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The Isopach Maps in Oil Geology

With Reference to the Cretaceous of Syria, South-Western Asia

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Foreword

Among the means of expressing graphically the geological characteristics of a country, *the isopach maps show the thickness variations of a given stratigraphic bed or sequence,* the points representing thicknesses of equal value being connected, on the map, by a like contour line (the isopach or the isopachous line).

An isopach map is of undeniable usefulness when, for instance, the volume of a reservoir has to be determined. But the interpretation of such a map requires great circumspection as soon as it must be introduced in the description of facts having affected a sedimentary area.

In the course of stratigraphic research undertaken on behalf of the Iraq Petroleum Company in Transjordan, Lebanon and Syria, we noted some examples which might tend to lessen the interest of a method in other respects so captivating by its mathematical accuracy. We will quote one of them in the following pages.

First, we wish to thank here Mr. N. E. Baker, Chief Geologist of the Iraq Petroleum Company, for having authorized the present publication. We likewise express our gratefulness to Mr. F. E. Wellings and particularly to Dr. F. R. S. Henson to whom the stratigraphy of the Middle East owes its intensive development.

Introduction

In the heart of the Syrian desert, a mountain range surges suddenly from the plain and forms a geologically well defined unit: the Palmyrene.

As we understand it here, the Palmyrene is bounded to the South by the Palmyra parallel and to the North by the Esriye one. It extends, between the Orontis westwards and the Euphrates eastwards, for a distance of 200 kilometres.

Thus limited, the Palmyrene covers about 18.500 square kilometres. It presents to the eye landscapes clear of any vegetation whatsoever, a geologist's paradise, where immense outcrops of golden weathered limestones alternating with green marls and dazzling white chalks are spread out in the ligth of the eastern sun. The stratigraphic sequence is observable from the Middle Cretaceous to the Mio-Pliocene.

In 1948, we were instructed to make a detailled study of these formations and in 1949, we recorded the results we obtained in a stratigraphic and tectonic synthesis of the Palmyra area. The matter of the present notice is extracted from this synthesis.

In order to illustrate the method of the isopach maps, we shall describe here a part of the Upper Cretaceous.

We have chosen that part because it is included between two constant horizons, its base and its top are, moreover, featureforming beds easily discernible on the field.

These paleontological and lithological characteristics confer on this Cretaceous sequence the precise qualifications required for the drawing of an isopach map.

We are going to investigate briefly what may be the interest of such maps in stratigraphic research as a whole and particularly in oil prospecting.

To make our exposition clear we shall first examine an Upper Cretaceous section.

In a second chapter we shall deal with the thickness variations of the chosen sequence, with the measurements constituting the base of the isopach map and then with the interpretation to which the latter leads.

A third chapter will contain a summarized stratigraphic study of the Upper Cretaceous, from which we shall draw conclusions regarding the use of isopach maps in oil geology.

The Upper Cretaceous of Palmyrene

Throughout the studied area there is no stratigraphic gap between the Middle and the Upper Cretaceous. The Middle Cretaceous is represented by a massive, featureforming, dolomitic limestone, generally called „Judea limestone" the top of which contains numerous *Scaphopods*. From the *Scaphopods*-horizons upwards, the formations become gradually chalky and their microfauna leaves no doubt as to their Upper Cretaceous age.

1. The El Marah stratigraphic section

In the centre of the Palmyrene, we have measured the El Marah section. The „Judea limestone" is here unbottomed; its top and the overlying Upper Cretaceous formations show the following sequence:

1. Lumachelle[1] of *Scaphopods*. Thick-bedded	2,20 m.
2. Dolomitic limestone with rare chert nodules	2,10 m.
3. As above. Locally chalky	3,00 m.
4. Lumachelle of *Pelecypods*	0,40 m.
5. Chalky limestone alternating with flint. Thin-bedded	2,50 m.
6. Lumachelle of *Scaphopods* and *Pelecypods*	0,30 m.
7. Dolomitic limestone becoming gradually calcarenite	0,50 m.
8. Calcarenite. Slightly bituminous	1,45 m.
9. Limestone. Somewhat bituminous	1,20 m.
10. Chalky marls. Numerous *Meletta* and other fish remains	3,10 m.
11. Chalky limestone	3,30 m.
12. Sublithographic limestone. Thin flint interbedded	1,20 m.

[1]) We use the French word „lumachelle" in the sense given by A. H. Fay to „shell limestone" i. e. a sedimentary rock composed chiefly of fragments of fossil shells (A. H. Fay, Glossary of the Mining and Mineral Industry; U. S. Bureau of Mines Bull. 95. 1920).

13. Alternation of chalky limestone and calcarenite. Yields abundant *Bulimina, Gumbelina* and *Globigerina*. Fish remains . . . . 6,05 m.
14. Massive limestone scattered with chert nodules. Locally strongly bituminous . 6,00 m.
15. Chalky marls . . . . 0,30 m.
16. Chalk alternating with slab limestone . . . . 6,70 m.
17. Compact limestone. *Ostrea villei* Coq, *Inoceramus* . . . . . . 0,80 m.
18. Chalky limestone . . . . 7,20 m.
19. Lumachelle of *Pelecypods* with, in relief on the weathered surfaces, chalcedony concretions and numerous, ironstained *Ostrea villei* Coq., *Ostrea nicaisei* Coq., *Ostrea vesicularis* aff. and *Inoceramus regularis* aff. . . . . . 6,00 m.
20. Flint alternating with chalky limestone . . . . 6,50 m.
21. Alternation of flint and granular limestone often entirely composed of microforaminifera. *Globigerina cretacea* d'Orb., *Nonionella robusta* Plum., *Bulimina, Gümbelina,* and *Anomalina* . . . . 9,80 m.
22. Alternation as above with fewer foraminifera . . . . 26,00 m.
23. Massive flint beds, sometimes intercalated with very thin pellicles of marl. Scattered loaf-concretions around which flints and marly pellicles are concentrically ordered. Evidence of the epigenetic origin of the flint (cf. pp. 42—43 2,10 m.
24. Flint alternating with chalky limestone. Very abundant fish remains . . 39,60 m.
25. Calcarenite alternating with chalky marls full of *Meletta* . . . . . 4,80 m.
26. Flint alternating with calcarenite. *Pelecypods* . . . . 7,80 m.
27. Flint alternating with chalky limestone. Numerous fish remains . . 37,00 m.
28. Limestone containing *Bulimina, Gümbelina, Globigerina, Globigerinella* and *Nodosaria* . . . . 0,30 m.
29. Flint alternating with locally recrystallized chalky limestone . . . 61,70 m.

