# Relationship Between Organic Matter and Sedimentation in the Lias of Lorraine (France)

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*Abstract.* The organic matter of the Lorraine Lias (eastern margin of the Paris Basin) has been analyzed in all its formations, from the north to the south of the area.

The results obtained serve to highlight the major geochemical variations at this study scale. Here, in time and in space, the contents and type of the organic matter result from paleogeographic features inherent in the situation of a zone of high subsidence with high sedimentation rate and in the proximity of the terrigenous sources. The highest values exist during transgressive pulsations, especially where the sedimentation rate is high and the environment confined. The units where the organic matter is richest and best preserved are found in northern Lorraine, outside the large coarse-grained terrigenous depositions.

Another objective of this analysis is to add to the geochemical analytical data and to provide further information on the source rocks of the Paris Basin.

## Introduction

The aim of this chapter is to analyze the Lias of the eastern margin of the Paris Basin (Lorraine) by trying to interpret the results of organic geochemistry in relationship with the environmental variations during the Lias. The results obtained also serve to supplement the earlier studies (Espitalié et al. 1987a, b) which showed that the Lias of the Paris Basin contained the main oil source rocks of the Trias and the Dogger, and that the center of the Basin (Brie/Champagne area), the most subsident zone, with very high sedimentation rate, generally contained the best organic matter contents and the hydrocarbon formation zone (Hanzo and Espitalié 1993).

The Lias outcrops along a westward concave aureole extending nearly 200 km from north to south (from Luxembourg to Langres) and 50 km from East to West (Fig. 1).

The axis of the zone of maximum subsidence of the Paris Basin trends approximately ESE/WNW throughout the Lias; it is located north of the area analyzed. Three areas are distinguished to the south of this axis in the following discussion, exhibiting varied paleogeographies and hence different genetic contexts for the deposition and preservation of organic matter, with shallow burial (Fig. 1). Northern Lorraine and central Lorraine are separated by the Metz Fault, a major tectonic feature, which controls the liassic sedimentation along a flexure zone associated with the high subsidence area of northern Lorraine (Fig. 2). On the contrary, another major fault, the Vittel Fault (between Nancy and Langres) has no effect on the sedimentation (Le Roux 1980). Accordingly, the central Lorraine/southern Lorraine areas are separated by a boundary located north of Fécocourt, and specified by some authors (Alpern and Huc 1976) as the limit between two geochemical provinces during early Toarcian times.

## Study Method

The sections were selected in order to identify the variations in environmental conditions over time, throughout Lorraine. In addition to 12 outcrops (rare in Lorraine), 26 boreholes (mostly cored) supplied by EDF, Scetauroute, and BRGM, were analyzed (Fig. 1). Two of these boreholes, Cattenom (Hanzo and Guérin-Franiatte 1985) and Tranqueville, together cover nearly the whole of the Lias.

The sampling on each section was carried out taking account of the variety of lithofacies, fluctuating between argilites and limestones. Studies aimed at a better understanding of the paleoenvironment in which the organic matter was deposited.

Samples were analyzed by using following techniques:

- lithologic analysis, based on microscopic observations, shale analyses, and determinations of inorganic carbon;
- paleontological analysis of macroorganisms, benthic foraminifera (C. Ruget 1985, pers. comm., Ruget and Hanzo 1992), and microflora (data from M. C. Adloff, and Hanzo et al. 1990);
- organic content study of 600 samples, analyzed by Rock-Eval pyrolysis (Espitalié et al. 1985).

## Bio-Lithostratigraphic Setting

In Lorraine, the sedimentological context of the Liassic series is that of a vast platform open to the Swabian and Alpine Basins, affected by a marine transgression from the base of the Jurassic (Maubeuge 1955; Allouc 1980; Groupe Français d'Etude du Jurassique 1980; Hanzo

