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Upper Miocene Salt Layer in the Western Mediterranean Basin

JEAN-MARIE AUZENDE, JEAN BONNIN, JEAN-LOUIS OLIVET & GUY PAUTOT
Centre Océanologique de Bretagne, B.P. 337, 29 N Brest

ALAIN MAUFFRET
Laboratoire de Géologie Dynamique, 9 Quai Saint-Bernard, Paris 5

"Flexotir" profiles in the Western Mediterranean Basin reveal a uniform salt layer, overlain by a sedimentary sequence affected by diapirism. The salt has been given an Upper Miocene age.

THE problem of salt deposits in a present deep-sea basin has been discussed recently in the case of the Atlantic Ocean[1]. In this article we present new data on the salt layer in the Western Mediterranean Basin. In the Balearic Basin and the Ligurian Sea, anticline structures and domes disturbing the upper part of the sedimentary cover have been reported by Alinat and Cousteau[2], Menard *et al.*[3], Hersey[4], Alinat *et al.*[5], Glangeaud[6], Leenhardt[7], Mauffret[8], and Watson and Johnson[9]. Various hypotheses have been put forward to explain their origin, and the most widely accepted is that they are salt structures; the presence of sulphur, chalcopyrite and an increase of salinity in interstitial waters have been noted[10,11]. There are various interpretations of the age and areal extent of the salt layer[12,13]. Because of their limited penetrating capabilities, the conventional profiling techniques do not penetrate beyond the layer disturbed by diapirism. In the Northern Balearic Basin, however, one of us[14] has interpreted a strong, diffracting, deep reflector (two-way travel time of more than 1 s) as the top of a salt layer. This interpretation has received strong support recently from records obtained with the "Flexotir" technique and new data have been acquired on the age and thickness of the salt layer[15].

From records obtained during the Polymede cruise of the R/V Jean Charcot (May–July 1970) we have traced the salt horizon over a large portion of the Western Mediterranean Basin. Moreover, we are able to distinguish a sequence of deep, flat or slightly folded reflectors (1.5 to 2.5 s two-way travel time) in contrast with the upper layer, strongly disturbed by diapirism. The top of the lower sequence is marked by a strong reflector, assumed to be the bottom of the evaporite layer. Five sections, representative of the margins and central zone of the Western Mediterranean Basin, are presented here (Fig. 1).

Description of the Data

Two Flexotir records are described here in some detail; the other records are described in the figure captions.

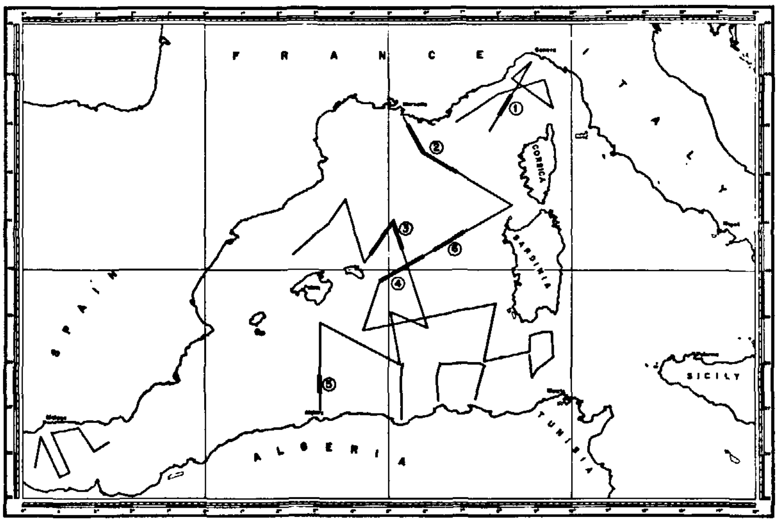

Fig. 1 Map of track of R/V Jean Charcot (Polymede cruise). Heavy lines and figures refer to sections presented here.

