CHAPTER 23

LITTORAL DRIFT PROBLEMS IN PORTUGAL WITH SPECIAL REFERENCE TO THE BEHAVIOR OF INLETS ON SANDY BEACHES

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After a brief description of the littoral drift regimen in the west and south coasts of Portugal, review is made of the behavior of the works performed in three lagoon inlets located on these coasts and some general principles are inferred which are felt to be valid in the treatment of any similar problems.

LITTORAL DRIFT REGIMEN

The coast line of continental Portugal has a total length of about 480 miles, of which 380 miles form the west coast, from the mouth of River Minho to the Cape of St. Vincent, and the remaining belong to the south coast, from this Cape to the mouth of River Guadiana (see Fig. 1).

Roughly 300 miles of the shoreline are sandy beaches, sometime more than fifty miles long.

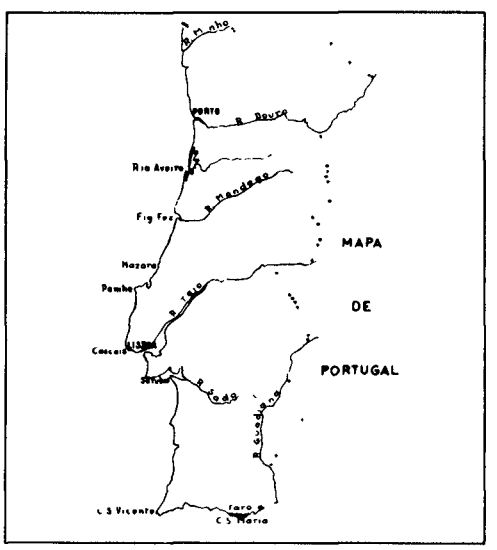

Fig. 1. The coastline of Portugal.

LITTORAL DRIFT PROBLEMS IN PORTUGAL WITH SPECIAL REFERENCE TO THE BEHAVIOR OF INLETS ON SANDY BEACHES

The west coast, which runs approximately north - southwards, is openly exposed to the winds and waves occurring in this area of the North Atlantic Ocean. In normal years, the north winds and seas are predominant, and they specially prevail in summer and the adjoining periods of spring and autumn, that is, in the dry season. South winds and seas are frquent in winter and the first half of spring, during the wet season, and the big storms usually start with their strong blowing. Meteorologically abnormal years may occur from time to time, and sometimes consecutively, in which the wet season lasts longer and the south wind and seas predominate. Similarly, it may arrive, in periods of exceptional drought, that the prevalence of the north winds and seas remains for the whole year and during consecutive years.

None of the mentioned abnormal features is very frequent, and it seems the former is the less common. While the available statistical data are not enough to allow any definite conclusion, the events in the last hundred and fifty years show that such meteorologically abnormal situations have occurred at intervals of 15 to 35 years. This means there is a really and largely predominant meteorological regimen, which therefore must model a marked littoral physiography.

As far as sediment drift is concerned - and in the Portuguese coast sediment means sand for all practical purposes - this littoral physiography is defined by an intensive alluvial movement, which proceeds alternatively southward and northward, according to the meteorological conditions at the moment, the former being predominant in normal years. Full quantitative evaluation of this littoral sand drift is unavailable, but the measures taken in some significant places where works were being carried show that in normal years the southward balance of the foreshore littoral drift amounts to approximately 200,000 c.m., which is about half of the total southward foreshore drift in those years. The offshore drift is harder to evaluate, but its volume is far in excess of this figure, and there are measures of depositions and erosions in outer bars, exclusively fed by littoral sand, at rates of one million c.m. in a few months.

This littoral drift regimen is subject to variations, according to the meteorological features of the year concerned, both as regards intensity and trend of the predominant alluvial movement.

As the major extent of this coast is straightline shaped, local regimens are very few, practically confined to the five bays of Figueira da Foz, Nazare, Peniche, Cascais and Setubal.

The southern coast of the country runs roughly in a west and east direction and its littoral drift regimen is similar to the west coast one, with the difference that modeling agents are less vigorous and local variations more pronounced. Storms are neither so frequent nor so violent. Drift is alternatively eastward and westward,

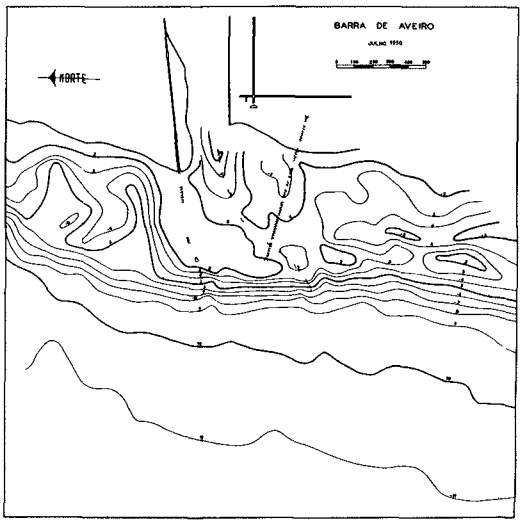

Fig. 2. July - August 1950

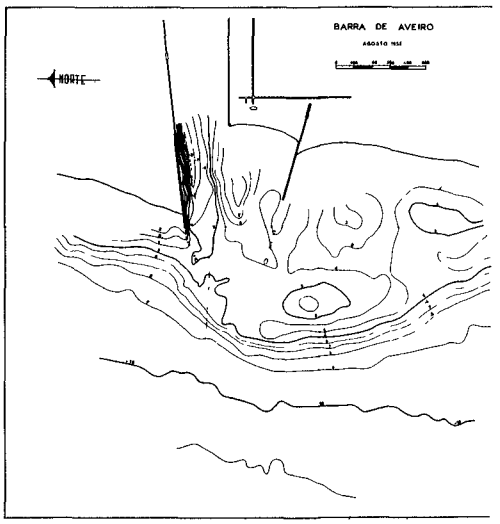

Fig. 3. August 1955

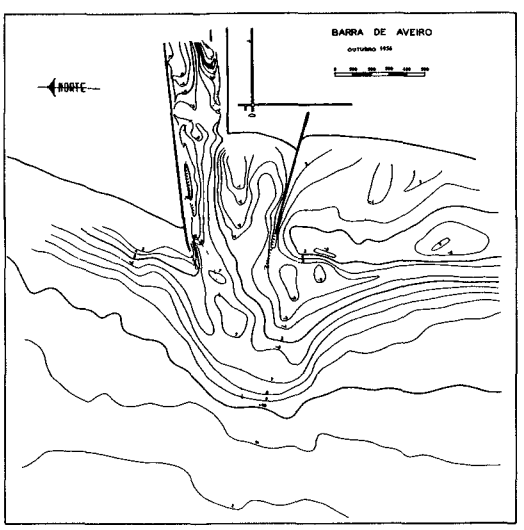

Fig. 4. April 1955

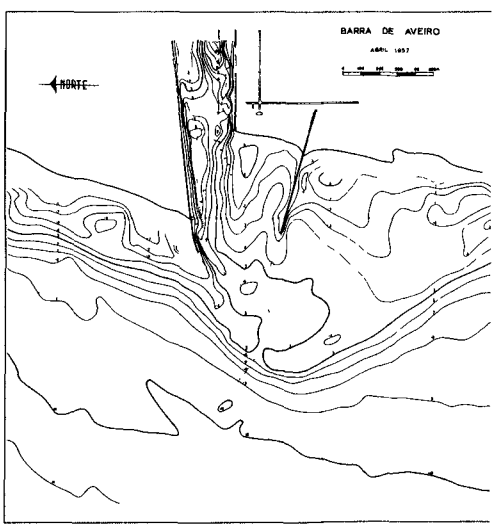

Fig. 5. April 1957

Hydrographic Surveys of the Inlet of Lagoon of Aveiro

the former being more or less predominant according to the meteorological feature of the year and to the layout of the coastal stretch concerned, its prevalence being the strongest to the east of Cape Santa Maria.

While there are no systematic evaluations of the amount of sand interested in littoral drift processes, there is evidence of it being much less than the figures registered on the western coast.

The foregoing description is confined to longshore alluvial movement, which is the main process to be considered when dealing with littoral drift problems in the continental Portuguese coastline. In fact, due to the characteristics of the waves occurring and their relative frequences, as also to the nature of sediments available, transversal alluvial movements may be occasionally very intense, specially during big storms, but they are statistically much less important than the longitidinal ones. Of course, they play their part in shaping the alluvial shoreline, but the main modelling process is the longshore drift, with the possible exception of some limited stretches on the south coast.

LAGOONS AND THEIR INLETS

There are two important lagoon systems along the coast: the lagoon of Aveiro in the central west coast, and the lagoon of Faro-Tavira in the eastern south coast. As stated, we intend specifically to treat the littoral drift problems connected with the regimen of the inlet channels giving access to those large bodies of water.

THE LAGOON OF AVEIRO

In the previous paper (C. Abecasis, 1954) we gave a description of the very interesting case of the Aveiro lagoon, as known from the Xth century up to the results of the improvement scheme being carried on by the middle of 1954. We shall not repeat the description, but we re-insert, for the sake of confront, the hydrographic survey of the inlet in August 1950, when the scheme was started (see Fig. 2).

It is now convenient to bring up to date the analysis of the behavior of the inlet channel in its reaction to the works undertaken. For the purpose, we shall insert in the graphs and tables of the preceding study the data collected since their publication, retaining the same designations and the numbering of the tables. Some of the hydrographic surveys on which those data were based are also included (see Figs. 3 to 5).

Table 1
Changes in volume of sand on the outer bar of Aveiro

Date of surveys		Changes with reference to 1865(c.m.)	Changes with reference to the preceding survey (c.m.)	
Month	Year		Deposition	Erosion
	1865	-	-	-
XI	1914	1.661.800	1.661.800	-
I	1935	378.000	-	1.283.800
VIII	1949	3.892.700	3.514.700	-
VII	1950	2.457.400	-	1.435.300
III	1951	2.349.200	-	108.200
IV	1951	2.083.100	-	206.100
VI	1951	2.115.200	32.100	-
IX	1951	2.979.730	864.530	-
III	1952	3.104.350	124.620	-
V	1952	2.292.650	-	811.700
VIII	1952	3.180.850	888.200	-
XI	1952	4.089.320	908.470	-
I	1953	3.516.790	-	572.530
V	1953	2.813.250	-	703.540
IX	1953	2.463.100	-	350.150
I	1954	3.258.530	795.430	-
IV	1954	3.107.170	-	151.360
VII	1954	2.977.230	-	129.940
III	1955	2.650.380	-	326.850
VIII	1955	3.585.250	934.870	-
X	1956	2.964.400	-	620.850

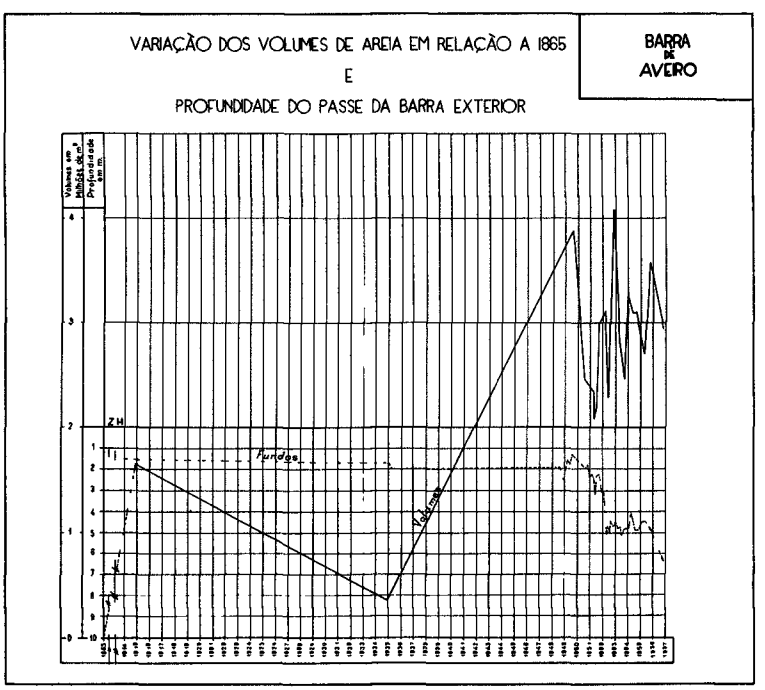

Fig. 6. Variation of the volume of sand in the outer bar of Aveiro

Table 1 and Fig. 6 show that the volume of sand in the outer bar platform remains stable, with the seasonal variations assigned before. As meteorologically anomalous years did not occur, no systematic alteration can be traced.

