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A short review of the petroleum prospects of Portugal

with 3 figs and 5 tabs

by DANILO A. RIGASSI*

Résumé

L'origine des bassins sédimentaires portugais est liée à l'ouverture et à l'évolution de l'Atlantique. Ces bassins, en grande partie libres de droits miniers, totalisent 44'500 km². Leurs épaisses séries sédimentaires (Trias-Pliocène) contiennent des roches-mères, des réservoirs carbonatés et clastiques, et une série de pièges structuraux, stratigraphiques et lithologiques. Les indices sont nombreux, en surface et dans les forages, mais, à ce jour, aucun gisement exploitable n'a été trouvé. Bien que des forages aient été entrepris dès le début du siècle, leur densité reste faible: un forage par 725 km², moins de 5 m forés par km². Cette faible densité, une géologie attrayante, et un environnement légal, fiscal et économico-politique favorable justifient une rapide et intense reprise de l'exploration.

Abstract

The origin of the Portuguese sedimentary basins is related with the opening and evolutin of the Atlantic. The basins cover an area of 44,500 sq km, for the most open. The thick sedimentary sequences (Triassic-Pliocene) contain source rocks and both carbonate and clastic reservoirs, and exhibit a variety of structural, stratigraphic and lithologic traps. There are numerous surface and subsurface shows, but no commercial hydrocarbons have as yet been found. Inspite of drilling having been started in the early part of this century, the density of wells is low — one well per 725 sq km, less than 5 m drilled per sq km. This, together with the attractive geology and a favorable legal, taxation, and economico-political environment, makes it advisable to quickly and actively resume exploration.

Overall geological setting

Metamorphics of Precambrian-Carboniferous age that were thrusted and intruded by granites during the Hercynian orogeny crop out on more than 70% of Portugal. They constitute the southwestern part of the Hesperian Massif. In the southwesternmost part of this Massif, the South Portugal Zone exposes Late Devonian-Middle Carboniferous slates and quartzites considered as overmature (reflectance above 1.5% according to Shell, 1977). Howerer, since the degree of maturation seems to decrease towards the SW, one may not exclude the possibility of underthrusted prospective Devonian-Carboniferous being present beneath the southwesterly thrusted South Portugal Zone. Late Paleozoics occur within three very narrow, highly tectonized belts. In the Douro belt, extending NW-SE from north of Porto to northeast of Viseu, the fluvial-lacustrine beds of Westphalian C-D and Stephanian C age contain some workable coal seams of meta-anthracite rank (LEMOS DE SOUSA, 1983). A small occurrence near

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Santa Susana, 75 km SE of Lisbon, is of Westphalian D age, the beds exhibiting a reflectance of 1.5% (Shell, 1977). In the Buçaco-Vale da Mo region near Coimbra, conglomerates and grey shales of latest Stephanian C to Autunian age are within the oil window (Ro 0.8 to 0.95%) but are believed to only have gas-generating potential (Shell, 1977). In places, the economic basement of the Hesperian Massif is covered by thin non-marine late Cretaceous-Tertiary sediments deposited within small troughs controlled by NE-SW and WNW-ESE faults.

The prospective sedimentary areas of Portugal correspond to various basins of Triassic-Tertiary age, of which the origin can be traced back to the early Atlantic opening. The further, spasmodic evolution of these basins was governed by successive events: the separation of Africa from Europe and America, the separation of Iberia, and the Pyrenaean (Laramian) and Alpine compressive phases. There are four main sedimentary basins from N to S: the Galician basin, entirely located offshore for the most in Spanish waters, the Lusitanian basin, the Tagus-Sado Tertiary basin of which the western part overlaps Lusitanian Mesozoics, and the Algarve basin.

Based on reconstructions showing the relationship of Africa, America, Iberia and N. Europe-Greenland prior to the main drifting phases, one can compare the Portuguese basins with other, hydrocarbonprone basins. Thus, the as yet little known Galician basin seems to exhibit similarities with both the Cantabrian-Aquitaine basins and with the Labrador basin, and the geological history of the Lusitanian basin is much alike that of the Grand Banks basins (in particular of the Jeanne d'Arc basin). The Mesozoic sequence of Algarve ressembles that of the Subbetic and Prebetic zones of southern Spain, as well as that found off Morocco, whereas analogies with some Canadian basins (Abenaki, Laurentian und S. Whale basins) are less conspicuous. Table A shows the areas of the various prospective Portuguese basins.