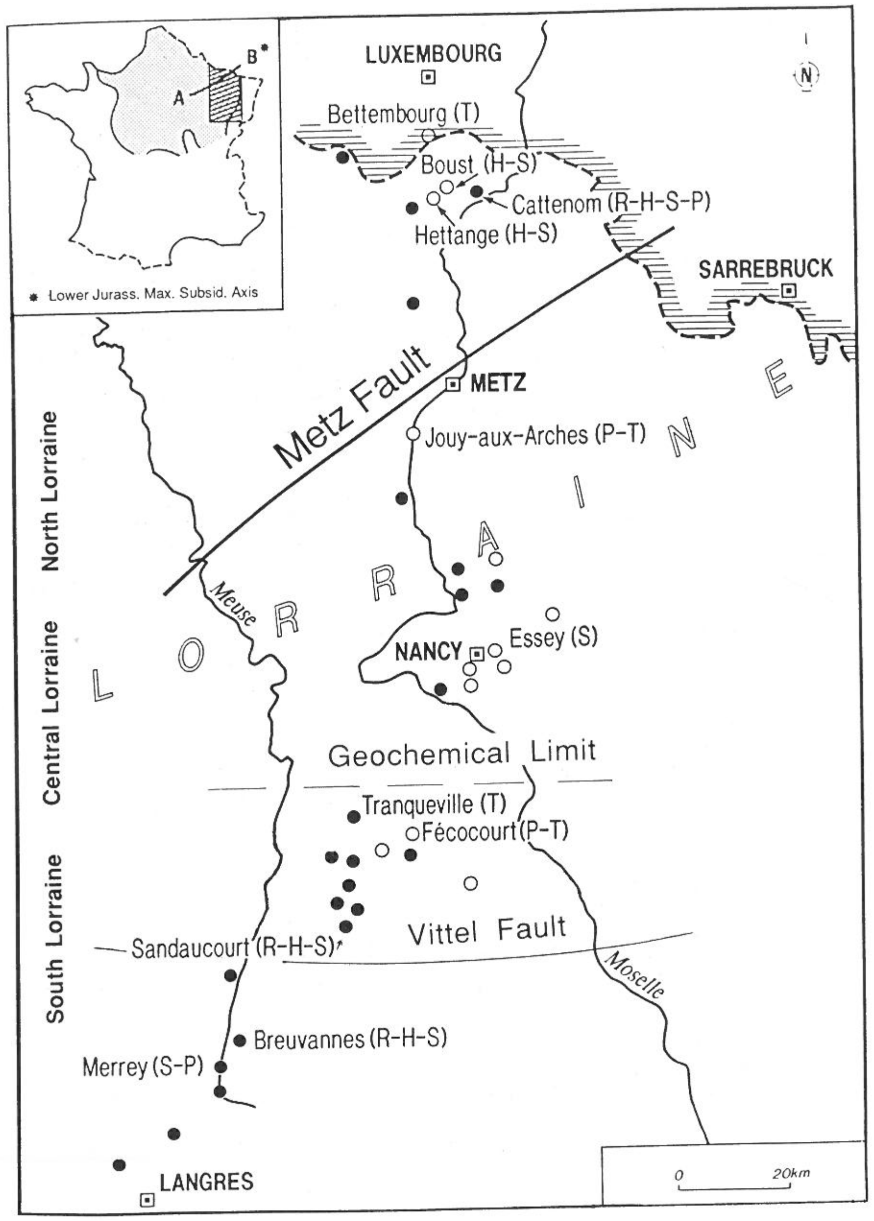



**Fig. 1.** Situation map of sites in northern, central and southern Lorraine. ○ outcrops; ● boreholes; *R* Rhaetian; *H* Hettangian; *S* Sinemurian; *P* Pliensbachian; *T* Toarcian

1980). The bio-lithostratigraphic series is shown in Table 1, with 550 m of Lias to the North and 200 m in the center and south. After an incipient transgression during Lower Rhaetian, from the base of the Lias, the sea advanced from east to west, associated with the opening of the basin.

### Classical Stratigraphy

In classical stratigraphy, the lithologic units obtained are grouped in klüpfelian sequences which grade upwards into filling up facies: argilites are followed by shelly or sandy limestones. Following the Calcaire à gryphées (including the Grès d'Hettange to the North), they are:

- Argiles à Promicroceras and Calcaire ocreux;
- Marnes à Numismalis and Calcaire à Davoei (northern area);
- Argiles à Amalthées and Grès médioliasique;
- the series ranging from Schistes carton to Marnes à Voltzi (at the peak of the transgression) and Grès supraliasique;
- ferriferous layers attributed to the Minette complete the liassic series.

