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ANALYSIS OF BOTTOM — HOLE TEMPERATURE AND PRELIMINARY ESTIMATION OF HEAT FLOW IN PORTUGUESE SEDIMENTARY BASINS

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Determination of the geothermal gradient and heat flow from bottom — hole temperatures (BHT) were measured for wells in the Portuguese offshore and onshore (Algarve and Lusitanian Basins).
The temperature BHT's are corrected by empirical relations with available data, but in cases where multiple BHT's are measured at the same depth at successive times the method developed by Dowdle & Cobb (1975) is used. The general least squares inversion theory is applied to the estimation of heat flow and its uncertainty, Vasseur & Lucazeau (1985).
Estimates for heat flow density in the Lusitanian Basin are around 80 mWm^{-2}, but values up to 106 mWm^{-2} occur where salt diapirs occur. Geothermal gradients range from 21.6 to 35.5°C/km, with an average of 27.7°C/km. One value for the Algarve Basin showed lower heat flow density.

Os gradientes geotérmicos e o fluxo de calor a partir de temperatura de fundo de poço (BHT) foram obtidos para poços terrestres e marinhos da costa Portuguesa (Bacias de Algarve e Lusitana).
As temperaturas de fundo de poço (BHT) foram corrigidas através de relações empíricas obtidas a partir dos dados observados, mas em casos em que múltiplas BHT na mesma profundidade e para tempos diferentes eram disponíveis, o método desenvolvido por Dowdle & Cobb (1975) foi utilizado.
A teoria de inversão generalizada por mínimos quadrados foi utilizada para estimar o fluxo térmico e sua respectiva incerteza (Vasseur & Lucazeau, 1985).
As estimativas de densidade de fluxo térmico na Bacia Lusitana são de aproximadamente 80 mWm^{-2}, mas valores de até 106 mWm^{-2} sao observados onde ocorrem diapiros de sal. Os gradientes geotérmicos variam de 21,6 a 35,5°C/km, com um valor médio de 27,7°C/km. Um único valor para a Bacia do Algarve sugere um valor de densidade de fluxo térmico inferior.

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INTRODUCTION

Evaluation of heat flow density is essential for the understanding of tectonic processes. Current values of heat flow, extracted from measurements taken at the surface, enable us to infer tectonic conditions in past geological eras, because of the fact that heat conduction is an extremely slow process.

Data available for the Portuguese sedimentary basins have been taken at oil prospection drilling wells, which do not offer the best condition for this type of data collection. Thus raw temperature data are strongly affected by the drilling process, in particular by the circulated mud used for cooling. In view of this, appropriate corrections have been taken into account as far as possible. The thermal conductivity of the different formations has been estimated from lithological logs.

In this paper the method applied by Vasseur & Lucazeau (1985) for determination of heat flow density has been followed.

GEOLOGICAL SETTING

In Portugal there are two Mesozoic-Cenozoic sedimentary basins which have been drilled for hydrocarbon prospecting. To the west of the Portuguese coast line, with an axis about north-south and extending along on and offshore between the 38th and 42nd parallels, is the Lusitanian Basin.

To the southern coast line, with an axis east-west and extending mainly in the offshore areas, is the Algarve Basin.

The Lusitanian Basin is stratigraphic and structuraly complex due to an inversion of the tectonic patterns. Fig. 1 shows a simplified stratigraphic chart for the Lusitanian Basin.

The initial Lusitanian Basin development is related to fault movements along Hercynian basement faults during late Permian or early Triassic time. Grabens and half-graben structures with a NNE trend were developed and filled by red clastics and evaporites, this represents the initial rifting phase.

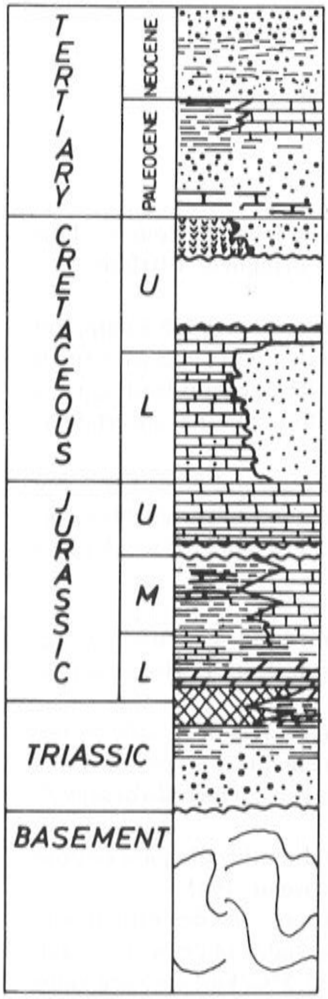

Figure 1. Simplified stratigraphic chart for the Lusitanian Basin

During early to middle Jurassic time the grabens were progressively infilled by clastics and carbonates. Probably during the midle Jurassic some minor salt movements may have commenced. The absence of lower Oxfordian formations marks an important and widespread unconformity that preceded rapid subsidence in some regions.