Basin:	land	offshore 0-200m	offshore 200-1000m	Total	
Gallician*	----	2,600	4,700	7,300	km^2
Lusitanian	13,000	11,500	---	24,500	
Tagus-Sado**	8,300	900	---	9,200	
Algarve*	1,700	3,250	5,800	10,750	
	16,500	17,500	10,500	44,500	km^2

*) Portuguese sector only

**) Patially overlaps Lusitanian basin

Table A - Area of prospective Portuguese basins

Lusitanian basin

Near Vale de Boi, some 24 km N of Coimbra, conglomerates and red shales up to 700 m thick apparently are unconformable on the Autunian Vale da Mo formation and beneath the Conraria formation (RIGASSI, 1973). This unnamed non-fossiliferous formation might be of either Late Permian or Early Triassic age. Table B summarizes the stratigraphy of the partially dated basal Mesozoic. The Silves series is made up of coarse clastics and of finer lithologies. Megafloras and palynomorphs (CHOFFAT, 1894, TEIXEIRA, 1948, PALAIN, 1976) indicate the middle part of the Conraria formation (beds C3 and C5-C7 of CHOFFAT, lower half of PALAIN's unit A2) to be of Keuper, pre-Rhaetic age. Faunal and floral evidence shows the Pereiros formation to belong to the Sinemurian and the Coimbra dolomite to the Hettangian. The lower part of the Conraria formation mainly was deposited by seasonal wadis, while its upper part, with abundant salt-pseudomorphs, indicates a sabkha environment. Flood-plain and playa conditions prevailed during deposition of the Castelo Viegas formation, and the Pereiros formation testifies of more and more frequent logoonal-shallow marine inundations. The correlation of exposures along the eastern edge of the basin with diapirs and subsurface exposures in its center suggests a rapid passage from the Silves clastics to Dagorda evaporite. Most existing publications and reports consider the Dagorda evaportie as being the lateral equivalent of the Pereiros formation. Howerer, palynological assemblages from red shale with thin dolomite directly overlying the gypsum, 1 km S of Leiria and 1.2 km NNE of Sesimbra, with *Patinatisporites densus, Paracirculina tenebrosa,* various species of *Triadispora,* etc., indicate for the evaporite a Norian or