### Sequence Stratigraphy

Four second-order transgressive-regressive cycles can be identified (Hanzo et al. 1992) in the Lorraine liassic sequence, from lithology, disconformities, and biostratigraphy:



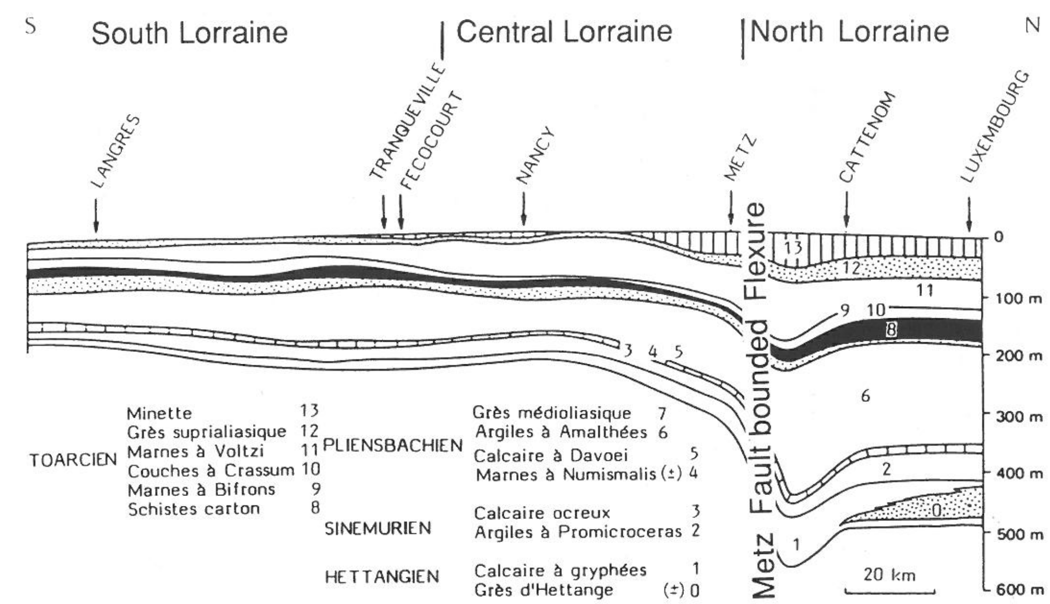



**Fig. 2.** Schematic section of Lorraine Lower Jurassic. (After M. Hanzo 1980)

**Table 1.** Bio- and lithostratigraphy of Lorraine Lower Jurassic

| BIO-LITHOSTRATIGRAPHY | | | | | FORMATION THICKNESS | | |
|---|---|---|---|---|---|---|---|
| | Ammonite Zones | Formations | Lithological Sequences | Genetical Sequences (2 order) | NORTH | MIDDLE | SOUTH |
| AALENIAN | Aalensis | | | | | | |
| | Pseudoradiosa | Minette | | | 15 - 60 m | 10 - 12 m | a few m |
| TOARCIAN | Dispansum | Grès supraliasique | | | 1 - 25 m | 10 m | a few m |
| | Thouarsense | Marnes à Voltzi | | | 20 - 60 m | 65 m | 20 - 60 m |
| | Variabilis | Couches à Crassum | | | 1 - a few m | 1 - a few m | 1 - a few m |
| | Bifrons | Marnes à Bifrons | | | 20 m | 7 - 10 m | 15 - 20 m |
| | Serpentinus Tenuicostatum | Schistes Carton | | | 25 - 60 m | 20 m | 2 - 20 m |
| PLIENSBACHIAN – DOMERIAN | Spinatum | Grès médioliasique | | | 40 m | 8 - 15 m | 30 m |
| | Margaritatus | Argiles à amalthées | | | 100 - 180 m | 30 m | 30 m |
| PLIENSBACHIAN – CARIXIAN | Davoei | Calcaire à Davoei | | | 0,5 - 3 m | 1 - 2,5 m | 3 - 5 m |
| | Ibex Jamesoni | ± Marnes à Numismalis | | | a few - 13 m | | 3 - 6 m |
| SINEMURIAN SL – LOTHARINGIAN | Raricostatum Oxynotum | Calcaire ocreux | | | 0,2 - 1 m | 1,5 m | 0,5 - 1,5 m |
| | Obtusum Turneri | Argiles à Promicroceras | | | 50 m | 30 m | 15 - 30 m |
| SINEMURIAN ss | Semicostatum Bucklandi | Calcaire à gryphées ± Grès d'Hettange | | | 20 - 70 m | 10 - 20 m | 4 - 30 m |
| HETTANGIAN | Angulata Liasicus Planorbis | | | | 0 - 30 m | | |