From here upwards the stratigraphic sequence is marked by a slight shallowing. Some phosphate horizons appear in the chalks.

30. Chalky marls . . . . 0,30 m.
31. Chert nodules, aligned parallelly to the bedding plane . . . . . . 0,03 m.
32. *Phosphate nodules* among which appear frequently metasomatosed fragments of conical vertebrae. The nodules contain 21 % PO_4 . . . . . 0,03 m.
33. Chalky marls . . . . 0,40 m.
34. Chert nodules as 31 . . . . 0,03 m.
35. *Phosphate nodules* as 32 . . . . 0,01 m.
36. Chert nodules as 31 . . . . 0,03 m.
37. Granular marls. Locally lumachellic . . . . 0,10 m.
38. Marls scattered with rare *phosphate nodules* . . . . 0,20 m.
39. Chalky limestone . . . . 0,03 m.
40. Chalky limestone with numerous *Meletta* . . . . 1,20 m.
41. Alternation of marly chalk (0,50 to 2 m.) and chalky limestone (0,10 to 0,20 m.). Some beds contain exclusively *Bulimina* . . . . 23,00 m.
42. Chalky limestone, pinkish striped and scattered with big loaf-concretions (sometimes 1 m. in diametre) . . . . 1,80 m.
43. *Phosphate nodules* as 32 . . . . 0,03 m.
44. Chalk interbedded with flint . . . . 15,20 m.
45. Recrystallized limestone alternating with marly chalk. Contains big loaf-concretion as 42 . . . . 12,90 m.
46. Silicified limestone. Very dense . . . . 0,30 m.

47. *Phosphate nodules* as 32 . . . . . . 0,02 m.
48. Chalk . . . . 0,10 m.
49. Nodular limestone. Partly silicified . . . 0,04 m.
50. *Phosphate nodules* as 32 . . . . . . 0,05 m.
51. Chalk . . . . 1,00 m.

The facies shows a more and more pronounced shallowing. The flint beds disappear whilst the chalky formations gradually become marly. The sequence overlying the chalk 51 is as follows:

52. Granular limestone. Somewhat glauconitic . 0,20 m.
53. As above but becoming marly . . . 0,30 m.
54. Microlumachelle of *Bulimina,* speckled with small *phosphate nodules* . . . . 1,60 m.
55. Marly chalk . . . . 3,30 m.
56. Alternation of green marls and thin bedded marly limestone . . . . 23,35 m.
57. Argillaceous marls, green. Limestone 5—10 cm bedded are here and there intercalated. Gypsum veins . . . . 17,90 m.
58. Limestone of concretionary structure . . 0,05 m.
59. *Phosphate nodules* as 32 . . . . . . 0,08 m.
60. Gypsiferous and argillaceous marls. Green greenish weathered. Contains autigenetic crystals . 15,75 m.
61. *Phosphate nodules.* This is the thickest phosphate horizon in El Marah. As the above mentioned bed 32 it contains numerous metasomatosed fragments of conical vertebrae. From several analysis it results that the PO_4 grade of the nodules is 18 to 25 % . . . . 0,65 m.
62. Marls. Sometime chalky. With abundant *Bulimina* 2,30 m.
63. Calcarenite . . . . 1,85 m.

Although there is no stratigraphical gap at the top of the calcarenite 63, the overlying formations are distinctly transgressive. These are called „Palmyra chalks". We shall not give here a detailed description of them. The lower part of the Palmyra chalks represents the Upper Cretaceous with *Globigerina cretacea* d'Orb., *Bolivina incrassata* Reuss, *Gumbelina costulata* Cush., *Gumbelina globulosa* Ehrenb., whilst their upper part is of Eocene age. The recognition of Cretaceous and Eocene can only be based on their micropaleontological study in laboratory. According to this study the Palmyra chalks of Cretaceous age are here 288 m. thick.

This brings to 651 m. the total thickness of the Upper Cretaceous at El Marah.

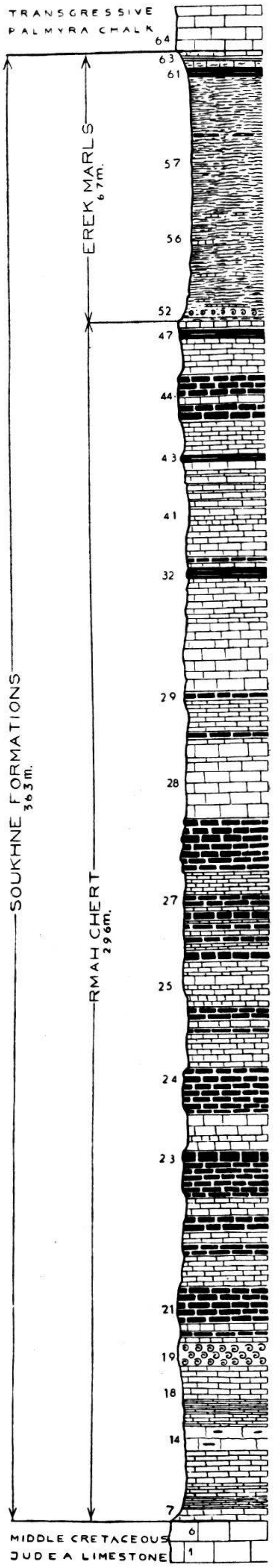

Fig. 1 — Stratigraphic section of the Upper Cretaceous at El Marah.