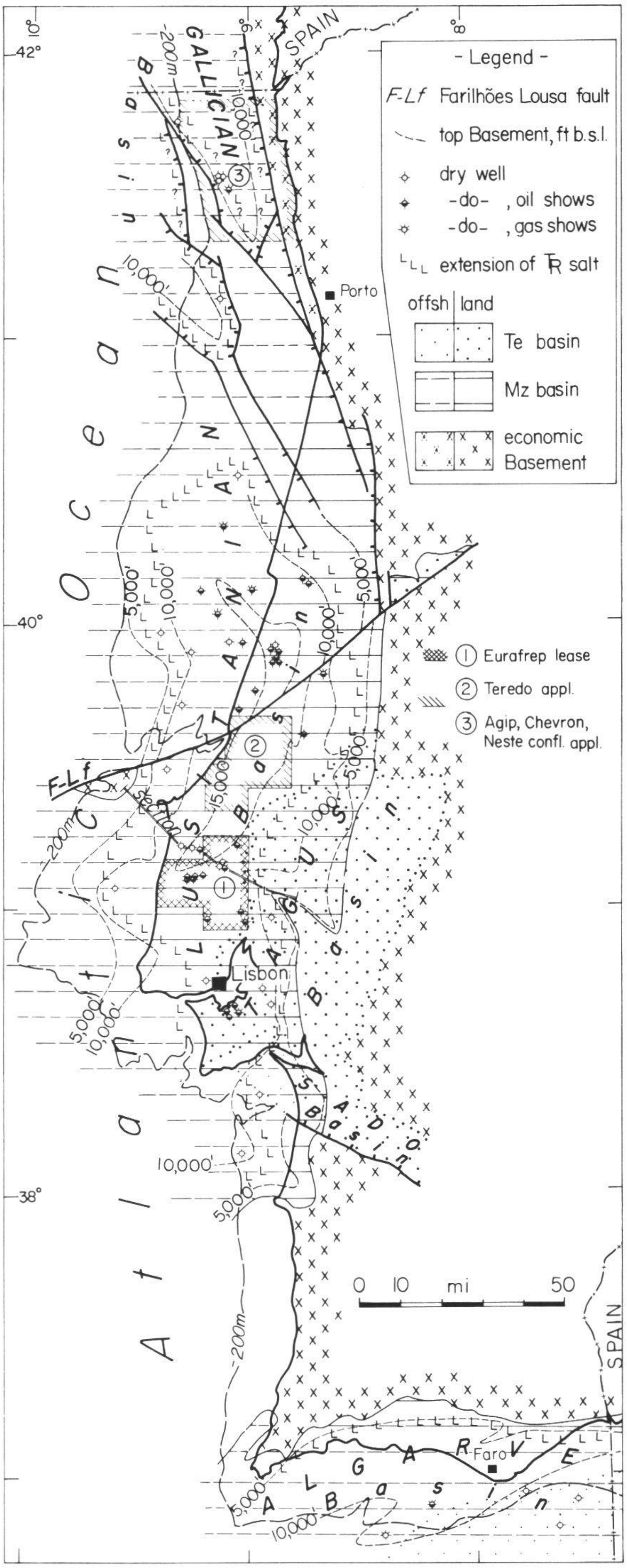

Figure 1 - Map of the sedimentary basins of Portugal.

	CHOFFAT, 1894,1903			SOARES DE C. 1950	PALAIN 1976	THIS PAPER		
	Couches de Coîmbre		dol,ls			Coimbra dolomite		Sinemuri
	Couches de Pereiros		dol,sh	Camadas de Pereiros	C2	Pereiros formation		Hettangi
			ss,sh,dol		C1			--?------
			shy ls		B2			
Grès de Silves	Grès à nuances claires		ss,cgl	Camadas de C.Viegas	B1	Castelo Viegas form.	Silves series	Rhaetic -?-----?- Norian-
	Grès rouge brique	C9,C10	ss,cgl	C. de Conraria		Conraria formation		-Carnian
		C3-C8	ss,sh		A2			
		C1,C2	cgl,ss		A1			--?----?-- ?pre-Carn

Table B - Stratigraphic units, basal Mesozoic, Estramadura

pre-Norian age (SCHEURING in RIGASSI, 1973) near the center of the basin. This does not preclude the Dagorda of being heterochronic, with generally older ages in basinal areas, younging towards the basin edges. A similar situation seems to characterize the Argo evaporite off Canada. The Jurasic starts with the deposition of the shallow marine, possibly also somewhat heterochronous (Hettangian to Lotharingian) Coimbra dolomite, followed by rapid subsidence. Greater sea depth in part under euxinic conditions accounts for the deposition of the Brenha formation. The later Mesozoic history of the basin is illustrated on figure 2. Fluvial-estuarine clastics and platform carbonates near the margins of the basin rapidly grade into deeper marine carbonates and shales. Four main cycles are recognized, starting with abrupt transgressions and continuing with progressive, often spasmodic regressions, these cycles being separated by regional unconformities:

1/ the Late Triassic-Callovian cycle (Monda group of Shell, unpublished reports),
2/ the Middle Oxfordian-Late Portlandian cycle (Estremadura group of Shell),
3/ the Early Cretaceous-Cenomanian cycle (Ericeira group of Shell),
4/ the Late Cretaceous cycle (Aveiro group of Shell).

The unconformity between cycles 1/ and 2/ can be related with the separation of Africa, the one between cycles 2/ and 3/ with the separation of Iberia. The major unconformity between the Tertiary and cycle 4/ which contains abundant intrusives and is topped by the Lisbon basalt, next to being another evidence of the major global event a the Cretaceous/Tertiary boundary, is contemporaneous with the separation of N. Europe-Greenland.
Connections of the Lusitanian embayment with the ocean greatly varied during the Mesozoic, from widely open to non-existent. In the Early Liassic, the link was with the North Atlantic and with both the North Atlantic and the Tethys during the Carixian-Toarcian. Connection was with the Tethys in Aalenian times, and with the North Atlantic during the Callovian. Basal beds of the Late Jurassic (Middle Oxfordian) again show North Atlantic influence, however soon equalled or even surpassed by Mesogean influences (Late Oxfordian-Early Portlandian). Neocomian marine beds, restricted to the area N and W of Lisbon, testify of shallow sea links with the Tethys. During the Barremian and later Cretaceous stages, connections existed, in the main indirectly, with both the Mesogea and the North Atlantic, this last link becoming predominant with time (MOUTERDE *et al.,* 1972, 1985, ANTUNES *et al.* in RIBEIRO *et al.* 1979).