The projections of the longitudinal profiles of the entrance channel on a vertical plane parallel to the old southern jetty (see Fig. 7) entirely confirm what has been inferred in the 1954 analysis, i.e., as the works proceed and the lagoon's ebb current is reinforced, the outer bar is displaced seawards, widened and deepened (note the 1956 survey). Also confirmed is the then suggested envelop curve of the controlling depths at the outer bar's crest as a function of this crest's distance to a fixed base-line across the inlet canal (see Fig. 8).

Tables 3 and 4* and Figs. 9 to 12 demonstrate that the inlet channel's hydraulic characteristics favorable reaction to the works is consolidated, if not slightly improved, which, as previously stated, is of vital importance to the maintenance of depths in the whole access to the port.

In the preceding paper we pointed out the great significance of the behavior of the inner bar as an index of the soudness of the inlet's improvement scheme being executed. Fig. 13 to 16 and Table 5 show that the favorable results obtained can now be considered definitively acquired.

Moreover, additional data show that these beneficial results are not restricted to the area of the inner bar on the main lagoon channel. Thus, the access channel to the southern lagoon branch of Mira, which for many years had been starving and slowly shoaling, spontaneously deepened, specially since 1953 (see Figs. 18 and 19).

This, again, clearly means that littoral sands are not retained by the inlet in their way down-coast, as the volume of sand expelled by the ebb tide fairly exceeds that brought in by the flood. And if so, the project being carried on correctly solved the problem of assuring the depths required (indeed, more than required) in the channel with the least interference with the littoral drift regimen: in fact, a strictly localized interference, both in the time and in the space, as is also confirmed by the absence of any permanent erosion effects on the down-drift section of the sea shoreline.

* A mistake in the computations of Table 4 concerning years 1934, 1945, 1951, is now corrected. It did not affect the conclusions inferred from the Table's analysis.

Table 3

Lagoon of Aveiro
Areas of the inlet's channel cross sections

Dates Ranges	1865	1914	1934	VIII 1945	VII 1948	V 1950	V 1951	V 1952	V 1953	V 1954	V 1955	V 1956
P.1	-	410	683	-	-	913	1.062	1.220	1.497	1.595	1.679	1.654
P.2	523	403	633	-	917	909	1.032	1.191	1.640	1.640	1.594	1.634
P.3	549	499	510	804	888	802	1.068	1.237	1.743	1.511	1.722	1.724
P.4	668	647	595	769	741	789	1.216	1.234	1.677	1.635	1.720	1.669
P.5	879	520	535	721	888	866	1.186	1.102	1.730	1.528	1.626	1.626
P.6	1.064	505	591	939	918	957	1.192	1.223	1.491	1.653	1.675	1.931
P.7	736	370	623	925	1.155	1.101	1.237	1.155	1.309	1.520	1.730	1.655
P.8	599	428	621	1.229	1.345	1.138	1.254	1.154	1.390	1.471	1.607	1.712
P.9	546	390	678	1.296	1.504	1.203	1.277	1.246	1.504	1.524	1.650	1.820
P.10	505	423	659	1.342	1.825	1.266	1.417	1.308	1.674	1.691	1.955	2.010
P.11	517	643	579	1.837	2.122	1.945	1.830	1.470	-	2.139	2.000	2.050

Areas, in eq.m., under datum

Table 4 (Part A)
Lagoon of Aveiro (1934-1952)
Hydraulic elements of the inlet's cross sections

Dates	1934			VIII-1945			V-1951			VIII-1952		
Range number	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m
P.1	1.123	245	4.6	-	-	-	1.522	245	6.2	1.838	308	6.0
P.2	993	200	5.0	-	-	-	1.482	238	6.2	1.974	300	6.6
P.3	850	190	4.5	1.164	216	5.4	1.526	270	5.6	2.031	308	6.6
P.4	975	210	4.6	1.039	183	5,7	1.756	294	5.9	1.877	318	5.9
P.5	775	185	4.2	1.031	160	6.4	1.746	295	5.9	1.755	324	5.4
P.6	941	160	5.9	1.289	167	7.7	1.752	307	5.7	1.727	329	5.3
P.7	1.083	255	4.2	1.295	200	6.5	1.837	311	5.9	1.956	340	5.8
P.8	1.061	238	4.5	1.689	242	6.6	1.712	305	5.6	2.024	343	5.9
P.9	1.178	255	4.6	1.856	307	6.0	1.867	308	6.0	1.988	344	5.8
P.10	1.089	228	4.8	1.902	305	6.2	2.077	342	6.0	2.100	353	5.9
P.11	1.045	213	4.9	2.467	334	7.3	2.530	359	7.0	2.354	344	6.8

Notes: a) Wetted area
p) Wetted perimeter
$R = \frac{a}{p}$ - Hydraulic radius (m)
Sections under mean level (+ 2,00 above datum)

Table 4 (Part B)
Lagoon of Aveiro (1953-1956)
Hydraulic elements of the inlet's cross sections

Dates	IX-1953			VII-1954			V-1955			V-1956		
Range number	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m
P.1	2.070	312	6.6	2.252	303	7.4	2.280	297	7.7	2.260	300	7.5
P.2	2.051	314	6.5	2.340	308	7.6	2.200	300	7.3	2.250	301	7.5
P.3	2.127	334	6.4	2.167	300	7.2	2.305	307	7.7	2.350	308	7.6
P.4	2.414	327	7.4	2.267	305	7.4	2.356	301	7.5	2.305	300	7.7
P.5	2.349	332	7.1	2.347	330	7.1	2.347	337	6.9	2.412	339	7.0
P.6	2.291	343	6.7	2.376	334	7.1	2.334	331	7.1	2.589	335	7.7
P.7	2.190	343	6.4	2.277	337	6.7	2.382	343	6.9	2.325	341	6.8
P.8	1.989	345	5.8	2.233	343	6.5	2.312	348	6.6	2.390	349	6.7
P.9	1.941	345	5.6	2.198	343	6.4	2.308	344	6.7	2.502	345	7.2
P.10	2.167	362	6.0	2.392	352	6.8	2.712	353	7.7	2.710	354	7.6
P.11	2.405	363	6.6	2.649	354	7.5	2.713	354	7.6	2.750	355	7.7

Notes: a) Wetted area
p) Wetted perimeter
$R = \frac{a}{p}$ - Hydraulic radius (m)
Sections under mean level (+2,00 above datum)

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Table 5 (Part A)
Lagoon of Aveiro (1948-1952)
Hydraulic elements of the inlet's cross sections (inner channel)

Dates	VII-1948			VII-1950			V-1951			XI-1952		
Range number	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m
P.12	1.639	283	5.7	1.406	281	5.0	1.774	278	6.4	1.680	280	6.0
P.13	1.818	321	5.6	1.873	323	5.8	1.984	322	6.1	2.163	320	6.7
P.14	1.870	323	5.7	1.805	327	5.5	1.792	326	5.5	1.758	324	5.4
P.15	1.895	358	5.3	1.885	360	5.2	1.967	356	5.5	2.065	358	5.8
P.16	2.190	374	5.8	2.123	379	5.6	2.188	379	5.7	2.058	375	5.5
P.17	2.320	410	5.7	2.504	409	6.1	2.350	408	5.7	2.060	407	5.0
P.18	2.742	468	5.9	2.694	468	5.7	2.392	471	5.0	2.450	469	5.2
P.19	2.625	523	5.0	2.600	522	4.8	2.438	522	4.6	2.508	522	4.8
P.20	2.665	549	4.8	2.450	549	4.5	2.330	550	4.2	2.008	549	3.7
P.21	2.506	585	4.3	2.446	583	4.2	2.294	583	3.9	1.945	582	3.3
P.22	2.311	605	3.8	1.875	603	3.1	2.208	603	3.6	1.923	603	3.2
P.23	2.302	604	3.8	1.885	603	3.1	2.027	603	3.3	1.878	603	3.1
P.24	2.225	613	3.5	2.052	610	3.3	2.158	613	3.5	2.172	613	3.5
P.25	2.347	609	3.8	2.097	605	3.4	2.321	606	3.8	2.090	605	3.4
P.26	2.440	558	4.3	1.690	552	3.1	2.105	553	3.8	1.808	550	3.3
P.27	2.290	635	3.6	2.150	632	3.4	2.367	634	3.5	1.850	632	2.9
P.28	2.345	618	3.7	2.088	617	3.3	2.174	617	3.5	1.943	615	3.1
P.29	2.195	547	4.0	2.015	546	3.7	2.135	547	3.9	1.830	543	3,4

Notes: a) Wetted area
p) Wetted perimeter
$R = \frac{a}{p}$ Hydraulic radius m
Sections under mean level (+2,00 above datum)

Table 5 (Part B)
Lagoon of Aveiro (1953-1956)
Hydraulic elements of the inlet's cross sections (inner channel)

Dates	XI-1953			VII-1954			V-1955			V-1956		
Range number	a m2	p m	R m	a m2	p m	R m	a m2	p m	F m	a m2	p m	R m
P.12	2.105	281	7.4	2.025	281	7.2	1.995	284	7.0	2.232	277	8.0
P.13	2.312	322	7.1	2.430	322	7.5	2.390	318	7.5	2.513	315	7.9
P.14	2.133	324	6.6	2.245	325	6.9	2.309	329	7.0	2.542	322	7.8
P.15	2.295	359	6.3	2.288	357	6.4	2.245	357	6.2	2.492	350	7.1
P.16	2.347	372	6.6	2.650	374	7.1	2.752	375	7.3	2.580	373	6.9
P.17	2.687	408	6.5	2.589	410	6.3	2.891	411	7.0	2.444	408	6.0
P.18	2.601	469	5.5	2.592	465	5.5	2.590	471	5.5	2.673	471	5.6
P.19	2.488	523	4.7	2.650	523	5.1	2.530	523	4.8	2.825	525	5.3
P.20	2.600	551	4.7	2.425	550	4.4	2.473	550	4.5	2.795	551	5.1
P.21	2.797	586	4.8	2.579	584	4.4	2.532	585	4.3	2.755	587	4.7
P.22	2.639	606	4.3	2.495	604	4.1	2.531	604	4.2	2.717	606	4.5
P.23	2.314	605	3.8	2.425	604	4.0	2.417	605	4.0	2.532	605	4.2
P.24	2.615	615	4.2	2.381	612	3.9	2.595	612	4.2	2.554	609	4.2
P.25	2.582	607	4.2	2.967	610	4.8	2.886	595	4.8	2.812	600	4.7
P.26	2.252	558	4.0	2.448	555	4.4	2.414	550	4.4	2.448	551	4.4
P.27	2.473	637	3.9	2.527	635	4.0	2.370	634	3.7	2.394	635	3.7
P.28	2.331	617	3.6	2.404	617	3.9	2.317	616	3.7	2.485	610	4.1
P.29	2.281	549	4.1	2.341	547	4.3	2.332	542	4.3	2.280	540	4.2

Notes: a) Wetted area
p) Wetted perimeter
$R = \frac{a}{p}$ Hydraulic radius m
Sections under mean level (+2,00 above datum)