Profile 2 (Fig. 2), from Marseille to South of Toulon, shows the Provence continental basement becoming buried under the abyssal plain to a maximum depth of 3 s (two-way travel time). The salt layer is clear near the margin, and wedges out against the basement. On the continental rise, a bulge and a "turtle-shape structure"[16] between two pinches are followed by a dome which affects the topography; the salt thickness is about 1/8 s (300 m assuming a seismic velocity of 4.5 km s^{-1} in salt[17]) at the bulge. Salt tectonism affects the whole upper sedimentary sequence (1.2 s thick), except on the rise where deformation seems to be related to slumping along the slope.

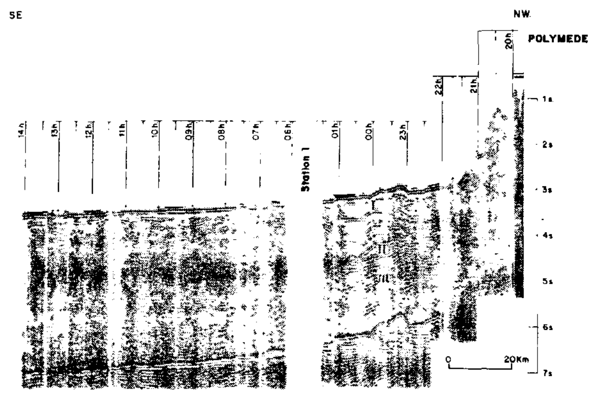

Fig. 2 Profile 2 south of Provence. See the text for comments. This is a variable intensity recording and vertical exaggeration is 18.

The lower series show strong reflectors which follow and attenuate the basement topography. The salt layer and these reflectors are dipping slightly to the south. Away from the margin, closely spaced domes (5 to 6 km apart) originate in the salt layer, bending up the upper sedimentary layers and masking the base of the salt. From 11.00 to 14.00, five domes affect the sea-floor topography. On this portion of the profile the lower reflectors (2 to 3 s deep) are nearly horizontal.

Profile 3 (Fig. 3) runs south-west–north-east, starting on the continental slope north of Minorca. The Balearic basement has a very small dip and is visible over 40 km, becoming buried beneath the abyssal plain. The salt layer wedges out near the basement and is apparent under 0.8 s (two way travel time) of sediments near 10.40. It is slightly disturbed up to 09.30. Its thickness is then of the order of 1/8 s (300 m). Below the salt layer, well defined reflectors abut onto the Balearic basement at depths between 1.5 and 2 s. From 09.30 to 07.15 a series of domes is followed by two salt anticlines where the salt horizon is again clear. The second anticline occurs where the salt layer changes its depth by about 1/2 s.

From 06.30 to the first change of course (04.25) the sedimentary sequence above the salt horizon is 1.3 s thick. The salt layer itself is horizontal with a well marked base at 1.8 s; its thickness is noteworthy: nearly 1,000 m. The lower sequence shows a strong reflector at 2.5 s, whose undulations could be related to the proximity of the basement.

From 03.10 onwards, the salt layer shows a large anticline similar to the turtle-shape structures of Trusheim[16]; the salt layer thickens here up to 0.6 s (1,300 m). Finally, at the north-east end of the profile, a large dome, flanked by a smaller one, disturbs the flatness of the abyssal plain.

Sedimentary Sequence

The Provence, Balearic, North African, and Corsican margins have the same characters. We propose the following scheme: the continental slope is a consequence of foundering (with faulting or "flexure") of the continental basement towards the central part of the basin. The basement, buried beneath the abyssal plain, is the continuation of the continental slope. On our Flexotir records we are able to follow the basement down to 3 s (two-way travel time). Over this depth a sub-horizontal sedimentary series is observed, transgressive on this basement.

Three groups of reflectors can be distinguished. The upper group (group I) is 1.2 s (two-way travel time) thick at the foot of the slope (up to 1.5 s in the central part of the basin). This group is typically disturbed by salt tectonism[8,16] (domes, peripheral sinks, turtle-shape structures) except on the continental rise where disturbances are connected with sedimentary processes related to the slope (Fig. 2).