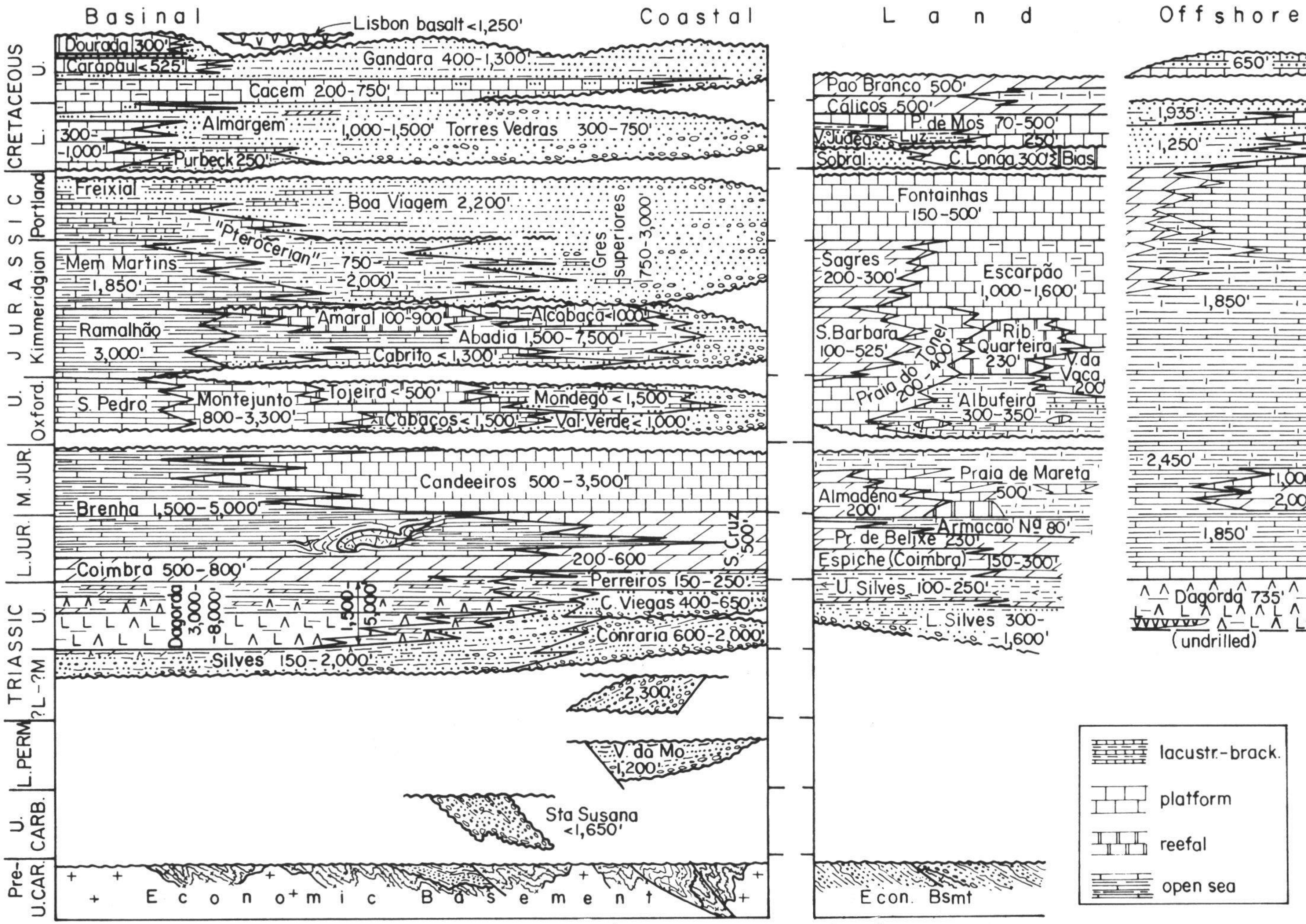

Figure 2 — Stratigraphic chart of Portugal. Left, Lusitanian basin, right Algarve basin.