In the late Oxfordian — early Kimmeridgian the reactivation of some important faults and the increase of salt movements controled the sedimentation patterns and the infilling of the Basin, this is the main rifting phase. This influence, sometimes less apparent, still remained during the late Kimmeridgian and early Cretaceous. Some transgressive — regressive cycles are shown on clastics sedimentary sequences, this is the late rift to drift stage.

During the Cenozoic, compressive movements inverted the evolution of the Lusitanian Basin producing severe deformation and structural complexity.

Algarve Basin

As for the Lusitanian Basin, the Algarve Basin contains Mesozoic-Cenozoic deposits. Tectonics and stratigraphic patterns are, in general, similar to those of the Lusitanian Basin. Late Miocene evolution is a little different with a thick, mainly clastic, sedimentary sequence.

The heat flow density has been evaluated in the Portuguese sedimentary basins on the basis of data collected in the oil prospect drilling holes which had been undertaken in these basins. (Bottom hole temperatures-BHT-and lithological logs).

Bottom hole temperatures have been corrected by means of the method proposed by Dowdle & Cobb (1974) whenever, for any depth, several values of BHT were observed at different times. However, in most of the cases only one value of BHT has been found. There fore, most of the data from the holes have been eliminated for the application of this method. For onshore data, only 10% of the wells have been considered. For the offshore regions, this percentage is 42%.

The temperature T at the bottom of the hole rises after circulation stops. Let T_f be the undisturbed formation temperature, t_c the circulation time, t_e the time after circulation stops and A a constant,

$$T(t_e) = T_f + A \log\left(\frac{t_c + t_e}{t_c}\right)$$

Thermal conductivity has been estimated from lithological logs using appropriate tables of rock thermal conductivity, because the observation of drilling samples has not been possible for the time being. However, it is intended to undertake conductivity determinations with these samples in the future.

Taking the collected data as representative of a stratified medium, the heat flow q is given by

$$T_i = T_s + q \sum_{j=1}^{n} H_{ij} \frac{1}{\lambda_j}$$

Where n is the total number of layers, H_{ij} are coefficients equal to the thickness of j layer from ground to depth Z_i (corresponding to T_i) and the j layer has a constant thermal conductivity λ_j.

In cases where several corrected values of bottom-hole temperatures exists for the same hole the heat flow and its uncertainty can be evaluated by the method proposed by Vasseur & Lucazeau (1985) based on the general least squares inversion theory developed by Tarantola & Valette (1982).

RESULTS AND DISCUSSION

Results are shown in Table 1 and Fig. 2. The Map, in Fig. 2, also shows the main geological features.