2. Thickness Measurement of a given Stratigraphic Sequence Isopach map

As is shown on fig. 1, three lithological units can clearly be distinguished in the Upper Cretaceous of the Palmyra area:

1. At the base, from the bed 7 to 51, a sequence characterized by the frequence of the cherts and hence generally termed „Rmah chert". Thickness .	296 m.
2. Then, from 52 to 63, a unit very well defined by its gypseous and marly formations known as „Erek marls"	67 m.
3. At the top, the transgressive „Palmyra chalks". From the horizon 64 to the beds containing the first Eocene microfauna, the thickness of the Cretaceous Palmyra chalks, as quoted above, is	288 m.

As the top of the third unit is lithologically not defined and cannot be discerned on the field (cf. page 6), we will consider, for our measurements, the first and the second series only, namely the Rmah chert and the Erek marls included between the *Scaphopods* lumachelle of the „Judea limestone" (horizon 6) and the transgressive „Palmyra chalk".

Lumachelle and transgressive deposits constitute excellent markers over all the studied area. The former represents, in fact, the last *Scaphopods* horizon of the Judea limestone and is, furthermore, a compact and very constant bed: we followed it from West to East for more than 150 kilometres without its exhibiting the slightest solution of continuity. As for the transgressive Palmyra chalks, their facies strongly contrasts with that of the subjacent gypseous marls. They are, moreover, compacter. The weathering colours are noteworthy too: white chalks overlying green marls, this gives rise to a visual sensation which may be compared to that caused by a coloured geological map.

Thus limited by the markers 6 and 64 (cf. fig. 1), the Rmah chert and Erek marls, which together are generally named „Soukhne formations", are 363 m. thick in the described El Marah section.

These 363 m. represent a maximum of thickness which is only to be found in the centre of the studied area.

From there, let us transfer our investigations northwards. We notice then a slow thickness decrease reaching 230 m. in the Dolaa well.

Towards the East and more particularly towards the South-East, the thinning down of the Soukhne formations rapidly becomes more marked. Thus, near Taibe, this lithological unit attains 220 m. and, in the Doubayat well, it is only 50 m. thick.

The same holds good in respect of the West and North-West of the Palmyra area. From the thickness of 363 metres at El Marah the Soukhne formations fall to 240 metres at Jebel Choumariye.

The behaviour of these formations towards the South shall not be described here. They crop out only partially in the studied area and, a little beyond it, the Cherrife well gives information, which we judge, for the time being, as insufficient.

We only mention the extreme values of the measured thicknesses. The enumeration of numbers obtained in the intermediary spaces would not be very useful here. The total of the measurements, made with a telescopic alidade, amount to 65.

Thus we have at our disposal a net of 65 marked points to which must be added those supplied by the deep wells. This net is sufficient to allow the drawing of an isopach map which is based only on positive facts, excluding any recourse to hypothesis.

We reproduce here such a map, on a reduced scale:

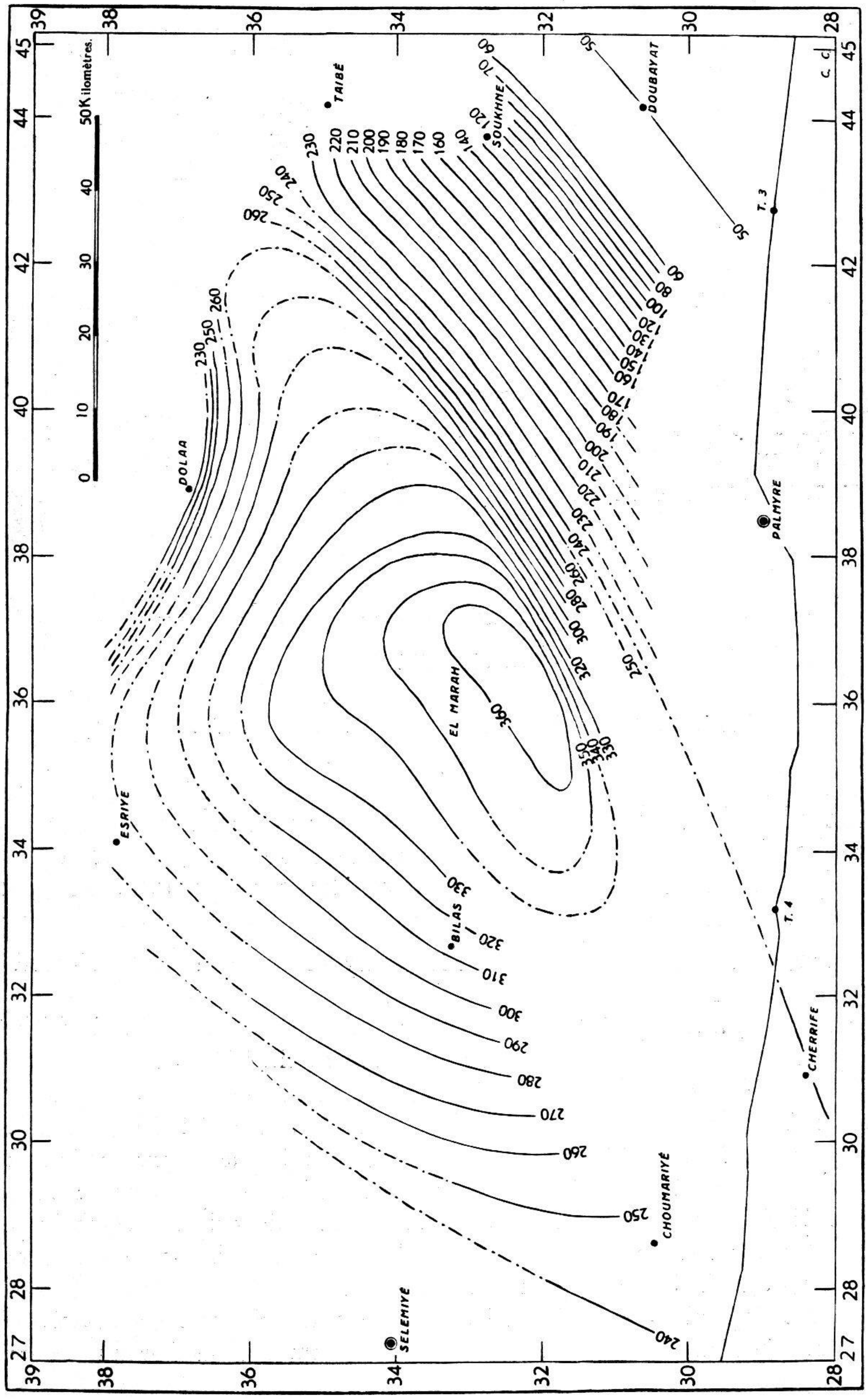

Fig. 2. Isopach map showing the thickness variations of the Soukhne formations (Upper Cretaceous).