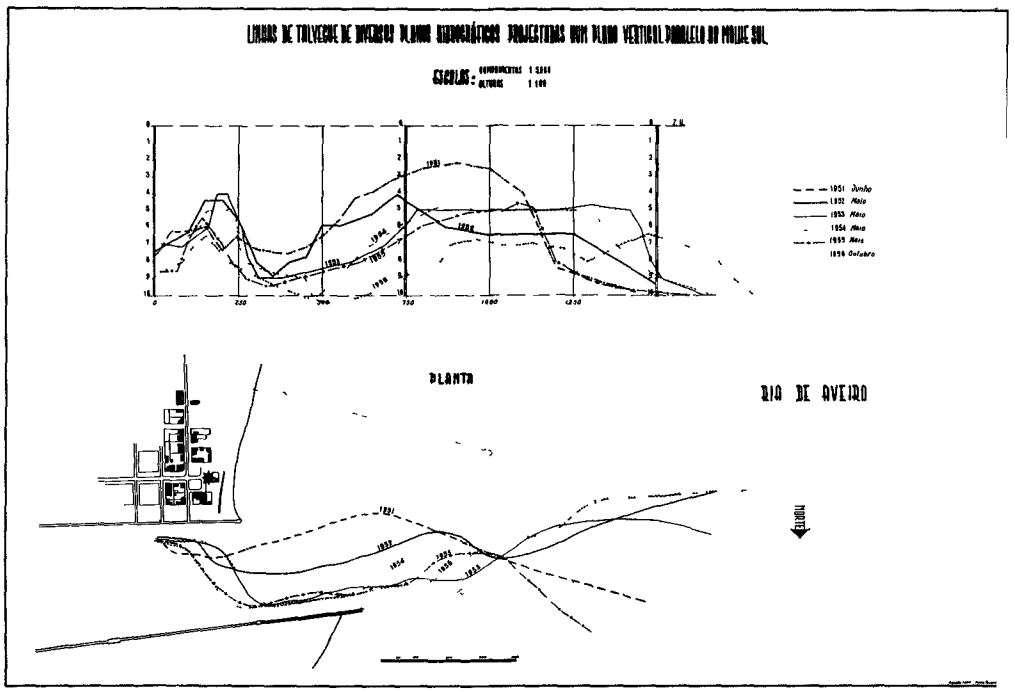


Fig. 7. Longitudinal profiles of the entrance channel projected on a vertical plane parallel to the old southern jetty

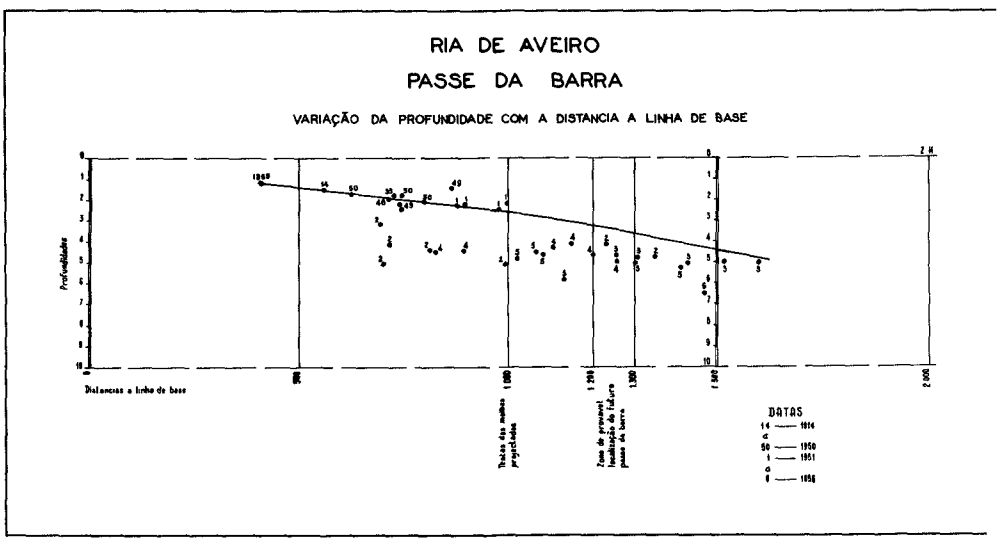


Fig. 8. Controlling depths on the outer bar (ordinates) as a function its distance to a base-line (abscissae). Envelop-curve of th minimum depths corresponding to each position of the bar-c

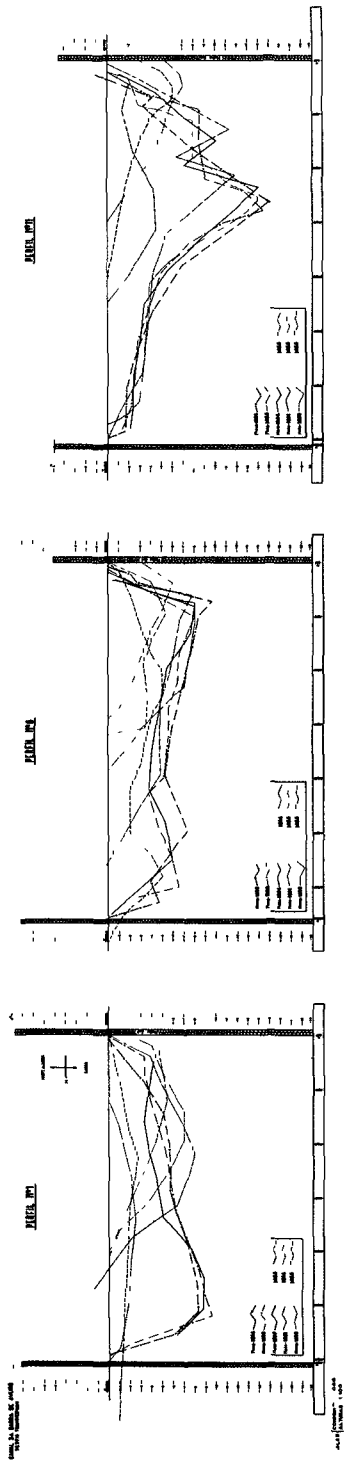


Fig. 9

Fig. 10

Fig. 11

Fig. 9 - Evolution of the inlet channel's cross sections due to the works (range nº.1)

Fig.10 - Evolution of the inlet channel's cross sections due to the works (range nº.6)

Fig.11 - Evolution of the inlet channel's cross sections due to the works (range nº.11)

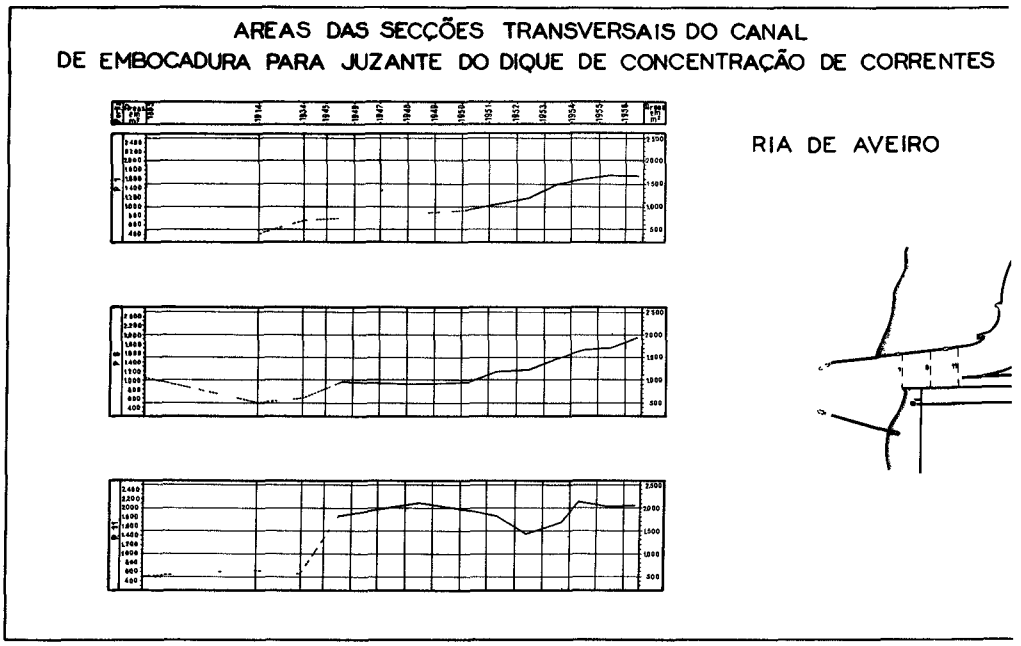


Fig. 12. Variation in the areas of cross sections at the same ranges

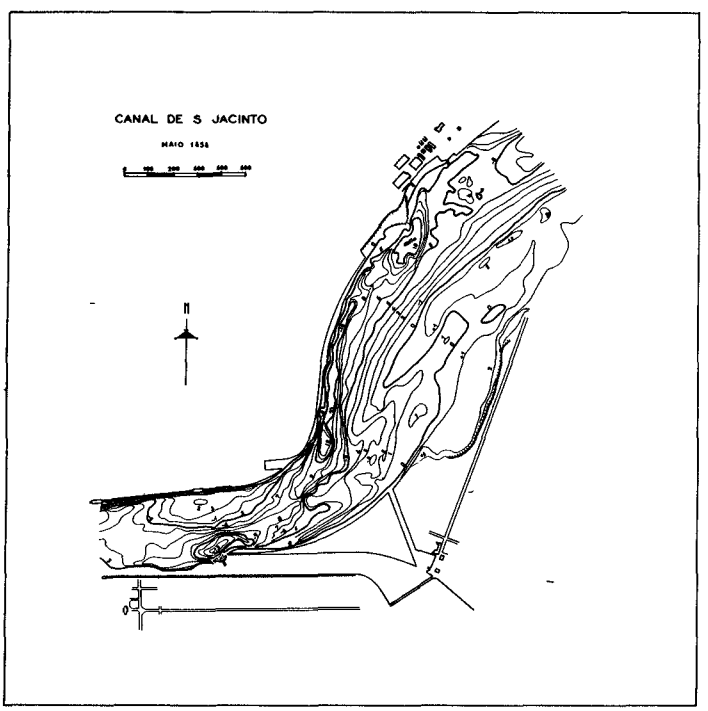


Fig. 13. Hydrographic survey of the inner channel in May 1956

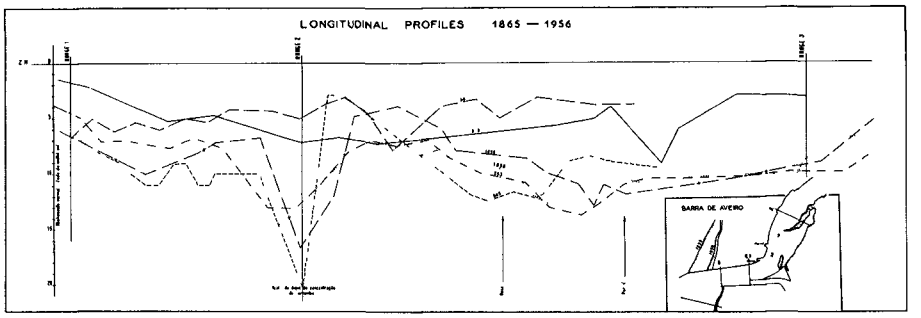


Fig. 14. Longitudinal profiles along the talweg between the inlet's mouth and S. Jacinto, from 1865 to 1956

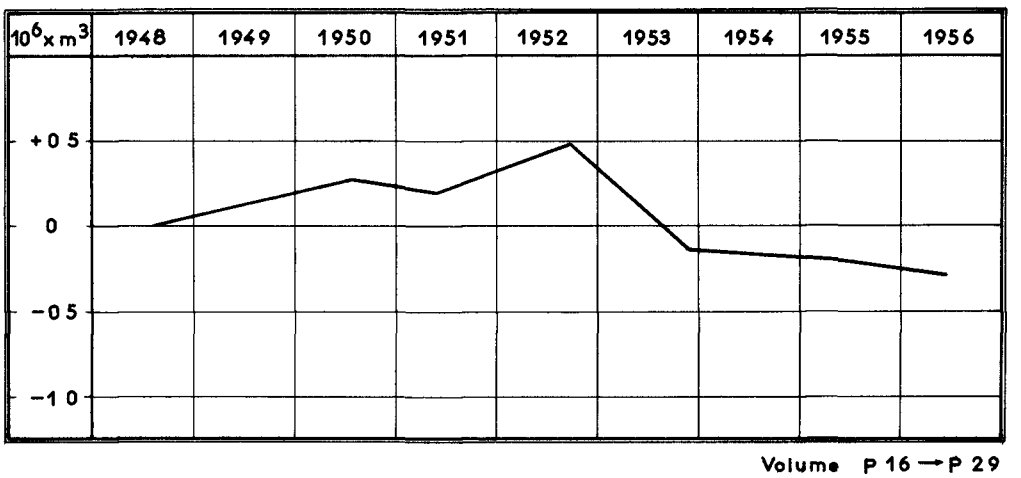
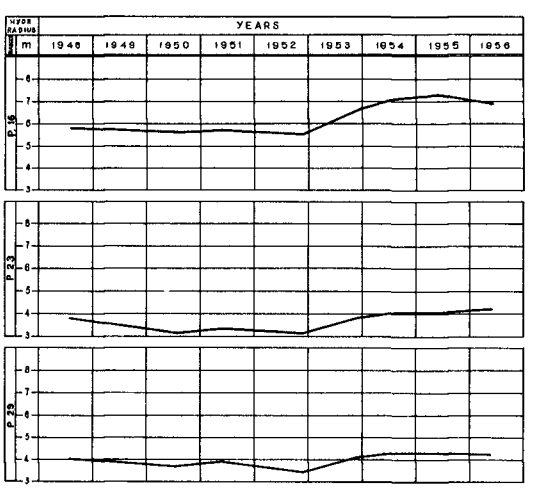