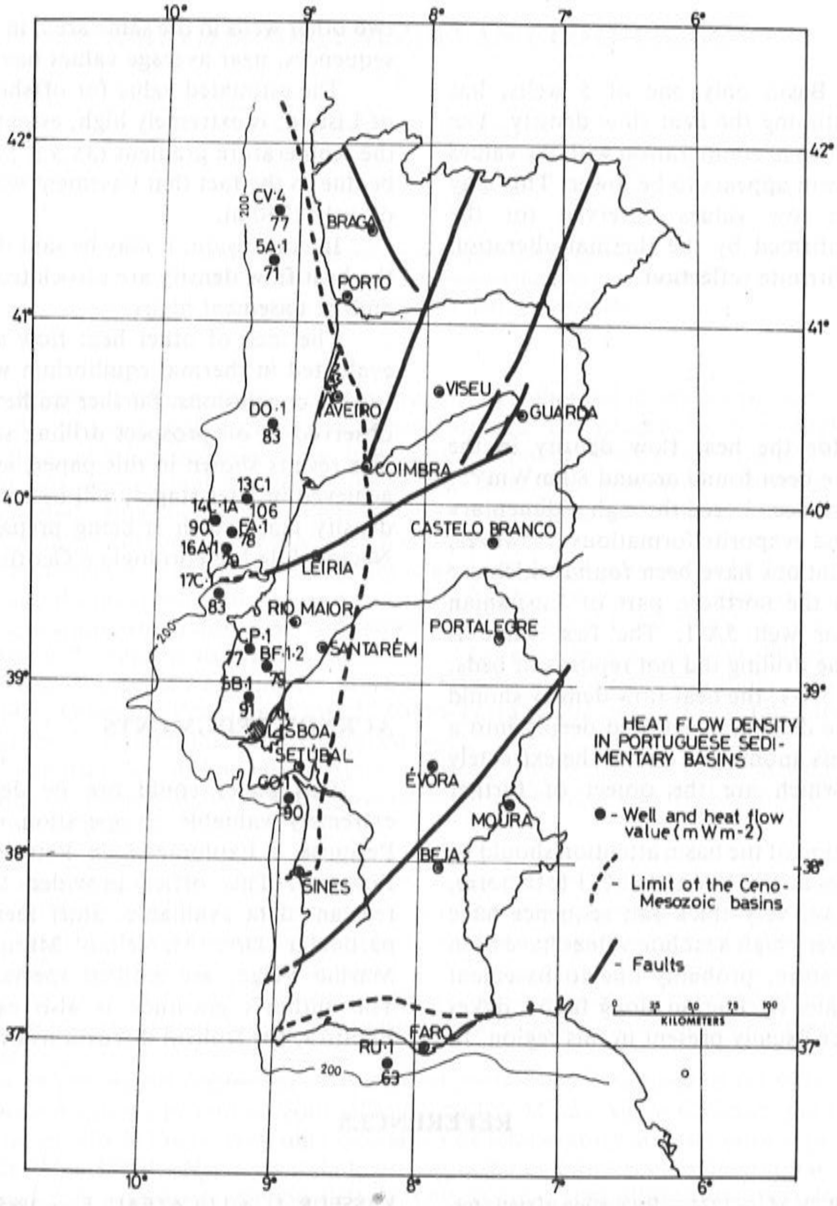

Figure 2. Heat flow density for Portuguese sedimentary basins

Table 1. Geothermal gradients and heat flow for Portuguese sedimentary basins.

Well	geothermal grad. °C/km	s.d. °C/km	heat flow mWm^{-2}	s.d. mWm^{-2}
Ruivo-1 (RU-1)	23.1	8.1	63	17
Golfinho-1 (GO-1)	35.5	5.6	90	21
17 C-1	22.8	6.6	83	19
16 A-1	26.6	5.7	79	16
Faneca-1 (FA-1)	29.5	2.9	78	15
14 C-1A	25.8	6.1	90	20
13 C-1	32.5	1.7	106	13
Dourada-1 (DO-1)	28.1	3.8	83	10
Cavala-4 (CV-4)	25.9	10.6	77	14
5 A-1	21.6	2.6	71	15
Benfeito-1 (BF-1)	29.9	1.5	79	11
Campelos-1 (CP-1)	27.9	5.7	77	17
Sobral-1 (SB-1)	31.2	0.5	91	18

s.d. = standard deviation
grad. = gradient

Algarve Basin

In the Algarve Basin only, one of 5 wells, has provided data for extiming the heat flow density. The value for this basin when in comparaison with the values for the Lusitanian Basin appears to be lower. This may be justified by the low values observed for the temperature and confirmed by the thermal alteration indices TAI and by vitrinite reflection.

Lusitanian Basin

The estimates for the heat flow density in the Lusitanian Basin have been found around 80 mWm^{-2}.

The drillings have been bored through sedimentary sequences with salt and evaporite formations. However, a few anomalous situations have been found which are given as follows. In the northern part of Lusitanian Basin 77 mWm^{-2} for well 5A-1. The first value is acceptable because the drilling did not report salt beds. On the contrary, for 5A-1, the heat flow density should be higher because the drilling penetrated deeply into a diapiric structure. This anomaly is due to the extremely low temperatures, which are the object of further clarification.

In the central region of the basin attention should be paid to the high values at 14C1-A and 13C-1 (offshore), where notwithstanding, very thick salt sequence have been found. In SB-1 very high absolute values have been observed for temperature, probably due to basement highs and/or deep water circulation along faults; dykes and volcanic rocks are usually present in this region. In two other wells in the same area, in the same lithological sequences, near average values have been determined.

The estimated value for offshore well GO-1, south of Lisbon, is extremely high, essentially with regards to the temperature gradient (35.5 ± 5.6°C/km). This may be due to the fact that basement was reached at a depth of only 1750 m.

In conclusion, it may be said that the ligh values of the heat flow density are associated with salt formation and/or basement highs.

The lack of other heat flow data in these basins, evaluated in thermal equilibrium wells, does not allow further conclusions. Further studies on the basis of data observed at oil prospect drilling should be developed. The results shown in this paper, as well as those to be achieved in later stages, will be considered for the flow density map which is being prepared by the Instituto Nacional de Meteorologia e Geofísica of Portugal.

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