Tertiaries of the Tagus-Sado basin (see below) overlap the Mesozoic of the ESE part of the Lusitanian basin. Eocene-Miocene terrestrial clastics and shales, not exceeding 300-500 m in thickness, are found in the NW part of the basin, grading northwestwards into shallow marine beds that are restricted to present coastal and offshore areas. A short Pliocene transgression extended somewhat further to the SE, resulting in the deposition of thin clastic-shaly beds that are in part filling the depressions topping Dagorda diapirs. The deep structure of the Lusitanian basin seems to be controlled by the sub-meridian faults associated with the early (Triassic) rifting phase. These faults probably exhibited wrench components-ever since their very birth. At different moments of the Meso-Cenozoic, these faults were rejuvenated, with both their vertical and horizontal throws being emphasized, or reduced, or even inverted. Halokinesis of the Dagorda started during the Middle Jurassic. At the same time, the major NE-SW Gouveira-Lousa-Leiria-Farilhões fault started to be active, initially with a dextral wrench displacement. This fault as well as the 550-km long Ávila-Odemira fault of southern Portugal and nearby Spain probably reflect an initial stage of the anti-clockwise rotation of the Iberian peninsula. The Lousa-Farilhões fault clearly divides the Lusitanian embayment into two sub-basins: the Figueira-Monte Real basin N of the fault, and the Bombarral-Lisbon basin S thereof. At the close of the Jurassic, the westerly displacement of the rifting center into the present oceanic realm resulted in thermal contraction of the Lusitanian embayment that can be defined as an abortive rift. With continuing trigonometrically positive rotation of Iberia, transpression produced NNW-SSE faults controling the half-grabens of the Galician basin and extending to the northernmost part of the Lusitanian basin. Some segments of the Lousa-Farilhões fault were turned into steep reverse faults, while wrenching along the main fault were inverted to sinistral — an inversion to climax during the Pyrenaean orogeny (Eocene). The above tectonic processes may explain the geometry of the basic dykes which mainly are of Late Jurassic-Early Cretaceous age with predominant ESE-WNW and NNE-SSW trends in the central part of the Lusitanian basin, and of Late Cretaceous age with NE-SW and NNW-SSE to N-S trends in the Lisbon-Torres Vedras region. The Betic (Alpine) diastrophism (Miocene), with SE-NW compression, apparently produced fairly significant SE-NW sinistral faults, as well as some overthrust of small extent and displacement. It is to remember that throughout, from Middle Jurassic to Late Miocene, the above tectonical processes induced repeated halokinetic movements of the Dagorda. The present structural pattern of the Lusitanian basin can thus be described as a complex one. In fact, next to being divided into two main parts by the Lousa-Farilhões fault, the Basement of the Lusitanian basin is a mosaic of pull-apart and transpressional grabens and horsts. Depending upon the thickness of the Dagorda evaporite and upon the lithology (shale:carbonate ratio) of the Jurassic, the surface structural pattern might either rather strictly reflect the deeper graben-and-horst structure, or, due to drapping, give a smoother picture of said deeper tectonics, or else invert it. The basin thus contains a variety of structural traps, including anticlines, diapirs and fault blocks (figure 3). Non-structural traps include reefs, clastic pinch-outs and turbidites, combined traps also being present. As can be judged from figure 2, there are both clastic and limy potential reservoirs, including subunconformity karstic carbonates. One problem might arise from the paucity of thick and impervious enough cap rocks. Good potential source rocks have been identified within the Montejunto and Brenha formations. Exposed Brenha oil shale, up to 135-ft thick, has a retorting yield averaging 4 gal/ton and reaching up to 16 gal/ton. Other potential sources include darker beds within the Mondego, Abadia and Coimbra formations, as well as thin black shale interbedded within the upper Dagorda. In general, most of the sources seem to be undermature. However, available reflectance figures might be biaised by the fact that most investigated surface samples come from crestal or near-crestal areas of ancient anticlines, nearly all subsurface samples being from prominent structural highs. Furthermore, samples from regions rich in Late Jurassic-Cretaceous dykes are as a rule within the oil window. The present geothermal gradient is low, apparently ranging from 31 m/1°C to over 40 m/1°C (56' to over 73'/1°F). The initially greater gradient associated with initial rifting likely strongly decreased towards the end of the Jurassic, but the abundance of late Cretaceous dykes with two large intrusive bodies (Sintra, 70 km^2, Sines, 35 km^2) suggests a gradient still above normal at the end of the Cretaceous, i.e. at a time when most potential sources were capped, at the least within paleo-lows, by 1.000 to 2.000, in places 4.000 m, of sediments. Surface and subsurface oil and gas shows are numerous. In the early 50s, seven shallow wells (TDs 144 to 391 m) near Abadia pumped a total of 1.500 BO (12°API, 3.2% S) from Kimmeridgian carbonates and sands, the best well yielding 5 BOPD. Another well in the same area tested 141 MCFGD. More recently, an offshore well tested less than one barrel of light oil from the Coimbra dolomite, a land-well yelding 2 BO from Montejunto.