Intrinsically, this isopach map represents a sedimentary basin, the edges of which slope towards the El Marah area, which area with its 360 metres thick sediments is the deepest part of the basin. Such as it is, this map only expresses the reality of a geometrical figure.

In order to arrive at a correct interpretation of the isopach map it is essential that this geometrical figure should be not considered in itself, but in function of its position in space at a given moment of the stratigraphic history.

The information alone that the graphic representation supplies, does not enable us to depart from the hypothesis of a sedimentary basin, the bottom of which is constituted by the lumachelle of *Scaphopods*. In that basin, the Upper Cretaceous sediments accumulate, varying in their thickness. The greatest thickness, 360 metres, would correspond to the deepest part of the basin. The decreasing thicknesses towards North, East, South-East, West and North-West, would indicate a shallowing towards some shore or submarine elevation.

This interpretation would thus assimilate the geological reality with the geometrical reality expressed by the map and would make the Palmyra area a closed sedimentary basin. It would concord in this way with the hypothesis generally accepted up to now.

Is such an interpretation of the isopach map reconcilable with what a careful stratigraphic study reveals? This is what we will now examine briefly by exposing the main results obtained.

3. Stratigraphy of the Upper Cretaceous of Palmyrene. Facies maps

a) Facies of the central part of Palmyrene

In the El Marah section, our starting point (cf. pp. 37-39 and fig. 1), the alternations of chalk and chert yield a fauna of rather shallow facies.

Though the question as to whether the chert beds represent a particular case of sedimentation is beyond the scope of the present note, we would like to mention here the few following facts:

The nature of the stratification of flint is clearly shown in the El Marah section. Thus, in the horizon 23 (p. 38), we can observe:

1. At the base, a chalky limestone becoming gradually more dense and which a micropetrographic examination reveals to be in course of silicification.

2. The second stage of silicification is illustrated by concretions which, at first sigth, seem to be chert nodules but which are, in fact, „chailles" that is to say incompletely silicified nodules, still reacting with HCl. The migration and concentration of SiO_2 occur in such a way that the silicified zones are concentrically arranged just as if the siliceous corpuscules, originally disseminated in the chalk, had been attracted towards a central point. The bed 23 presents the whole range of concretions from the chaille to the true chert nodule.

3. By following this bed 23 laterally, we have observed chert nodules aligned in the same bedding-plane. Some of them are isolated from one another but several show a

tendency to join together, then they gradually weld without changing their own concentric structure and finally they constitute a continuous flint bed.

It is clear that the silica was not deposited as nodules and beds but was, during or after the sedimentation of the chalk, in a state of suspension in the sea water. Its concentration in chert nodules and chert beds is quite certainly of epigenetic nature in the studied area[2]. Consequently the alternations of chalk and flint have not by themselves a sedimentary significance. The silica might be a criterion of facies only considered in its first state as saturating element. We cannot develop here this point of view, we will simply quote a fact in that connexion:

Without making a general rule of a particular case, we can say, that in the Palmyra area, the quantity of vertebrate fragments is in function of the frequency of chert beds. There is a great accumulation of *Meletta* and other fish remains in the chalks alternating with flint, whilst there is an almost total lack of these fossils where the chalk is alone.

The facies of shallow water which characterizes the Upper Cretaceous formations persists from the top of the Judea limestone throughout the Rmah chert unit, the upper part of which is scattered with phosphate nodules (cf. horizons 30 to 51).

With the Erek marls unit (horizons 52 to 63), the shallowing becomes more pronounced, leading to deposition of gypseous marls interbedded with phosphate layers and microlumachelles.

At the top of the Erek marls, the shallowing terminates without having brought to emergence the El Marah area.

As regards the distance of this area from land, we will mention, beside the absence of any clastic sediments, the coexistence of benthonic and pelagic faunas as well in the Rmah chert as in the Erek marls.

From these briefly exposed data, we conclude that the central part of Palmyrene is characterized by a pelagic[3] sedimentation of shallow water facies.

b) *Facies of the northern part*

At first sigth, the facies of the Upper Cretaceous does not seem to vary from El Marah toward the northern part of Palmyrene. However, by closely examining detailed sections, it is clearly noticeable that the decreasing thickness which we mentioned in the preceding chapter (cf. p. 40) corresponds too a deepening of the sea.

This deepening towards the North is expressed, on the one hand, by the diminution of the flint beds in the Rmah unit and, on the other hand, by the total disappearance of the gypsum from the Erek marls.

Both these facts, partially observable in the field, are evident in the Dolaa well. In our opinion, they signify that Dolaa is situated in a deeper part of

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2) Another really striking example is observable on the flank of the El Marah anticline. A little fault is there filled up with chalk in which chert nodules are at present in course of formation.

3) We use the word „pelagic" in the second sense given in C. M. Rice's dictionary, viz. as opposed to littoral.

the sedimentary area and farther from a shore than El Marah. As regards the hypothesis that the gypsum of the Soukhme formations might originate from the oxidation of pyrites[4] and, being a weathering-product, is not to be expected in a deep well, we agree that the present structure and position of the gypsum in the marls (veins of gypsum crystals) is obviously of epigenetic nature and thus the above hypothesis is fully justified. But, should the gypsum result from pyrites or from simple recrystallization of primary deposits, the fact remains that it indicates a shallow water facies and, hence, its absence as well as the absence of pyrite in Dolaa is quite significant.