Fig. 15. Variation in the volume of sand on the inner bar from 1948 to 1956



Lagoon of Aveiro

Evolution of the inner bar's channel - Cross sections' hydraulic radius

Location of ranges

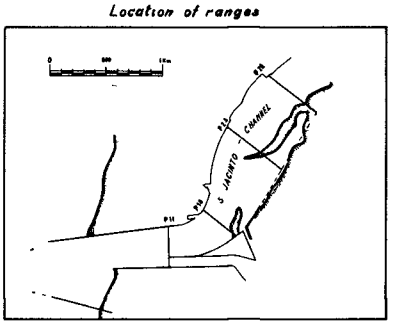


Fig. 16. Variation in the hydraulic radius of the inner channel's cross sections from 1948 to 1956

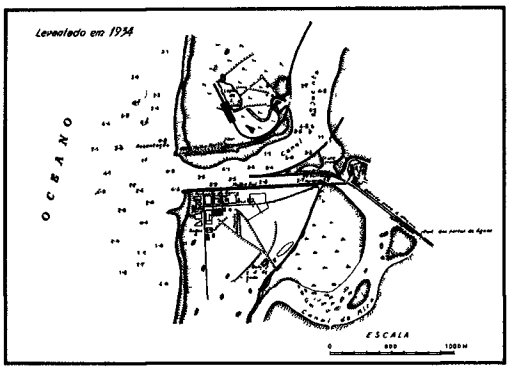


Fig. 17. The Mira inner channel lay-out

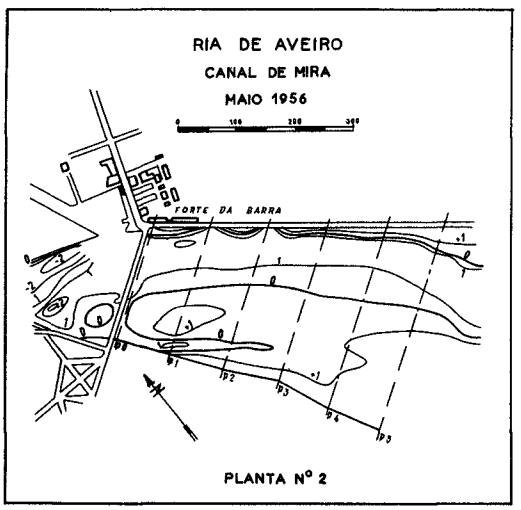


Fig. 18. The Mira channel of the Lagoon: hydrographic survey of the downstream section in 1956

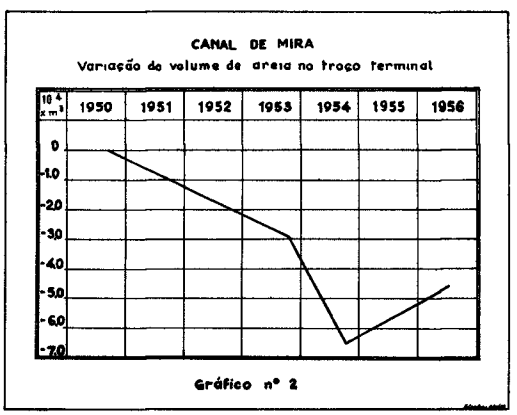


Fig. 19. Variation in the volume of sand on the same section of the Mira channel from 1950 to 1956

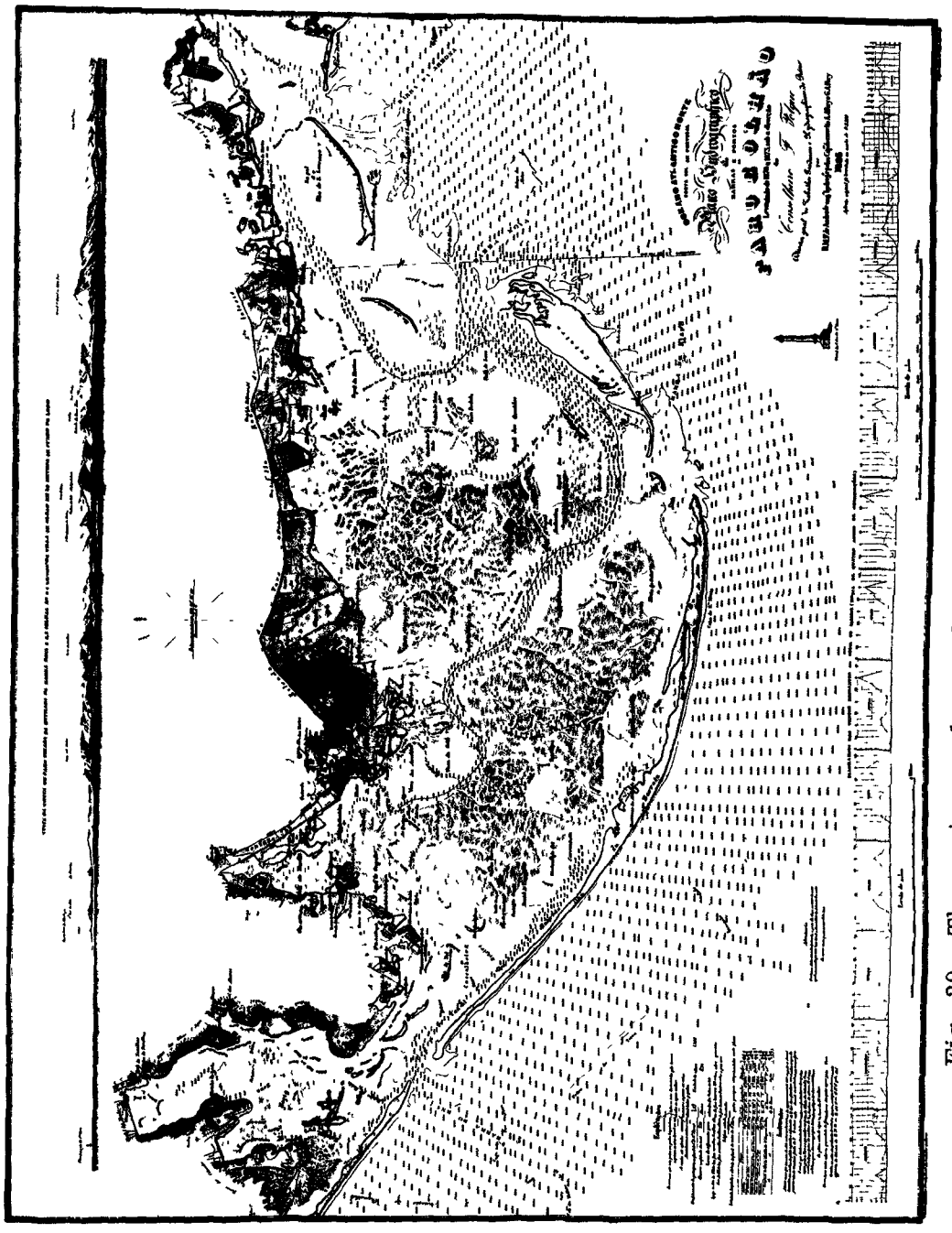


Fig. 20. The western and central part of the south coast Lagoon

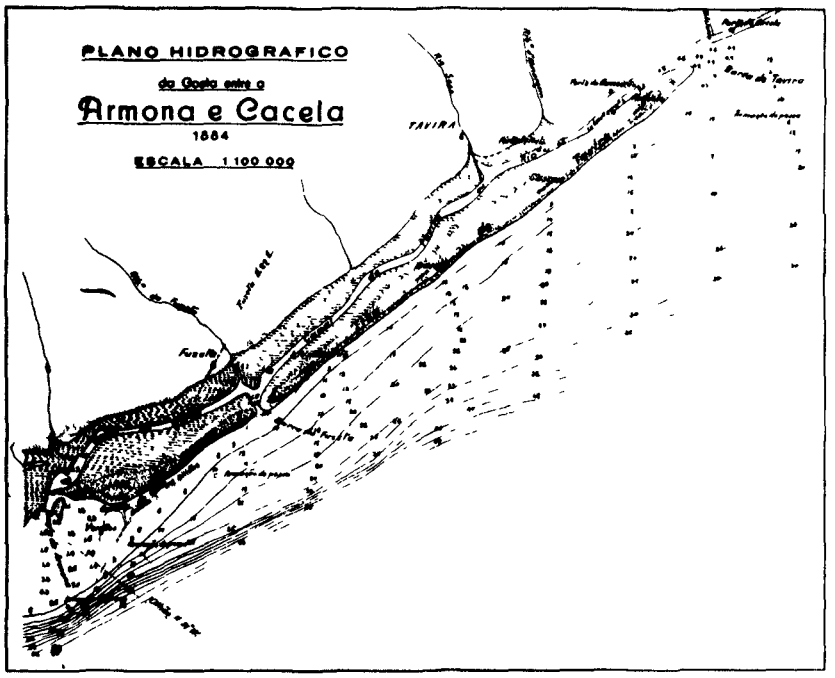


Fig. 21. The eastern part of the south coast Lagoon

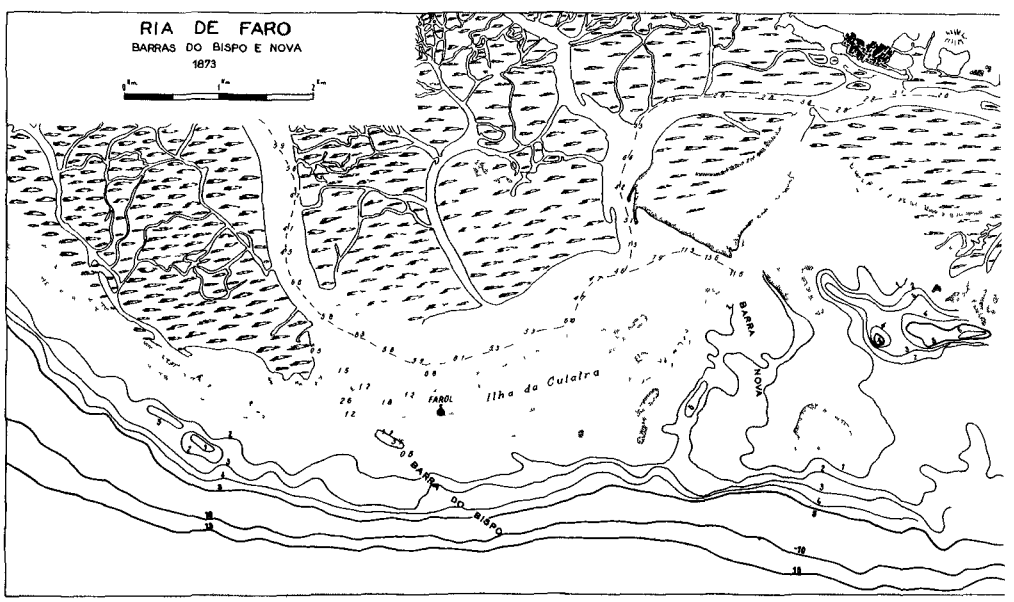


Fig. 22. The inlets of Faro - Olhao in 1873

LITTORAL DRIFT PROBLEMS IN PORTUGAL WITH SPECIAL REFERENCE TO THE BEHAVIOR OF INLETS ON SANDY BEACHES

THE LAGOON OF FARO-TAVIRA

The barrier beach limiting this lagoon extends along the whole eastern third of the country's south coast, with a length of about thirty miles. It is rather a lagoon system than a single lagoon, as there are several inlets giving access to different lagoon areas, more or less individualized, while all interconnected (see Figs, 20 and 21). These are elongated and parallel to the coast-line and in the major part relatively narrow.

Historical background of the physiography of this lagoon system has not yet been thoroughly investigated as it was in the case of the lagoon of Aveiro (C. Abecasis, 1951 and 1954). Therefore its formation is not so well understood, and is supposed to be somewhat more complex.