The intermediate group (group II) is the "mother bed" of the diapiric structures. This group wedges out against the basement, and when it is not warped it is 300 to 500 m thick, except north-east of the Balearic Islands (Fig. 3) where its thickness reaches 1,000 m. The top and bottom of the salt layer are apparent when the domes are not too close; often (but not always) along the continental margins, the salt layer can be easily followed (Figs. 2–4). When the domes are closely spaced (for example in the central zone), the continuity of the base of the salt layer and of the lower horizons is often obscured. But the reflector marking the top of the layer is usually well defined and confirms the continuity of the salt layer at a constant level in the sedimentary column. The layer is continuous, uniform in thickness in the whole basin, and interbedded in a slightly deformed or undeformed sedimentary sequence.

Below the salt layer, group III displays flat, continuous reflectors down to 3 s (3–4 km) beneath the abyssal plain. These horizons are well marked at the foot of the margins, where the salt layer is not disturbed. Elsewhere they are ill-defined because of the screen effect of domes. Off Toulon (Fig. 2), however, they are seen perfectly up to 50 km from the slope. This fact suggests that they are continuous over the surveyed area.

Deformations

Deformations of group I are essentially related to salt tectonism, except at the foot of the continental margins where gliding processes are evident.

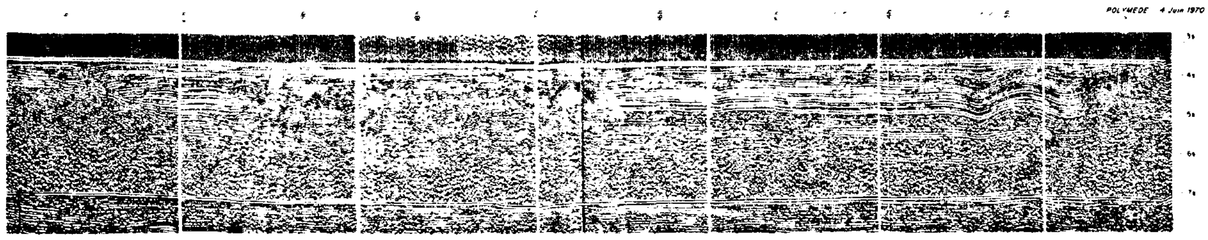

Fig. 3 Profile 3 north-east of the Balearic Islands. See the text for comments. This is a variable area recording and the vertical exaggeration is 5.