Therefore we consider the northern part of the studied area as being of deeper facies than the central part.

c) Facies of the eastern and south-eastern part of Palmyrene

We have seen how the Upper Cretaceous formations show a rapid decrease of thickness from the centre towards the East and South-East, namely from El Marah, 360 m., to Doubayat, 50 m. (cf. p. 40).

When following these formations in both directions, we first observe that the Rmah unit grows thinner with increasing thickness of the Erek marls. Secondly, that these formations nowhere disclose a stratigraphic unconformity. Thirdly, that from a distance of about 60 kilometres to the East of El Marah, the chalks and the marls begin to be strewn with clastic debris. These debris which are rolled polygenic sand grains, become laterally more and more abundant and attain their maximum towards the South-East where they form veritable beds of sandstone.

The sandstone beds are especially numerous in the Rmah chert where they alternate with highly fossiliferous chalks and flint whereas in the Erek marls they are, on the whole, localized towards the top and the base.

The last outcrop of the south-eastern part of the Palmyra area is near Soukhne. In this type-locality, the Soukhne formations become fundamentally detrital and organic with big limestone pebbles of 10 to 15 cm. in diameter, lumachelles sometimes 7 m. thick and innumerable phosphatic nodules in the chalks and sandstones.

The typical littoral facies, as defined by E. Haug, is here perfectly realized.

d) Facies of the western and north-western part.

The most important facies changes of the Palmyra Upper Cretaceous appear towards the West and the Nord-West.

The Rmah chert unit, although still characterized by the chalk and chert alternations, become distinctly more calcareous.

At Choumariye, a summit situated at the western extremity of the studied area, the abundance of *Ammonites* shells is noteworthy in spite of the fact that such shells, owing to their great buoyancy, do not necessarily indicate a deeper facies.

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[4]) Dr. F. R. S. Henson. Unpublished reports.

The Erek marls are revealing most clearly the bathymetric differences which exist between the diverse parts of our sedimentary area.

These marls, which are, as mentioned above, very gypseous and argillaceous in El Marah, may easily be followed from there over 25 kilometres westwards. They become then somewhat chalky and soon marls and chalks alternate equal in quantity. Little by little and in proportion as they are situated more to the West and North-West, the marls decrease and finally the whole Erek marls unit merges laterally into chalks. At the foot of the Jebel Choumariye, in the Maksar section, the Erek marls no longer exist as lithological unit and are represented by chalks of the same age.

Thus, a sedimentation of *deeper facies* than at El Marah characterizes the western and north-western part of the Palmyra area.

e) Coordination of observed facts and stratigraphic conclusions

The facies we have now examined mark the Upper Cretaceous sediments between the Judea limestone and the transgressive Palmyra chalks, sediments which we have termed „Soukhne formations".

Without going into the details of the paleontological determinations, we will mention that the lower part of the Soukhne formations, i. e. the Rmah chert unit, yields a macro- and micro-fauna of Santonian and Lower Campanian age whilst the upper part, i. e. the Erek marls unit, represents the Middle Campanian.

To facilitate the description, we shall adopt here the American classification which does not include the Maestrichtian in the Senonian as it is usually done in France and in England. Thus, we have:

Upper Cretaceous	Danian	
	Maestrichtian	
	Campanian	Senonian
	Santonian	
	Coniacian	

what enables us to designate the Palmyra chalks as deposits of the Upper Senonian and hence to define our lithological units as being of Senonian age, respectively:

Senonian	Upper	Upper Campanian	*Transgressive Palmyra Chalk*
	Middle	Middle Campanian	*Erek Marls*
	Lower	Lower Campanian Santonian	*Rmah Chert*

Now, we will examine the horizontal distribution of the Senonian sediments in the Palmyra area.

We notice first that the various facies are distributed in zones parallel to one another along a sinuous line of a general SW-NE orientation and that this distribution is appreciably the same for the two units, Rmah chert and Erek marls.

It is clear that the facies thus distributed indicate, on the one hand, the existence of a shore in the SE and, on the other hand, a deepening of the sea towards the North and the North-West.

These facts are illustrated by the two facies maps of plate I, (fig. b and c). The facies map of the Lower Senonian, fig. b, shows the localization of the clastic deposits, sand and conglomerates, in the eastern part of the studied area, with the difference that, at Taibe, these clastic deposits are much more seldom found than at Soukhne. Sand and conglomerates gradually disappear towards the North and the North-West.

The second map, fig. c, makes the fact clear that during the Middle Senonian the sedimentation has been governed by the same factors as previously. The Erek marls contain clastic debris only in the south-western part of the Palmyrene. The deepening of the sea towards the North and the North-West is marked by the distribution of the sand and by the lateral progressive transition of the gypseous marls into chalks.

This constancy in the horizontal distribution of the facies during the greater part of the Senonian[5]) excludes accidental events such as for instance, the transport of clastic debris by submarine currents to a deep zone situated very far from the shore, or the existence of uplift movements in the sedimentary area.

The persistence of the detrital facies in the Soukhne-Taibe area implies, in fact, the permanence of the structural features generative of sand and conglomerates, and, consequently, places the south-eastern part of Palmyrene at no great distance from a shore.

In the same way, the parallelism between the facies zones involves, for these zones, a common dependence on the same sedimentary factor: the distance which separates them respectively from the shore. Had any orogenic movements taken place in the centre or in any other point whatsoever of the sedimentary area, forming the embryos of the present anticlines, the facies zones would be distributed likewise around these anticlines and not only according to a line parallel to the shore. Nothing of this kind occured and the facies lines are all oblique in relation to the present tectonic lines. Thus, if it is likely that the Cretaceous of the Arabian shield has seen the outline of movements analogous to the antesenonian movements of the subalpine ranges (Devoluy ranges) or to the pre-Gossau movements of the Eastern Alps, it is certain that these movements have not folded the sedimentary area of Palmyrene.

Admitting that some surrounding area, situated outside the boundaries that we have assigned to the Palmyrene, has been affected by an antese-

5) The top of the Judea limestone shows the same horizontal distribution of the facies zones as the Senonian described here. Near Taibe, for instance, a thick bedded, cavernous lumachelle of *Scaphopods* is locally strewn with polygenic sand grains.

nonian orogeny[6], it is to that orogeny that we should ascribe the movements which hence could be considered as „compensative movements", we mean the movements of subsidence marking chiefly the centre of the studied area. But, whatever may be its causes and provided that it can be proved, this subsidence eliminates by its very existence every possibility that the uplift of the present Palmyra anticlines started during the Cretaceous time.