Nevertheless, a plausible explanation for this great accumulation of sands has been proposed and seems to be confirmed by the available data. Accordingly, the inflection of the coastline in a southeastward direction immediately to the east of Quarteira gave rise, due to the prevailing southwest winds and seas, to a massive deposition of sediments proceeding from the active erosion of shoreline to the west of it. To the east of the big projection of Cape Santa Maria, the coastline recedes and suddenly turns into a northeastward direction, with the consequence that the littoral drift, strongly pushed forward by the prevailing seas from the southwest, becomes very intense (D. Abecasis, 1926).

Behavior of the lagoon system's inlets is in agreement with this line of thought: to the west of the Cape there is only one inlet, shallow and relatively stable, while to the east, starting immediately after the Cape, there are and there have been several inlets, sometimes naturally deep but always unstable in their configuration and position, some of them fastly migrating.

We intend to deal with the cases of two inlets which in recent times were subject to improvement works: the inlet of Faro-Olhao and the inlet of Tavira, the former located near Cape Santa Maria, the latter to the far east of the lagoon.

The inlet of Faro-Olhao - The central and most important lagoon basin is situated between the towns of Faro and Olhao and the littoral sandy island or barrier beach, in the vicinity of Cape Santa Maria. Its wet area is roughly twenty square miles, including numerous marshes and the channels; its length is about eight miles and its maximum width, between the barrier beach and the mainland, approximates three miles. The Cape is just at mid-length of the basin.

This lagoon section is connected with the adjoining ones by narrow and shallow channels and with the sea by two inlets: one which was artificially opened and canalized near the Cape in 1928, and anoth one, about three miles eastward, which is called "Barra Nova", i.e. "New Inlet", a natural one (for approximate locations see Fig. 22).

It is worth to briefly review the behavior of these inlets under the acting natural agents (A. Loureiro, 1909 and D. Abecasis, 1926).

In 1861, the barrier island immediately to the east of the Cape was broken off during some storm occurring in a period of poor sediment feeding of the beach, and a narrow and deep inlet originated which was called "Barra do Bispo". Shortly afterwards, this proved to be very unstable and divided into two shoaling and moving channels, which swung across the sands of the island and migrated eastward, quickly deteriorating (see Fig. 23) and becoming completely closed by the end of the century, when the continuity of the barrier beach was re-established.

The "Barra Nova" inlet was by 1870 a wide and deep one, freely connecting with the eastern end of the main lagoon channel, where natural depths of 25 to 45 feet existed. The outer stretch of the channel points to the southwest, which is a generalized feature in this coast and is probably due to the trend of the coastal ebb-current; while the inner section is pushed to the northeast by the powerful lagoon current and the strong littoral sand drift. Those circumstances impose to the inlet channel a very defective and unstable configuration, in a long curv of small radius of curvature, across numerous shoals. Yet in the last century it was reported as a wide and fairly deep channel, but unsafe for navigation due to its instability and bent lay-out.

The subsequent free evolution of this natural inlet which for about thirty years was practically the only one connecting the main lagoon body to the ocean, as shown in Figs. 24 and 25, deserves a careful and detailed analysis by any one who may be interested in this kind of problem. For the moment, we simply want to point out that in spite of its size, of the big tidal flow circulating through and of the massive barrier of sandy islands and shoals lying down-drift, this inlet badly deteriorated and migrated eastward in the course of the years.

When, due to navigation's increased requirements and to the shoaling of the "Barra Nova" inlet, the necessity for an improved access became imperative and the impossibility of obtaining it by any natural or self-maintaining channel was evident, the argument was raised as to whether it would be advisable to artificially improve and correct the existing inlet rather than trying to establish

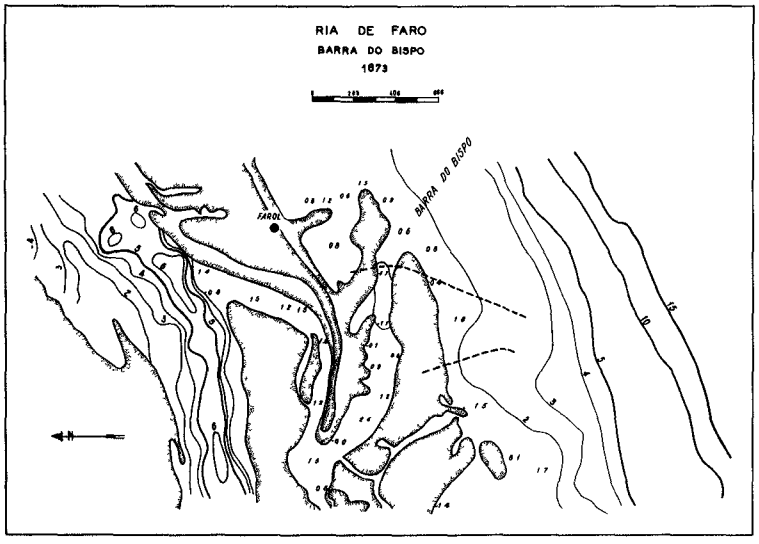


Fig. 23. The inlet of Cape Santa Maria by 1873

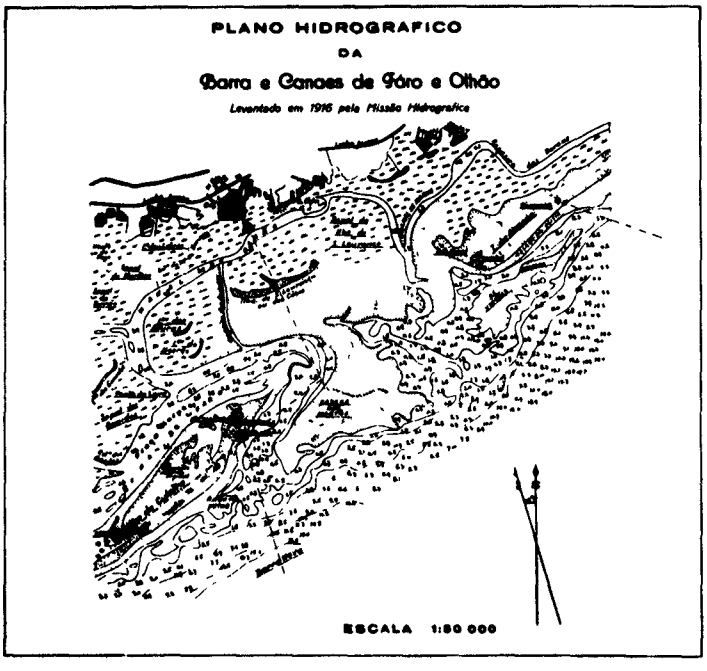


Fig. 24. The "Barra Nova" inlet in 1916

Fig. 25. The "Barra Nova" inlet in 1930

an entirely new one, and if so, as to the best location to be chosen.

The study of the local physiography which was undertaken let to the latter, based on the following reasons:

(a) It would be easy to pierce the barrier island near and to the east of Cape Santa Maria, and so to restore the ancient "Barra do Bispo" inlet, to connect it frankly with the main lagoon channel about midway between Faro and Olhao, to fix it by canalization through the barrier-beach and to direct its outer alignment in the best way concerning the circulation of the tidal flow, i.e. to SW or SSW;

(b) This site, near the projection of the Cape, would afford the occurrence of two very favorable factors as regards the self-maintenance of the new entrance channel, namely, the strength of the littoral current and the immediate proximity of the outside deep water.

(c) Should a deeper entrance channel be required, it would be easy to build a system of outer breakwaters, that wouldn't need any exaggerated length to reach the suitable depths.

Briefly, an artificial inlet so located and duly designed would be given good hydraulic conditions and the vicinity, both of the lagoon waters' center of masses and the outer deep waters.

Based on these reasonings, a scheme of works was designed and carried forward, as shown in the included hydrographic surveys. The first phase, piercing of the barrier-beach and fixing the inlet through it by means of the concave shore's revetment and the building of inner stretches of the breakwaters, was carried from 1928 to 1931. The second phase, completing of the outer stretches of breakwaters, was carried on from 1947 to 1955.

Results obtained can be seen in the hydrographic surveys (Figs. 26 to 31) and in the graphs and tables which are included and are similar to those concerning the inlet channel of Aveiro.

When comparing, it must be borne in mind that the physiographic factors' activity is much less intense in the south coast and that the lagoon tributary to the inlet of Faro-Olhao is much smaller than the lagoon of Aveiro and is connected with the ocean by another important inlet. Consequently, slower reactions and less important sediment movement are to be expected. It must also be recalled that, until now, the studies were not carried forward to the same extent as in the case of Aveiro, neither as regards the items examined nor as to the area covered.

