment, being suggested by the history of lagoons generally, is the principle which should be adopted in all cases where sanitary improvement is called for, and will generally be found advantageous in an economic sense.

The communication is accompanied by a series of diagrams, from which Plates 13, 14, and 15 have been compiled.

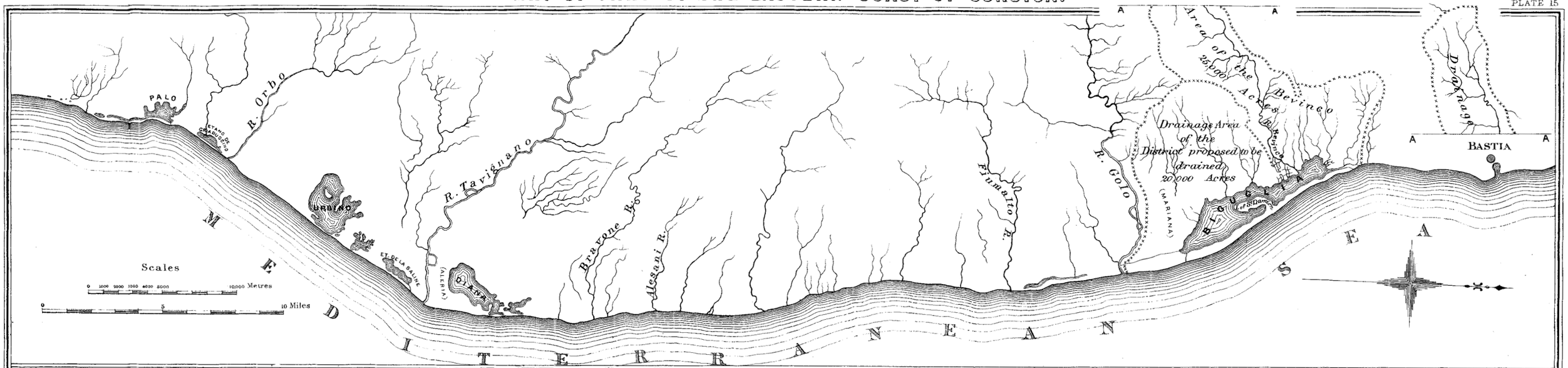
[Professor ANSTED



KELL BROS LITH.rs CASTLE ST HOLBORN

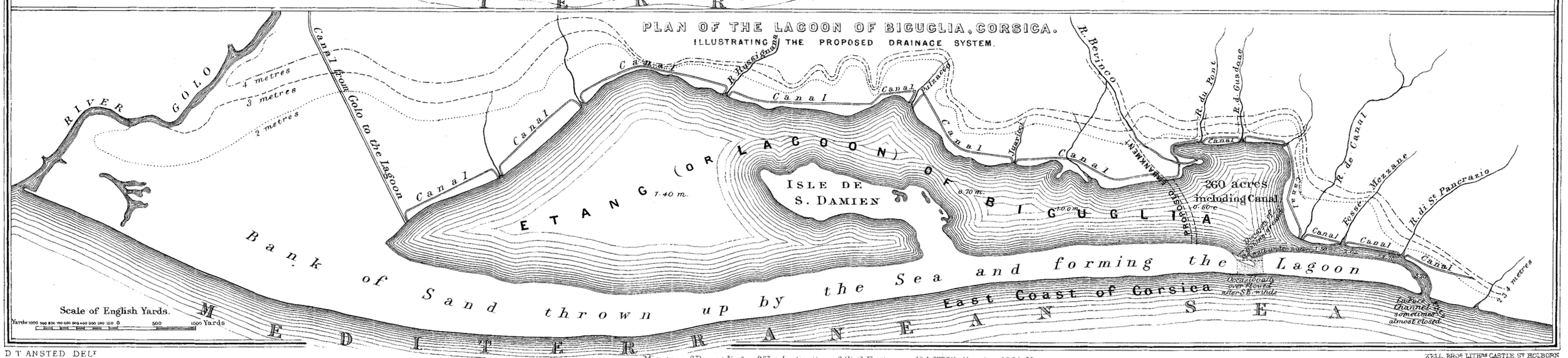
MAP OF PART OF THE EASTERN COAST OF CORSICA.

PLATE 15



PLAN OF THE LAGOON OF BIGUGLIA, CORSICA.

ILLUSTRATING THE PROPOSED DRAINAGE SYSTEM.



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