Effectively, we have mentioned that the Soukhne formations at El Marah, where they attain their maximum thickness, are characterized by facies of shallow water from their base to their top. This observation holds good not only for this Senonian sequence, but also for all the Cretaceous and Eocene formations croping out in the central part of the Palmyra area[7]. If we measure these formations from the base of the Judea limestone[8] of Middle Cretaceous age to the top of the Palmyra chalks of Eocene age, we obtain a thickness of almost 1400 metres of sediments deposited in shallow water[9].

Such an accumulation renders sufficient evidence for the existence of a subsiding zone and, consequently, the hypothesis of Cretaceous uplift movements in the Palmyra area can be set aside.

This zone of subsidence, the axis of which may very well have been displaced during the Middle Cretaceous or the Eocene, is characterized, during the Senonian, by its orientation parallel to the shore and by a gradual shallowing (cf. p. 43). We take this shallowing to be due either to a gentle regression or to a disharmony between the slow sinking of the sea bottom and the intensity of the sedimentary filling in (the deposits accumulate more rapidly than the area subsides), or to both together.

Whilst this shallowing is easily observable in the littoral zone of Soukhne-Taibe, as well as in the subsiding area of El Marah, it is less clearly marked beyond El Marah and becomes less and less discernible towards the pelagic regions of the North-West.

To sum up we can conclude that *the stratigraphical study of the Palmyra area reveals the existence of a shallow Senonian sea on the border of the Arabian shield.*

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6) In fact, it really does seem that to the South-East of the Palmyra area, that is in the direction in which we locate our shore line, some Cretaceous movements have taken place. We fully accept Dr. F. R. S. Henson's hypothesis that the Ga'ara area, situated at 180 kilometres to the South-East of Soukhne, was dry land during the Senonian.

7) We could add the Oligocene and Miocene formations, likewise of shallow facies. But as they differ, by their essentially syntectonic nature, from the Cretaceous and Eocene sediments, we prefer not to include them in this study.

8) By „base of the Judea limestone" we mean the beds yielding the first Cenomanian fauna *(Exogyra flabellata, E. columba* etc.).

9) E. g. an average of 250 m. of Judea limestone, 296 m. of Rmah chert, 67 m. of Erek marls, 763 m. of Palmyra chalk (of which 288 m. of Cretaceous age), which represents in other terms:

Middle Cretaceous	250 m.	
Upper Cretaceous	651 m.	
Eocene	475 m.	Total thickness: 1376 metres.

While this sea is closed by a shore-line towards the South-East, it is open towards the North and the North-West.

This sedimentary area of Palmyrene is marked by a subsiding zone, the axis of which runs SW-NE parallelly to the shore-line.

Save a slow subsidence, no deformation has affected the Palmyra area during the Upper Cretaceous.

At the close of the Senonian, the transgressive Palmyra chalks are deposited without an angular unconformity and in constant sequence on the Soukhne formations. This fact and the great lithologic uniformity of the transgressive chalks prove, once more, the absence of structural highs during the Upper Cretaceous in the studied area.

General Conclusions

The interpretation of the isopach map (cf. p. 41, fig. 2 and p. 42), supported by the sole positive facts which geometric measures express, suggests the Palmyra area to be a closed basin. Figure 3 shows this basin schematically:

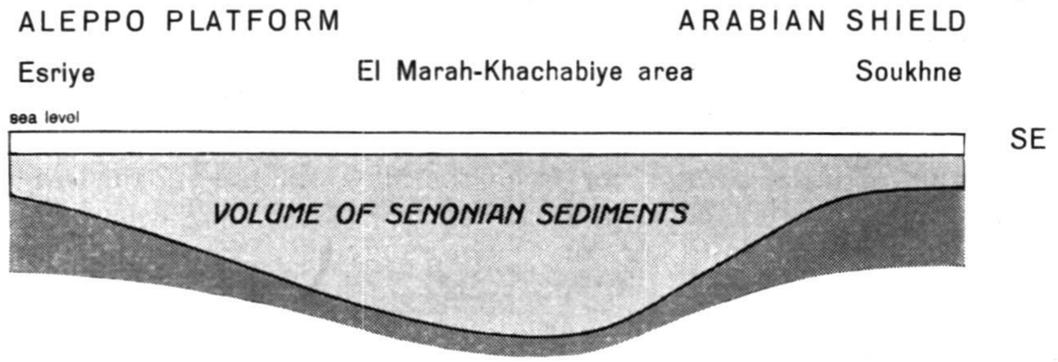

Fig. 3 — Sketched section across the Palmyra area illustrating the interpretation of the isopach map.

The stratigraphical study, essentially based on field observations and connecting the geometric data with the geologic facts, leads to the conclusion, summarized above, that the Palmyrene was during the Upper Cretaceous a sedimentary area of which figure 4 represents a schematic cross-section:

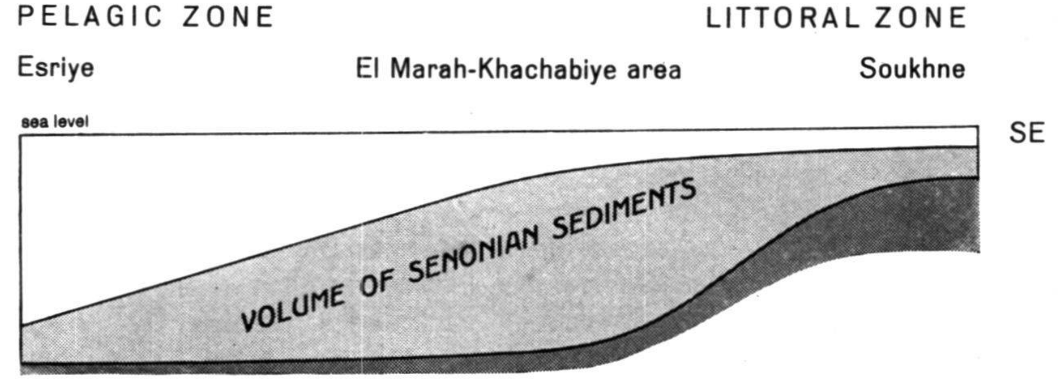

Fig. 4 — Sketched section across the Palmyra area taking into account the geometric data (isopach map) and the geologic facts (facies maps).