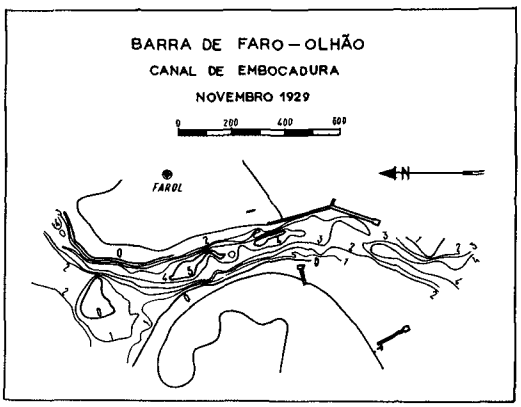


Fig. 26. November 1929

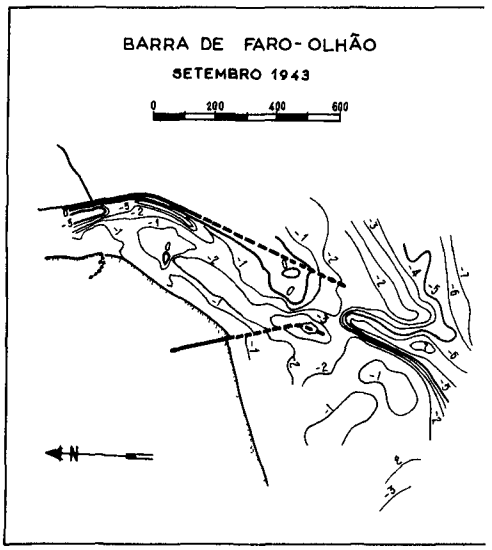


Fig. 27. September 1943

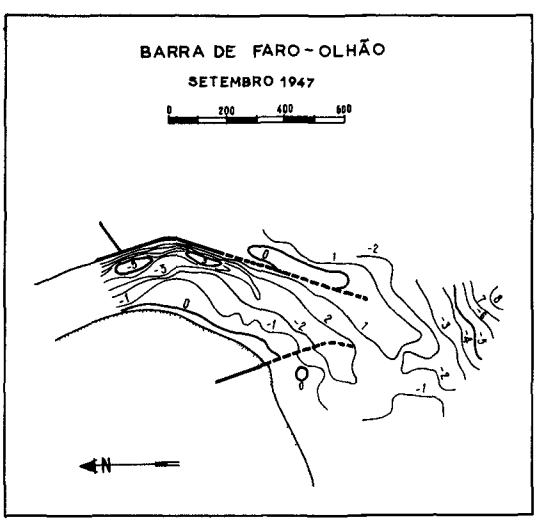


Fig. 28. September 1947

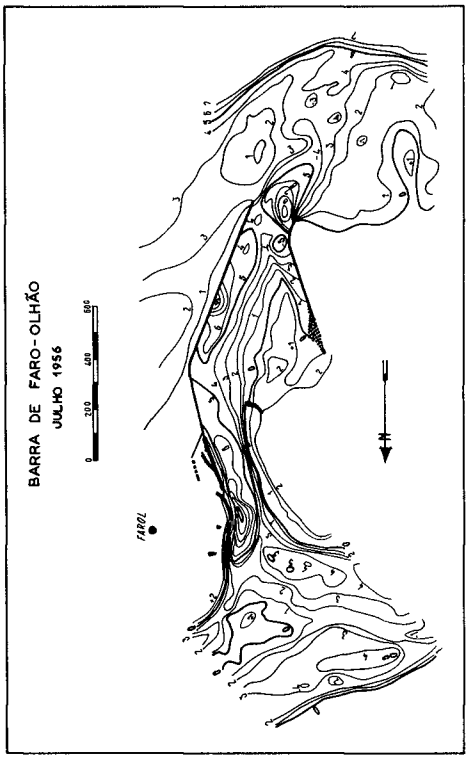


Fig. 30. August 1956

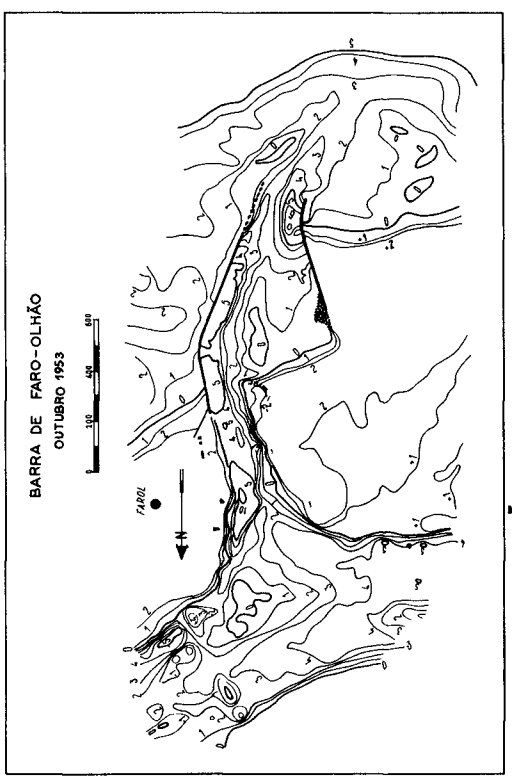


Fig. 29. October 1953

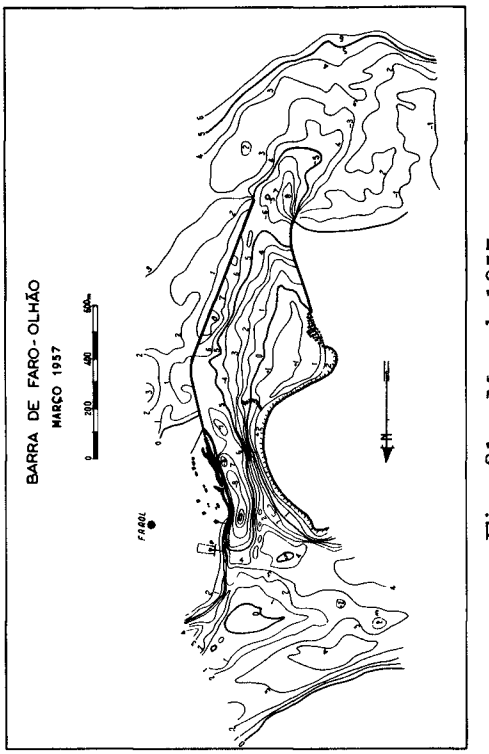


Fig. 31. March 1957

The slower reaction of the inlet to the improvement works is quite evident in the variation of the volume of sands and the controlling depths on the outer bar (see Table 6 and Fig. 32). These data also show that the meteorological influence on the volume of sands lying on the bar is of an entirely different order of magnitude than it was in the western coast's inlet. So, it is not extraordinary that the deepening of the outer bar crest was not noticed until nearing the completion of the breakwaters in 1955 (see Fig. 33). This effect was then helped by dredging in 1955-1956 some 100,000 cubic meters of sand in the outer bar and entrance channel.

But where the progressive beneficial results of the improvement works could be noticed almost step by step was in the amelioration of the hydraulic characteristics of the inlet channel as the works proceeded and in the spontaneous disappearance of the inner bar in the branch channel that leads to Faro (see Table 7 and Fig. 34 to 37). This is the best guarantee of an easier circulation of the tidal flow, whi in turn is the most efficient agent for the maintenance of depths in the entrance channel (Fig. 38).

It is also to be stressed that the absence of a sand accumulation on the updrift side of the works beyond certain limits, as well as the absence of any appreciable shoaling in the inner channel and of any systematic erosion in the down-drift beach, are good tests of the ability of the executed scheme to meet the requirements of the project. It is legitimate to infer, here again, that the littoral sands are transposing the inlet and not retained by it.

The inlet of Tavira. This inlet connects the far east section of the southern coast's lagoon system with the ocean. This section of the lagoon, which lies eastward of Olhao, is composed of a single channel with adjoining marshes and extends for about 17 miles parallel to the sea coast of the barrier-islands and to the shore of the mainland.

By 1884, the ancient inlet of Tavira, formerly situated just opposite the town and the lagoon outlet of the river crossing it, had migrated eastward for more than five miles, under the strong push of the littoral sand drift. By the end of the century, this migration had progressed for some additional 2.5 miles and the inlet reached the end of the lagoon, where it quickly shoaled. Some time later, a new inlet was opened by a storm, about one mile to the west, which took a curved configuration similar to the above-mentioned "Barra Nova" inlet and stood for years (see Fig. 39).

Later on, the deterioration of this natural inlet and the necessity of meeting the navigation requirements, specially of the important fishing activities, gave rise to the project of artificially restoring the

Table 6

Changes in the volume of sand on the outer bar of Faro-Olhao

Date of surveys		Changes with reference to 1946(c.m.)	Changes with reference to the preceding survey (c.m.)	
Month	Year		Deposition	Erosion
XII	1946	-	-	-
III	1947	101.515	101.515	-
IX	1947	152.990	51.475	-
X	1948	11.990	-	141.000
V	1949	223.525	211.535	-
XII	1949	48.530	-	174.995
IV	1950	78.490	29.960	-
VI	1950	214.970	136.480	-
VII	1950	201.810	-	13.160
IV	1951	193.710	-	8.100
VII	1951	183.875	-	9.835
III	1952	178.785	-	5.090
III	1953	35.829	-	142.956
X	1953	179.910	144.081	-
III	1954	189.950	10.040	-
V	1954	309.190	119.240	-
VII	1954	253.825	-	55.365
VIII	1954	212.885	-	40.940
IX	1954	218.200	5.315	-
IX	1954	235.100	16.900	-
XI	1954	169.255	-	65.845
II	1955	136.060	-	33.195
VI	1955	74.030	-	62.030
II	1956	4.985	-	69.045
VII	1956	41.895	36.910	-

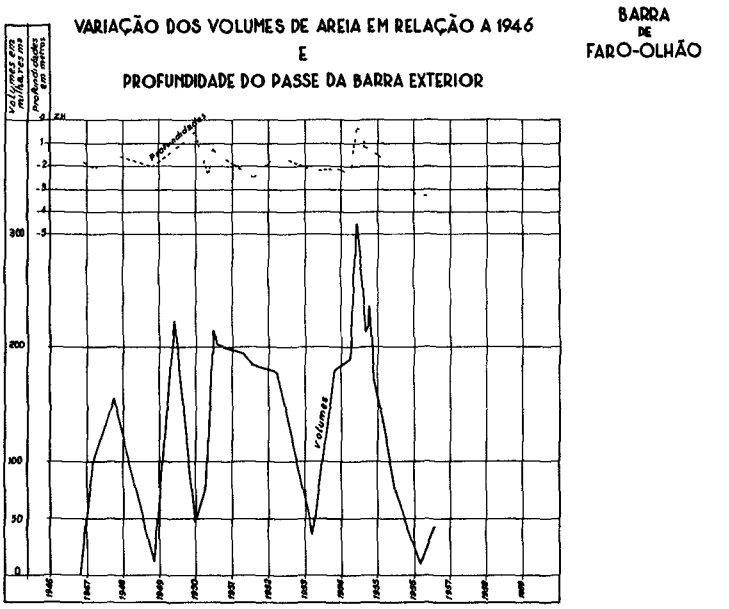


Fig. 32. Variation in the volume of sands and controlling depths on the outer-bar of the Faro-Olhao inlet

Table 7 (Part A)
Lagoon of Faro-Olhao (1929-1945)
Hydraulic elements of the inlet's cross sections

Dates	X-1929			VII-1932			VI-1933			VII-1938			VII-1942			VIII-1945		
Range number	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m
0																		
1																		
2																		
3																		
4																		
5																404	270	1,50
6													393	290	1,35	404	278	1,45
7													424	266	1,59	346	239	1,45
8				177	140	1,26							519	248	2,09	300	202	1,49
9				215	129	1,67	344	163	2,11				503	255	1,97	309	192	1,61
10				283	120	2,36	346	175	1,98				510	225	2,27	314	167	1,88
11				217	127	1,71	350	165	2,12	446	238	1,87	348	243	1,43	366	160	2,29
12				277	178	1,56	383	166	2,31	479	229	2,16	476	235	2,03			
13				285	141	2,02	426	178	2,39	439	202	2,17	410	223	1,84			
14				255	168	1,52	418	175	3,39	400	175	2,29	416	216	1,93			
15				298	175	1,70	413	185	2,23	362	165	2,19	429	201	2,13			
16	415	170	2,44	337	152	2,22	464	167	2,78	377	140	2,69	425	186	2,28			
17	365	150	2,43	325	160	2,03	466	137	3,40	458	115	3,98	538	175	3,07			
18	377	118	3,19	409	99	4,13	483	118	4,09	417	95	4,39	383	157	2,44			
19	321	118	2,72	428	125	3,42	571	135	4,23	561	150	3,74	400	152	2,63			
20	432	125	3,46	489	145	3,47	446	124	3,60	473	135	3,50	402	152	2,64			
21	356	130	2,74	414	140	2,96	375	145	2,59	496	159	3,12	527	145	3,63			
22	488	144	3,39	461	142	3,25	383	130	2,95	418	155	2,70	544	145	3,75			
23	437	155	2,82	362	162	2,23	420	145	2,89	576	177	3,25	624	158	3,95			
24	509	140	3,64	435	155	2,81	493	149	3,31	561	160	3,51	670	150	4,47			
25	514	135	3,81	529	140	3,78	627	165	3,80	704	152	4,63	696	134	5,19			
26	516	133	3,88	468	140	3,34	539	126	4,28				649	187	3,47			
27	523	148	3,53	410	153	2,68	537	160	3,36				561	202	2,78			
28	498	240	2,08	399	220	1,81	603	240	2,51				365	155	2,35			
29	583	304	1,92	402	295	1,36	606	295	2,05				581	298	3,03			

Table 7 (Part B)
Lagoon of Faro-Olhao (1947-1956)
Hydraulic elements of the inlet's cross sections

Dates	IX-1947			VII-1950			X-1953			VII-1954			VII-1956		
Range number	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m
0							530	150	3,53	803	155	5,18	895	157	5,15
1				307	156	1,97	581	150	3,87	704	152	4,53	630	150	4,20
2				308	189	2,05	717	192	3,74	810	182	4,45	831	185	4,49
3				431	224	1,92	830	235	3,53	1050	226	4,65	794	220	3,61
4				518	274	1,89	814	266	3,06	1043	265	3,93	786	264	2,97
5	393	272	1,44	474	273	1,74	780	315	2,48	964	315	3,06	745	256	2,91
6	380	247	1,54	464	263	1,76	751	355	2,11	880	355	2,48	645	196	3,29
7	405	246	1,65	470	286	1,64	665	402	1,63	889	395	2,25	670	230	2,91
8	397	260	1,53	425	280	1,52	636	390	1,63	828	394	2,10	716	257	2,78
9	425	265	1,60	356	305	1,17	725	480	1,51	806	435	1,85	699	220	3,18
10	399	240	1,66	329	245	1,34	729	470	1,55	569	330	1,72	702	328	2,14
11	459	235	1,95	305	218	1,41	617	368	1,68	708	306	2,31	680	220	3,09
12	521	248	2,10	381	205	1,86	563	312	1,80	689	263	2,62	659	245	2,69
13	554	285	1,91	471	260	1,81	615	263	2,34	734	253	2,90	693	240	2,89
14	560	225	2,49	614	255	2,41	629	317	1,98	754	232	3,25	739	214	3,45
15	521	202	2,58	604	275	2,20	648	298	2,17	720	218	3,30	721	208	3,47
16	510	199	2,56	526	253	2,08	687	256	2,68	738	245	3,01	716	201	3,56
17	575	202	2,85	469	265	1,77	569	140	4,06	875	248	3,53	709	191	3,78
18	521	170	3,06	487	175	2,78	534	152	3,51	717	180	3,98	679	180	3,77
19				521	160	3,26	431	147	2,93	711	165	4,31	740	165	4,48
20							508	166	3,06	629	150	4,19	700	154	4,54
21							412	150	2,75	636	150	4,24	714	140	5,10
22							499	172	2,90	730	172	4,24	717	165	4,35
23							543	160	3,39	727	165	4,41	770	170	4,53
24							630	168	3,75	827	183	4,52	721	180	4,00
25							728	180	4,04	887	180	4,93	911	175	5,20
26							924	200	4,62	910	205	4,44	956	200	4,28
27							880	260	3,38	915	253	3,62	1073	272	3,94
28							822	300	2,74	949	298	3,18	989	293	3,37
29							945	358	2,64	1240	355	3,49	1091	345	3,16

a) area; p) wetted perimeter; $p = \frac{a}{P}$ = Hydraulic radius Sections under datum