Period, company	Wells	Km drilled	TD deepest well,m	Wells to Basement
1906-1949 various	4	4,2	2,089	---
1950-1955 CPP/Axelson	11	14,3	2,339	1
1955-1959 CPP/Mobil	13	27,0	3,610	---
1960-1961 CPP	2	2,0	1,362	---
1962-1963 CPP/Copefa-CEP	5	9,9	2,884	---
1980-1983 Petrogal,Sceptre	4	12,8	3,590	1
	39	70,2	3,610	2

Table C — Land exploratory drilling, Portugal (All drilling in Lusitanian and Tagus-Sado basins, coreholes of less than 500 m disregarded)

Land:	One well per:	m/km^2
Lusitanian basin	325 km^2	5.5
Other basins	---	---
	430 km^2	4.2
Offshore:		
Gallician basin	1,200 km^2	1.9
Lusitanian basin	890	2.8
Algarve basin	2,150	1.3
	1,085 km^2	2.3
Total	725 km^2	4.9
(for comparison, Swiss Molasse)	(565 km^2)	(4.6)

Table D — Density of exploratory drilling, Portugal

Basin, period	Wells	km drilled	TD deepest well, m	Wells to Basement
Gallician, 1975-79, 1984	6	14.0	4,040	1
Lusitanian, 1974-77	14	35.5	3,668	2
Algarve, 1975-76, 1981-82	5	13.8	3,597	---
	25	63.3	4,039	3

Table E — Offshore exploratory drilling, Portugal

Though having been fairly intensely drilled (Tables C to E), the Lusitanian basin is far from being mature. It should be noted that most of the wells drilled on-land have been sited based on divinig rod, surface geology, or obsolete seismic. Furthermore, drilling was unevenly distributed, with no fewer than 20 wells concentrated on three small structures (Torres Vedras-Abadia, Monte Real, Barreiro), and two wells only having reached Basement. Offshore drilling was made based on more modern seismic, well density however remaining low, with three wells only having reached Basement (Table E). In addition, considerations as to the sedimentological and structural evolution of the basin point to its eastern (present land) part being more prospective than its western (present offshore) part.

Galician basin

This basin is entirely located offshore, with less than one-third of its total area under Portuguese jurisdiction. It consists of a set of NNW-SSE trending half-grabens. The Dagorda evaporite is thinner than in the Lusitanian basin, and salt pillowing and diapirism is much less developed in the Galician basin. The Jurassic section ressembles that of the Lusitanian basin, though being thinner, with a maximum of about 1.500 m in the Portuguese sector and 2.000-2.500 m under Spanish waters. Deep marine Tithonian Calpionella-micritic limestone occurs. On the other hand, the Galician Cretaceous is much thicker, the Lower Cretaceous reaching up to 1.700 m in Portugal and probably up to 4.000 m in Spain, and consisting of interbedded marine and deltaic-estuarine facies that may grade into deep-water shale and turbidites in basinal areas. Beyond the present shelf edge, a Tertiary wedge (3.000 m) develops in the deep offshore. The total sedimentary thickness attains 5-6 km in Portugal and 8 km or more off Spain. The basin is as yet little known, but all available data indicate that it could be a major petroleum province.