THICKNESS AND FACIES CORRELATION

CONSIDERED FOR THE PURPOSE OF LOCATING THE SHORE-LINES IN OIL PROSPECTING

L E G E N D

ISOPACH AND FACIES MAPS

Fig. *a*, *b*, *c*

- Chalk
- Argillaceous marl
- Gypsum
- Sandstone
- Conglomerate
- Chert
- Chalky limestone
- Point of observation
- Pipe-line and station
- Isopach inferred

Fig. *d*

- Chalk
- Argillaceous marl
- Gypsum
- Limestone interbedded in marls
- Sandstone
- Conglomerate
- Chert
- Chalky limestone

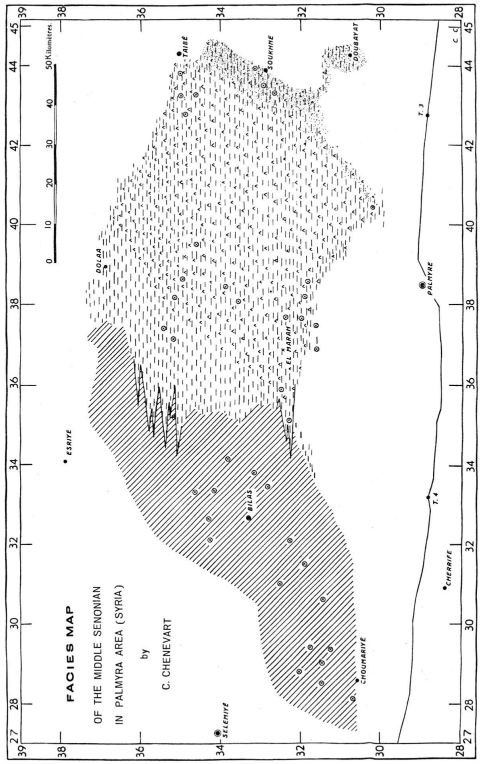

Fig. *c*

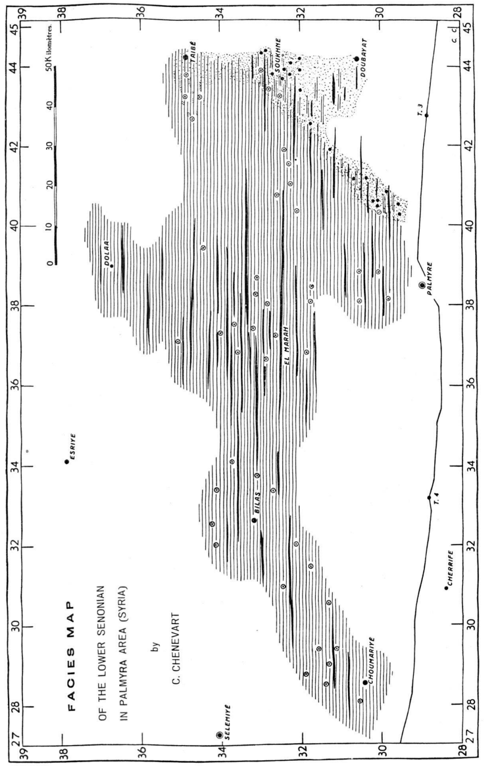

Fig. *b*

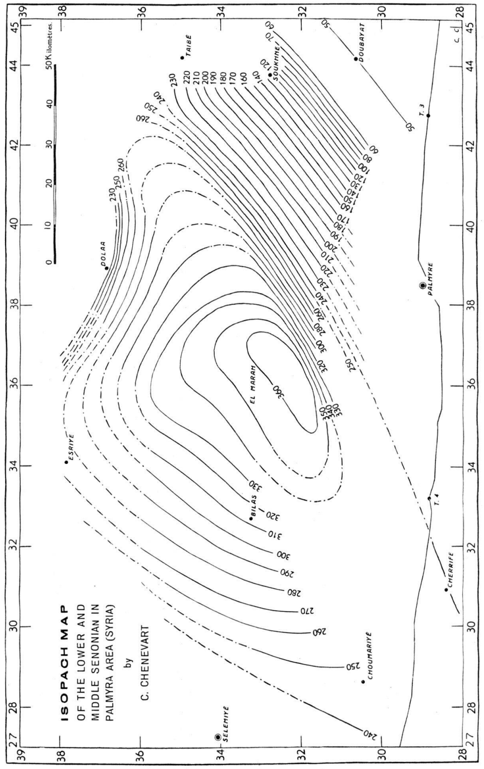

Fig. *a*

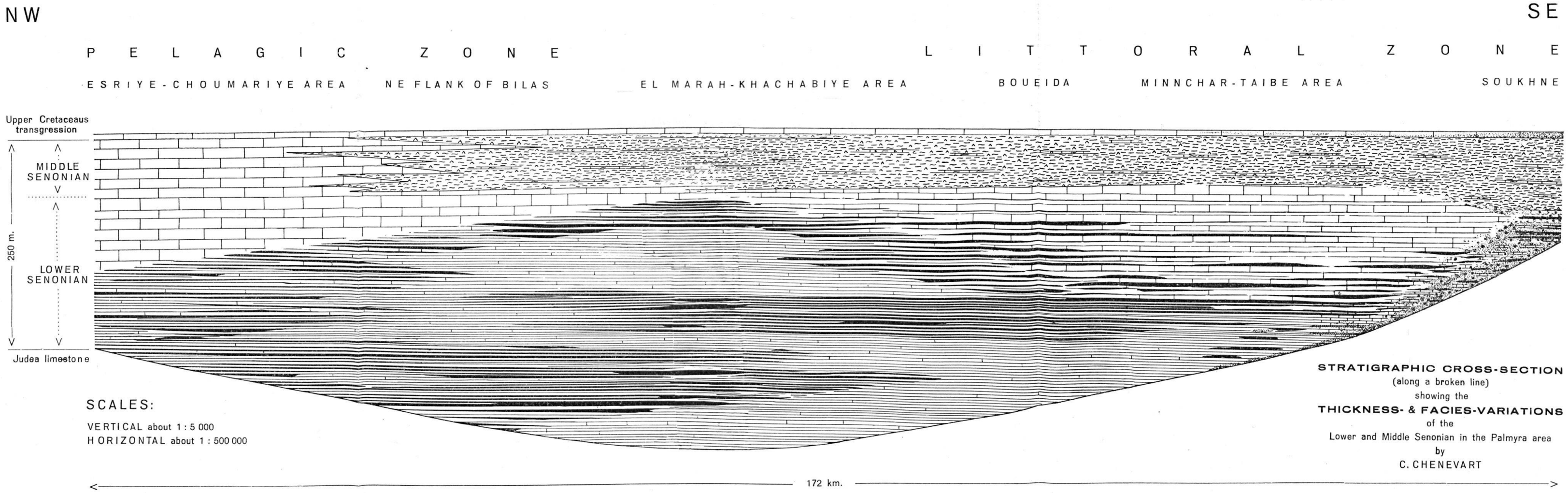

Fig. *d*

These two figures show the same volume of Senonian sediments, but owing to their different position with regard to sea level, the geometric reality expressed by figure 3 is totally opposed to the paleogeographic reality outlined in figure 4.

As a matter of fact, the implicit hypothesis of the geometric method confers on the thickness decrease of the sediments towards the North-West the same significance as on that observed towards the South-East. Likewise, it places the formations of greatest thickness into the central and deepest part of the sedimentary area.

But the stratigraphic study proves that, of two areas where the thickness of Senonian sediments decreases, one, that of the South-East, implies the vicinity of a shore, whilst the other one, that of the North-West, indicates on the contrary an increasing distance from this shore. The greatest thickness of the sediments is not situated in the centre and in the deepest part of a closed basin, but on the border of an open sea, the deepest parts of which are much farther off towards the North-West.

Thus the hypothesis suggested by an exclusive use of the isopach map is not reconcilable with the actual facts established by the detailed stratigraphic study. Such an hypothesis is only supported by data which, in spite of their mathematical accuracy, only permit mere surmises when searching for shore lines, a search which is so important in oil geology. Effectively, the interpretation of an isopach map will remain highly conjectural as long as it does not take into account the following quite obvious facts:

1. The thinning out of stratigraphic formations in a given direction does not imply necessarily the existence, in that direction, of a shore or of some structural highs above or below sea level. *This thinnig out may indicate a pelagic zone of shallow or deep facies as well as a littoral zone.* In consequence a stratigraphic gap is not always a criterion of emersion (cf. p. 50).

2. The thickest formations are not necessarily situated in the deepest part of a sedimentary area. On the contrary, we have noted during recent explorations in the Middle-East and North-Africa, that deep zones generally comprise sediments of slight thickness, whilst *the thickest formations are to be found in the intermediate zone between the littoral and the pelagic facies*[10].

Consequently, the only method which allows the geological interpretation of thickness variation is to draw isopach maps in combination with facies maps of time units.