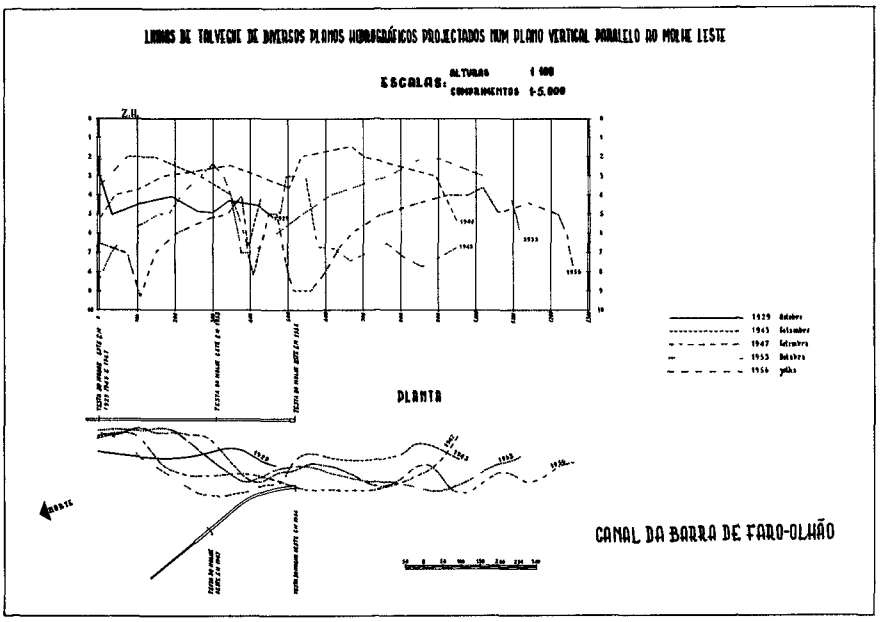


Fig. 33. Inlet of Faro-Olhao: longitudinal profiles of the entrance channel projected on a vertical plane parallel to the outer stretch of the east breakwater

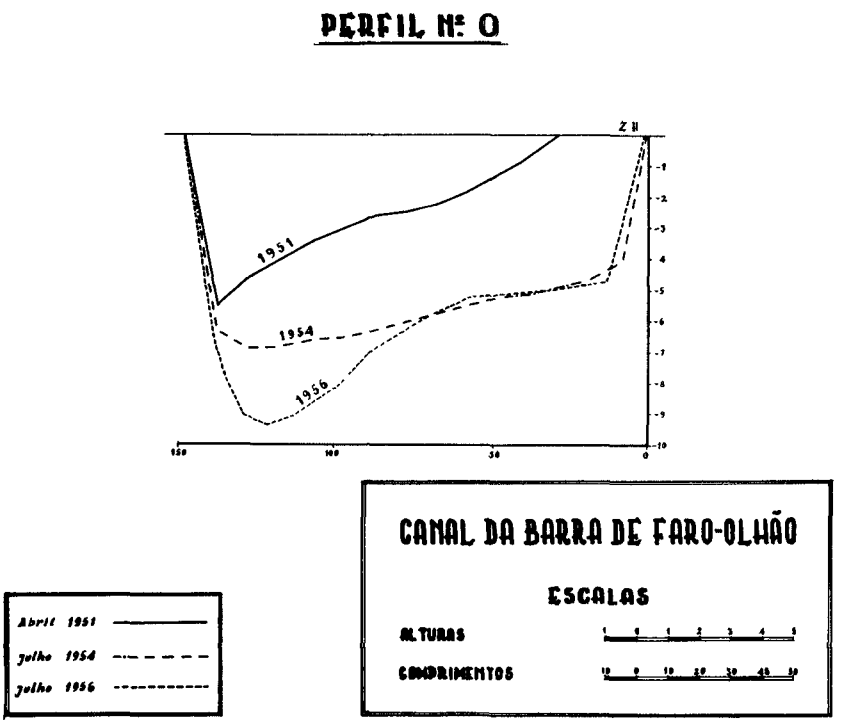


Fig. 34. Evolution of the inlet channel's cross sections due to the works (range No. 0)

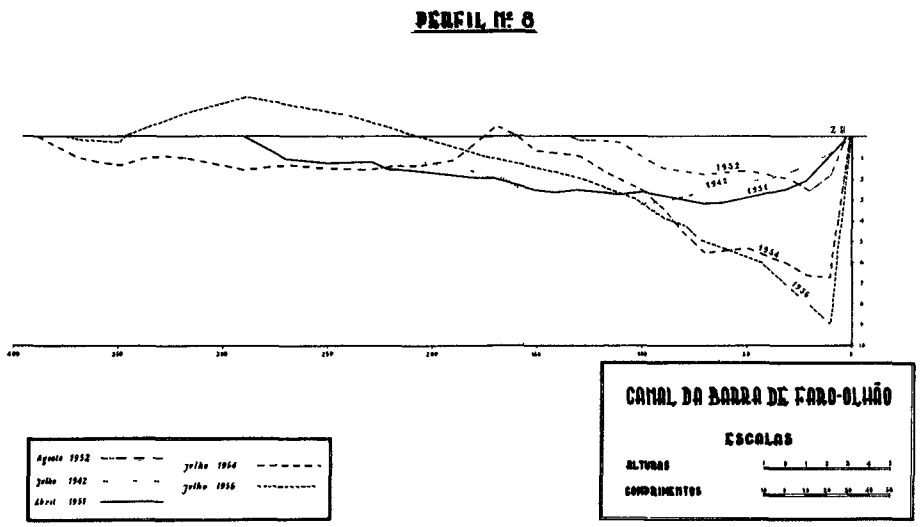


Fig. 35. Evolution of the inlet channel's cross sections due to the works (range No. 8)

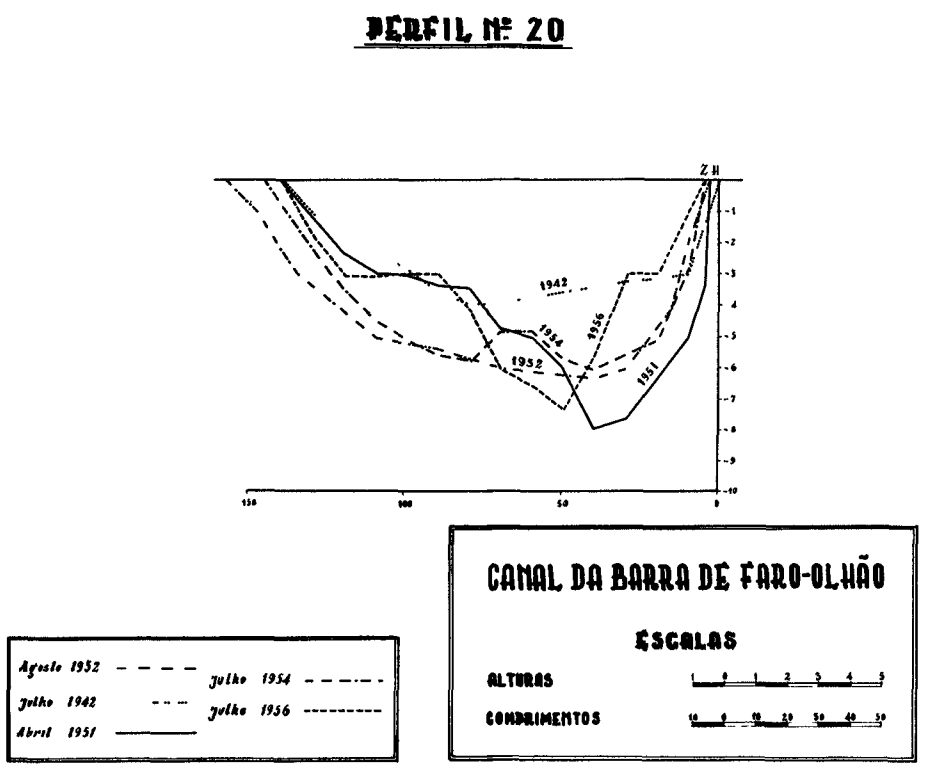


Fig. 36. Evolution of the inlet channel's cross sections due to the works (range No. 20)

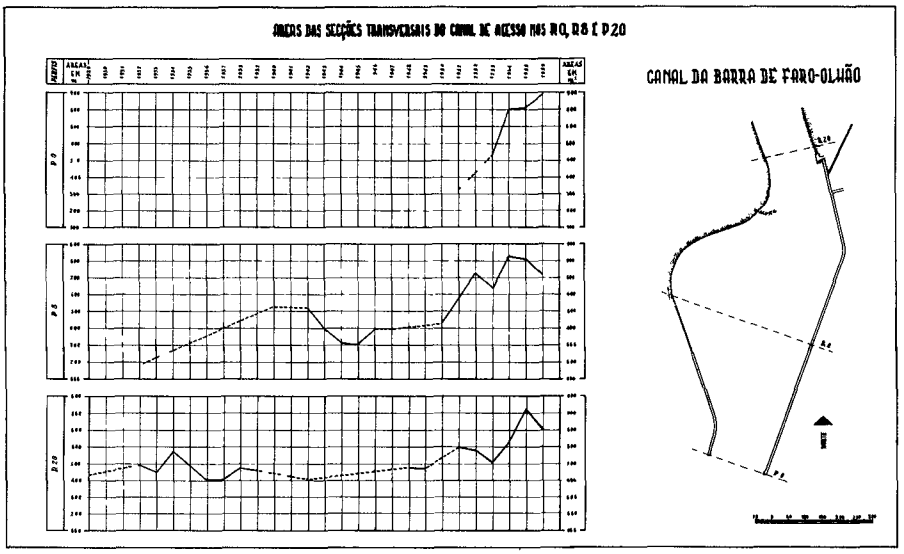


Fig. 37. Areas of inlet's cross sections

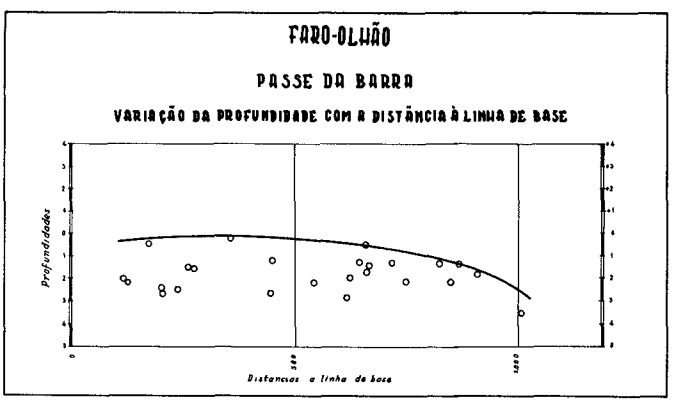


Fig. 38. Controlling depths on the outer bar of Faro-Olhao as a function of its distance to a base line

Fig. 39. Tavira inlet's hydrographic survey in 1916

ancient Tavira inlet, by piercing the barrier-beach near the town.

In fact, this was undertaken by 1927 and the artificial inlet, lyir to the SE of the Tavira's river lagoon outlet was canalized by means of two stone and concrete shore revetments across the barrier island, the eastern jetty being carried seaward for a length of about 700 feet, after wards lengthened by 250 feet more.

The 1936, 1942, 1944 and 1956 hydrographic surveys herein pre sented show what results were obtained by the initial works and the additional amendments (see Figs. 40 to 43).

Fundamentally, the works failed because they were not planned so as to obtain the transposition of the inlet by the moving littoral sands, with the less possible interference with the coastal regimen. The outer east breakwater was in fact a sand-trap in the way of the littoral drift, making a bigger amount of sand to enter the lagoon than the ebb current, although guided by it, was able to expel. Moreover, the original project contemplated a regular dredging to maintain the depths and the establishment and maintenance of an outer sand-pit, to protect the inlet against the invasion of the littoral sands. Certainly because the entrance channel itself did not shoal and the dredging was not cheap, neither item was implemented, and groynes were instead built on the west side ocean beach to prevent the littoral sands from reaching the inlet, and so to reduce the shoaling inside the lagoon. But the feeding of the barrier-beach to the east of the inlet was concurrently and substantially reduced, with the result that in 1941, during a big storm, a new inlet was opened opposite the mouth of river Almargem, due to the joint action of the river flood and the ocean waves on a weakened section of the barrier-island. In some years, the new inlet, through which the tide started to circulate, widened to hundreds of meters, due to the local destruction of the barrier-beach, and the artificial one, progressively deprived of the tidal flow and invaded by the littoral sands, completely closed.