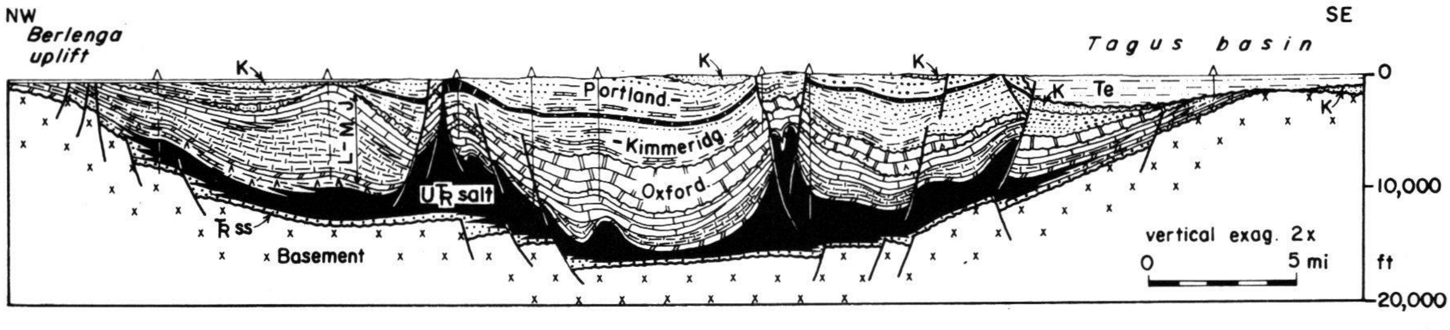

Figure 3 — Cross-section of Lusitanian basin. Location shown on figure 1.

Tagus - Sado basin

The NNE-SSW trending Tagus basin seems to be a pull-apart feature related with sinistral movements along SW-NE faults, though their might also be some influence of the S-N to SSW-NNE compression that produced the Cantabrian-Pyrenaean folds. On the eastern edge of the basin, the Tertiary rests on the Hesperian Basement. Not far to the west, the Tertiary is known or suspected to overlie the easterly wedge out of the Lusitanian Mesozoic that rapidly thickens westwards. Late Eocene-Oligocene clastics, red shales and lacustrine limestones of which the distribution is poorly known seem to be up to 350 m thick. The Neogene (up to 800-1.000 m) is made up of several cycles starting with marine carbonates and/or shales grading upwards into coastal-fluvial clastics and shales. At the times of maximum transgression (Aquitanian, Burdigalian, Upper Langhian), marine beds extended to some 80-90 km upstream from the Tagus estuary, passing further to the NE into fluvial-lacustrine formations. Seven wells have been drilled in the southwestern part of the basin, all having as primary target the Lusitanian Mesozoic underlying the Tertiary. Except perhaps for biogenic gas, the Tagus Tertiary seems to be devoid of hydrocarbon generating potential. On the other hand, clastics and carbonates (including algal bioherms und coquinas) could be good reservoirs hosting hydrocarbons generated in the Mesozoic.

The Sado basin consists of two segments, a northern NW-SE trending segment and a southern, NNE-SSW trending segment of which the tectonical origin is analogous with that of the Tagus basin. The northern segment links the Tagus basin with the southern segment, the Tagus-Sado embayment having thus a dog-leg shape. The Tertiary rests on either Hesperian Basement or on highly tectonized, over-mature Late Devonian-Carboniferous. Paleogene (?Late Oligocene) fluvial clastics chiefly present in the basin's southern segment represent the oldest Tertiary beds. In the main, the overlying Neogene consists of fluvial-estuarine clastics and shales, and lacustrine shales and limestones. Except during the Burdigalian-Langhian, when a sea arm encroached to about 80 km upstream from the present Sado mouth, marine deposition never extended much beyond today's coast. The land part of the basin has never been drilled, and there is thus much uncertainty as to the nature and thickness of the Tertiary filling. Two offshore wells have shown the Miocene to be marine and up to 620 m thick, directly resting on Lusitanian Mesozoic.