In order to emphasize the necessity of applying this method, we have put in juxtaposition the isopach map, the facies maps and a stratigraphic cross-section of the Lower and Middle Senonian of the Palmyra area (cf. plate I).

The text referring to the figure a of plate I is on pages 40 and ff. Figures b and c are described on page 46. The confrontation of these

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[10] M. Gignoux quoted these facts as being a general rule (Géologie stratigraphique, p. 13. 4th Edition, 1950. Masson, Paris) and many descriptions of J. Bourcart, J. Jung, R. Laffite, J. Tercier confirm this point of view. Similar facts have been established in the Western Alps by M. Lugeon, A. Jeannet and E. Gagnebin.

three maps is self-explanatory. Figure d makes clear in section what the maps indicate in plan, i. e. the lateral variations of thickness and facies of the Senonian. This section completes the schema represented at the beginning of this chapter (cf. fig. 4, p. 48).

In illustration of what has been stated previously, it is noteworthy to observe the position of El Marah-Khachabiye in the zone of maximum subsidence which is also the intermediate zone between the littoral and the pelagic facies. Then, as regards the thinning out of the Senonian towards the North-West, if we assume that it persists beyond the studied area, it would lead to a nondepositional surface or to a portion of the sea floor where deposition is insignificant. Thus, a stratigraphic gap of the Senonian might be expected in our pelagic regions, which gap would not necessarily be due to currents inhibiting the sedimentation[11].

We conclude now that in stratigraphic research as a whole and particularly in oil prospecting the isopach maps are only really useful when they are accompanied by facies maps. However, we admit the value of isopach maps used alone when it is a question of estimating, in a broad sense, the development of basinal conditions of areas comprising thick series of uniform facies involving no great bathymetric extremes. On the other hand, when we are dealing with thick formations of wide extent as, for instance, the entire Cretaceous-Eocene-Oligocene of Syria, phenomena such as the migration of subsidence axis or the increase of the bottom curvature with subsequent displacement of the facies zones, would render illusory any attempt to correlate thickness and facies. Relations between thickness and facies, as clear as those presented in the Senonian of Palmyra, can only be established when we are dealing with units of small extent both vertically (time) and horizontally (space).

Thus, the synthesis of geometric and stratigraphic data has enabled us to bring out the essential features of the Palmyra area during the Senonian. In our opinion, this area, often considered as being a closed basin, was during the Upper Cretaceous a shallow sedimentary area limited towards the South-East by the Arabian continent and open to the North-West towards the pelagic regions of the Mediterranean geosyncline.

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11) F. P. Shepard mentions other highly important cases of nondepositional surfaces in deep seas. (F. P. Shepard, Submarine Geology, pp. 164, 303. New York 1948).