The essential misconceptions seem to have been the obstacles raised in the way of the littoral sands, i.e., the outer eastern breakwater and specially the groynes to the west of the inlet, while the location of this one could also be a matter of argument as to the advantages of moving it a little more to the west. The elected location, based on economic grounds, does not seem to have been able to meet the modest requirements contemplated, nor its displacement to the west would have prevented the consequences of the formerly mentionec misconceptions. These, of course, could have been avoided if the port was rich enough to pay for a strong and extensive protection of the barrier beach to the east side of the inlet.

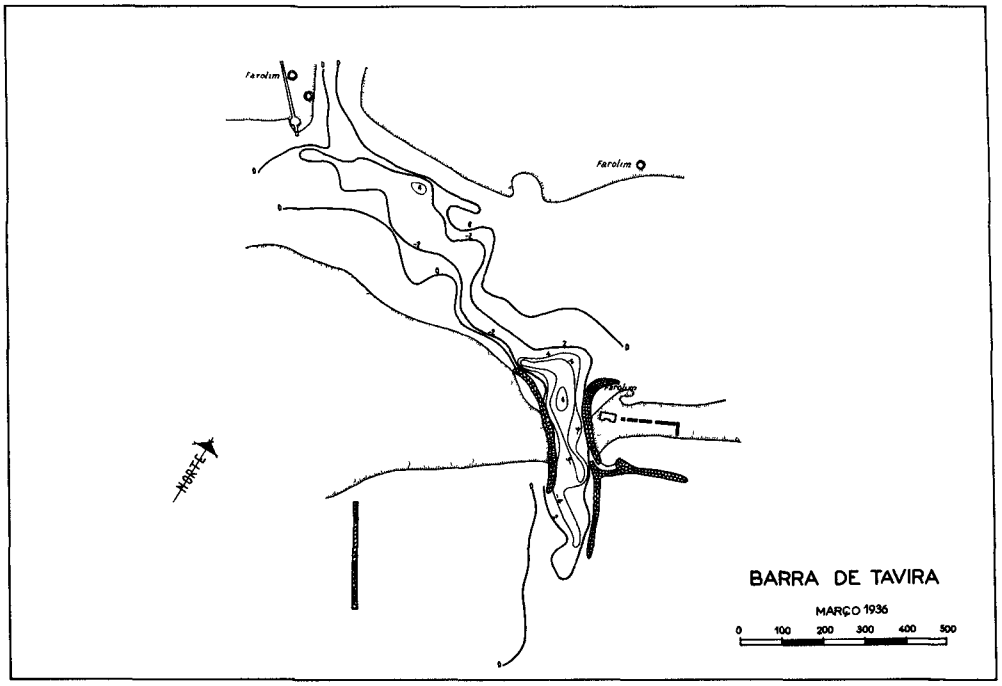


Fig. 40. Tavira inlet's hydrographic survey in March 1936

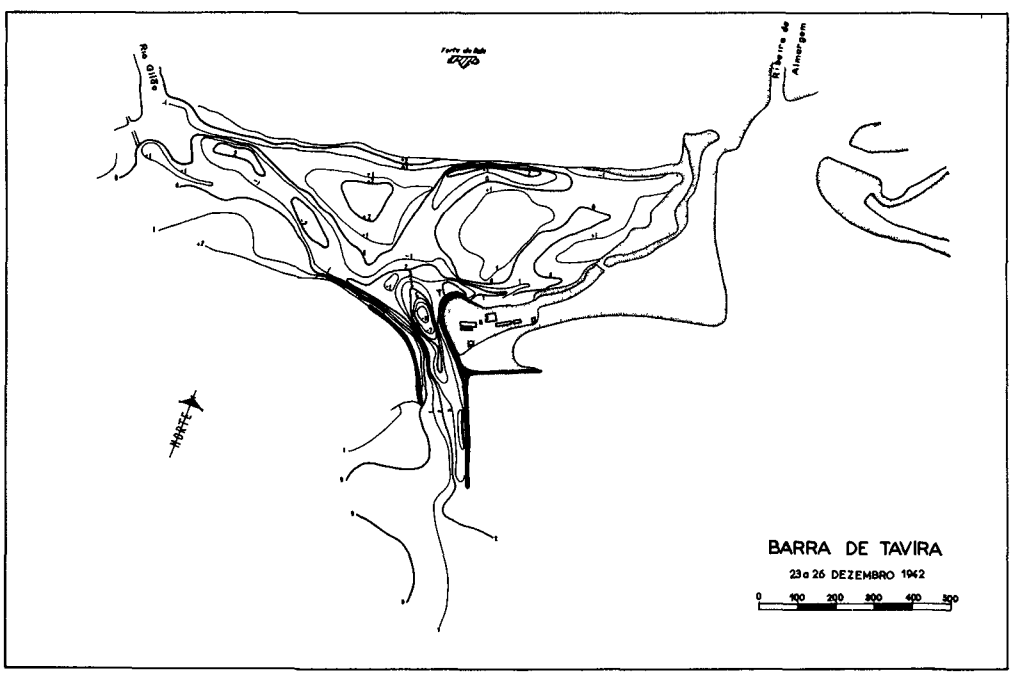


Fig. 41. Tavira inlet's hydrographic survey in December 1942

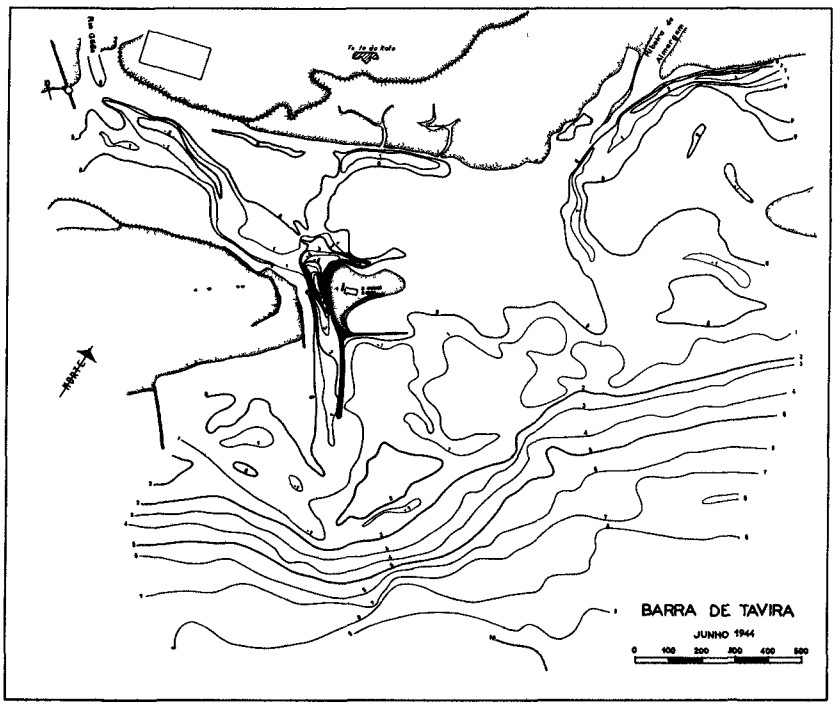


Fig. 42. Tavira inlet's hydrographic survey in July 1944

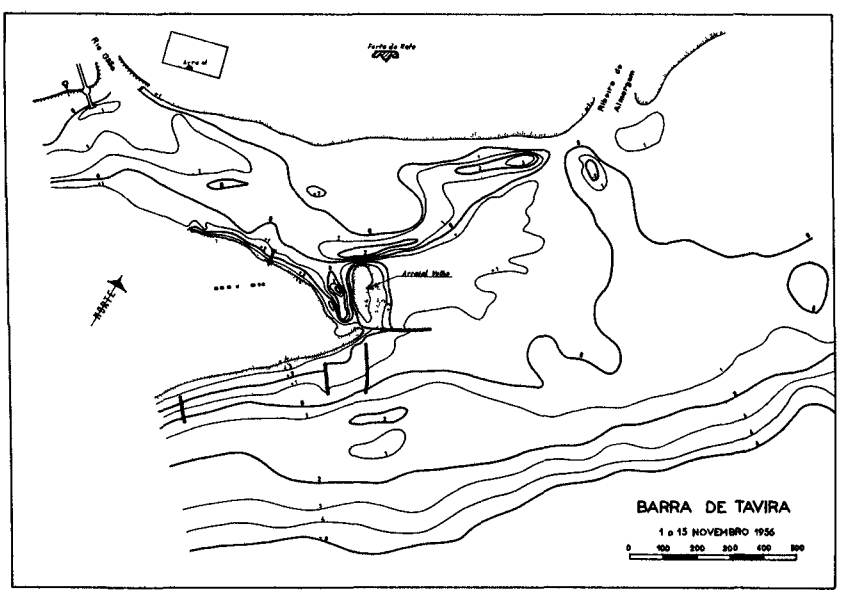


Fig. 43. Tavira inlet's hydrographic survey in November 1956

This specific case shows that the real test on the soundness of an inlet improvement scheme is not the depth on the entrance channel, but the variation of the volume of sand both on the inner bar and on the down-drift section of the coast. If the former increases and the latter decreases systematically, failure of the scheme is real, while it can be masked if there is enough money available for the purpose.

THE IMPROVEMENT OF LAGOON INLETS

In our opinion, consideration of the above-mentioned examples, together with the free evolution of a number of natural inlets on sand coasts, legitimates the inference of some principles valid in the treatment of these physiographic entities for navigation or drainage purposes. But, to prevent any misinterpretation of what has been stated, we want to stress the point that none of the herein referred successful cases is to be considered a completely solved problem, as far as taking full advantage of the lagoon-and-inlet system's potentialities for the improvement of the entrance channel is concerned: next step will probably be the correction of the hydraulic flow conditions in the inner approaches to the inlet channel.

We have had the opportunity of pointing out the fundamental differences between the suitable methods for dealing with the improvement of estuaries and those adequate to improve the lagoon entrance channels (C. Abecasis, 1954). It is enough to say that the additional data now presented solidly confirm our previous statement, so that the coastal engineer must be extremely cautious whenever he feels tempted to make use of similarity methods to solve any particular problem on lagoons' accesses by referring to the sanctioned and successful practices adhered to in estuaries' knowledge.

For the effective improvement of an inlet on a sandy coast, it seems essential, under the physiographical point of view:

(a) to increase as much as possible the relation of the volume of the tidal flow through the inlet to the volume of sands carried by the littoral drift;

(b) to interfere the less possible with the littoral drift existing along the barrier-beach, looking at that the volume of sand expelled out by the ebb be not less than that brought in by the flood tide.

Needless to say, those conditions are to a certain extent interconnected, but any of them may be more or less fulfilled in a given case. The former requires to improve as far as possible the hydraulic characteristics of the inlet channel and depends on the space available in the

lagoon and the conditions prevailing along the main lagoon channels as regards the propagation of the tide; it can hardly, if ever, be performed without the canalization of the inlet channel across the barrier-beach. The latter requires a well designed and balanced canalization or protection scheme, allowing the littoral sands to reach the inlet and to follow their way downcoast, either entering the inlet or not; sometimes, dredging or canalization works may be needed in the lagoon are adjacent to the upstream section of the inlet channel to help in getting this result.

Analysis of the inner bar's and of the leeward beach's behavior as regards accretion or erosion is the best way to check the soundness or successfulness of any inlet improvement work being or having been executed.

As practical rules for performing the above stated conditions, we advised elsewhere and now confirm that:

i. the inlet should be located as close as possible to the center of masses of the waters in the lagoon and to the biggest depths outside;

ii. the inlet should be canalized through the barrier-beach and when necessary on account of the required depths and/or on account of the volume of littoral drift, the currents from the different lagoon bodies should be harmonized and so guided to the inlet channel;

iii. the outer bar should be situated as far out in the sea as required for obtaining the depths wanted, which must be obtained by means of jetties, those being preferably slightly convergent whenever they must go beyond the previous shoreline.

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