Algarve basin

Figure 2 (right) summarizes the stratigraphy of the Algarve basin. The Silves series rests on the highly folded, very- to supra-mature Carboniferous slates and quartzites. On land, the Jurassic is rather similar to that of the Lusitanian basin, however with much more abundant barrier and back-barrier carbonates and fewer clastics. As may be expected, the faunas have Mesogean affinities, yet at times (Aalenian-Bathonian) with North Atlantic influences. The Cretaceous, with predominant shallow marine carbonates and subordinate fluvial sands, is similar to that of the area west of Lisbon. It is restricted to present coastal areas, south of the arcuate, WSW/W-ENE/E Espiche-Portimão-Algoz fault — a fault that apparently marks the northern limit of Dagorda deposition during the Late Triassic. The Mesozoic is unconformably overlain by thin shallow marine Miocene. The poor quality of exposures, and the lack of seismic and subsurface data make it very difficult to draw any conclusions as to the deeper structure and oil potential of the land part of Algarve.

Offshore, the Mesozoic stratigraphy seems to be controlled by WSW-ENE paleofaults. Wells drilled off central Algarve found the Dagorda to be overlain by open-sea Liassic shales and carbonates, grading into Late Jurassic platform carbonates and Early Cretaceous shallow marine carbonates shales and sands, similar to the formations exposed along the coast in west-central Algarve. On the other hand, two wells off eastern Algarve drilled Middle-Late Jurassic carbonates and shales (older formations not reached) of outer shelf-slope facies, rapidly grading towards the ESE into deeper marine micrite and shale comparable with formations of the Subbetic zone of southern Spain. Above the Jurassic there is a thick Lower Cretaceous, mainly consisting of non-marine clastics and shales. Thin marine U. Cretaceous unconformably rests on older formation. The Tertiary includes a transgressive Oligocene carbonate (200 m) that truncates Eocene carbonates (up to 600 m, thickening towards ESE) topping thin Paleocene marine shale and clastics. On the shelf, the Oligocene is disconformably overlain by neritic Neogene sands and shales (700 m), while in deeper waters to the SE a sharp unconformity separates the Paleogene from thick (1.000 m +) Pliocene clays. As far as can be judged from the scanty available data, the Algarve offshore seems to lack in the Neogene delta-front clastics that contain commercial gas in the Gulf of Cadiz-Guadalquivir basin (Spain). This might be due to the rather smooth continental morphology of southern Portugal during the Neogene, or to the mainly slaty, quartz-poor nature of the Carboniferous formations eroded on land during the Neogene, or to both. Should this explanation be correct, than hopes of finding suitable deeper marine clastic reservoirs (deep-sea fan, turbidites) beneath undrilled parts of the contiental slope would be remote. Except for on-land gas shows (?marsh gas) in water wells, and minor shows of oil and/or gas (Oligocene, L. Cretaceous) in two of the offshore wells, no hydrocarbons are known from Algarve. No assessment of the land prospects can be made, due to the lack of any seismic data. Offshore, the passage from deep marine to platform Jurassic would seem attractive, the problem, however, being the reduced thickness and, probably, the limited areal extent of cap rocks. In any event, the density of exploratory wells is very low (Table D), and more efforts are worthwhile undertaking.

Conclusions

The Galician basin can be considered as very attractive, most of it however being under Spanish jurisdiction. Renewed exploratory efforts will likely result in commercial hydrocarbons being found in the Lusitanian basin. The inappropriately and insufficiently drilled land part of the basin ranks first: its location with regard to the source of clastic supply, to basinal organic-rich rocks, to the platform-slope transition and to sand pinch-outs makes it more attractive than the offshore part. The centralwestern part of the Tagus basin, with Mesozoic formations progressively pinching out eastwards and covered by the Tertiary containing both seals and reservoirs also deserves being drilled. No clear statement can be made as to the prospects of the Sado basin, the meagre data suggesting a rather low rating. Guesses as to the prospects of the land part of the Algarve basin only will be feasible if and when seismic sections are available. The offshore part, though apparently not as promising as the Galician and Lusitanian basins, may have fair merit, and several more wells are justified. The geology of the Portuguese basins points out to conditions favorable to the generation and entrapment of hydrocarbons. To this should be added a liberal legal and taxation regime and an economic-political environment beneficial to foreign investors. Most acreage is open — it actually being very hard to understand why the oil industry has in the main neglected and still neglects Portugal.

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