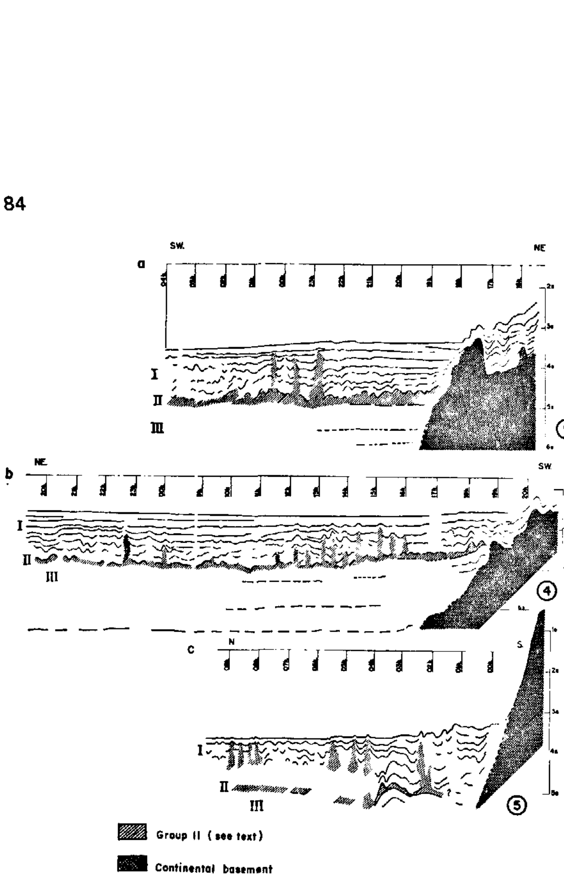

Fig. 4 Sketch profiles with a vertical exaggeration of 18. *a*, Profile 1 parallels the axis of the Ligurian Sea. On the right the salt layer appears under 1.2 s of well stratified sediments. The base of the salt layer is flat, 1.5 s below the seafloor. The upper layers are slightly deformed. On the left the upper layers are affected by diapirism. *b*, Profile 4 east of the Balearic Islands to the central part of the basin. The salt layer is clearly seen between 18.15 and 17.30; it gets deeper to the left. From 17.00 to the north-east, sedimentary group I (see text) is affected by salt tectonism. Numerous domes are apparent. In the Balearic basin, reflectors of group III (see text) are visible at a depth of 3 s. *c*, Profile 5, north of Algiers, clearly shows the salt layer limited by two domes reaching the seafloor. Groups II and III (see text) show an anticlinal structure probably related to basement topography. Note the turtle-shape structures and the peripheral sinks bordering the domes near which the salt layer almost disappears.

On three of the sections presented here groups II and III are warped. At the foot of the continental slope south of Toulon (Fig. 2), the salt layer and lower reflectors are dipping towards the basin (500 m in 27 km). Such a warping is observed near the margin of the Balearic Islands (Fig. 3). A pronounced swell of the salt layer and group III is seen in the profile off Algiers (Fig. 4*c*). This swell is marked in the topography. This phenomenon is local as it is not observed in the other sections of the Algerian margin. The deformations reported represent local, vertical movements of the continental basement.

In areas distant from the margins, deformation of the salt layer and lower reflectors is observed only in one location (profile 3, Fig. 3). This deformation may be related to the faults, striking north-west south-east, which offset the basement east of the Balearic Islands[18]. On the same profile, undulations of the strong reflector at 2.5 s (two-way travel time) (group III) will be connected with the proximity of the basement.

As well as these local deformations, a small syncline-like structure, with its axis in the central part of the basin, seems to affect the whole sedimentary sequence. The salt horizon, 1.2 s (two-way travel time) deep near the margins, reaches 1.5 s in the median zone.

Age and Significance of the Salt Layer

The problem of the subsidence of the Western Mediterranean Basin will be investigated further in another article. We propose a scheme based on a study of our records and previous geological studies, from which we can give an age to the salt layer. On most of the profiles presented here the salt layer overlies a thick, undeformed sedimentary sequence and is overlain by about 1 km of recent sediments. The latter sediments are affected by salt tectonism in the abyssal plain. Deformations of these sediments on the continental rise are related to slumping. In particular, these deformations have been reported on the Provence and Algerian margins. They indicate quasicatastrophic "flexure" of the margins caused by the foundering of the central part of the basin. The Plio-Pleistocene foundering of the basin has brought down the Miocene erosion surfaces by at least 2,000 m (refs. 19–24). The age of the cutting of the slopes by the submarine canyons confirms this movement[19]. Furthermore, the uplift of the continental borders is simultaneous with the foundering of the basin. On the continental side, Pliocene sediments and sometimes underlying Miocene salt are uplifted by as much as 1,000 m (ref. 25).

In summary, the proposed model allows us to assign an Upper Miocene age to the salt. The salt was deposited after an episode of quiet sedimentation. The Plio-Pleistocene "flexure" caused the burial of the salt beneath the present abyssal plain and its uplifting on the continental side. One of us (G. P.) was on board the drilling vessel Glomar Challenger during leg 13 in the Mediterranean Sea. Salt was recovered from three holes in the Western Mediterranean Basin and shown to be Upper Miocene in age. The conclusions of the present article were reached before the results of the Glomar Challenger's cruise in the Mediterranean were known. The drilling results were reported by K. J. Hsü at a press conference in Paris on October 9, 1970.

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