**Table 2.** Organic geochemistry of Lorraine Lower Jurassic: average parameters from five areas on all outcrops and boreholes

| Areas | | Average Thickness (m) | T.O.C. (%) | Mean S2 (mg HC /g rock) | Total S2 ($10^6$t HC /km$^2$) | H.I. (mg HC /g T.O.C.) | Outcrops and Boreholes |
|---|---|---|---|---|---|---|---|
| Thionville | 4 | | | | | | |
| | 3 | 45.7 | 6.8 | 43 | 4.91 | 588 | L1-Bettembourg-G1-G2 |
| | 2 | 253 | 1 | 1.47 | 0.93 | 101 | Cattenom |
| | 1 | 60 | 1.74 | 5.44 | 0.82 | 220 | Cattenom |
| Metz | 4 | | | | | | |
| | 3 | 16.5 | 4.6 | 24.5 | 1.01 | 426 | G3-Jouy aux Arches |
| | 2 | | | | | | |
| | 1 | | | | | | |
| Nancy | 4 | | | | | | |
| | 3 | 18.5 | 7.10 | 45.0 | 2.08 | 636 | N1-N2-G4-G5 |
| | 2 | 13.1 | 0.25 | 0.19 | 0.006 | 40 | Jeandelaincourt-Heillecourt-Essey-Ludres |
| | 1 | 7.7 | 0.58 | 0.76 | 0.01 | 53 | Mazerulles-Cerville |
| Fécocourt | 4 | 47.8 | 1.38 | 4.88 | 0.58 | 174 | Tranqueville-Aboncourt |
| | 3 | 17.2 | 6.4 | 39 | 1.67 | 575 | F1-Tranqueville-Fécocourt-G6-G7-Aouze |
| | 2 | 7.3 | 0.36 | 0.24 | 0.004 | 59 | Fécocourt-Aouze-Châtenois-Balléville-Mannecourt |
| | 1 | 15.5 | 0.94 | 2.63 | 0.10 | 70 | Poussay-Sandaucourt |
| Langres | 4 | 15 | 1.01 | 1.63 | 0.06 | 138 | Dampierre |
| | 3 | 4.3 | 5.24 | 29.78 | 0.32 | 510 | G8-Dampierre-G9 |
| | 2 | 8.9 | 0.47 | 1.71 | 0.04 | 79 | Breuvannes-Merrey-Dampierre |
| | 1 | 4.4 | 0.33 | 0.17 | 0.002 | 33 | Breuvannes-Provenchères |

4 = Middle-Upper Toarcian --> Marnes à Bifrons - Couches à Crassum - Marnes à Voltzi - Grès supraliasique
3 = Lower Toarcian --> Schistes carton
2 = Upper Sinemurian-Pliensbachian --> Argiles à Promicroceras - Calcaire ocreux - Marnes à Numismalis (±) - Calcaire à Davoei - Argiles à Amalthées - Grès médioliasique
1 = Hettangian - Lower Sinemurian --> Calcaire à gryphées ( - Grès d'Hettange)

- Lower Calcaire à gryphées and Grès d'Hettange (only in northern Lorraine), with transgressive system tract and highstand system tract; they correspond to subzones from Planorbis to Angulata;
- upper Calcaire à gryphées, Argiles à Promicroceras, Calcaire ocreux, Marnes à Numismalis and Calcaire à Davoei, with a rhythmic succession of transgressive and highstand system tracts (with still some uncertainties); they correspond to subzones from Conybeari to Figulinum;
- Argiles à Amalthées and Grès médioliasique, with two episods transgressive-highstand system tracts; they correspond to subzones from Stokesi to Apyrenum;
- Schistes carton, Marnes à Bifrons, Couches à Crassum, Marnes à Voltzi, and Grès supraliasique, with a rhythmic succession of transgressive and highstand system tracts (with still some incertainties); they correspond to subzones from Hawskerense to Gruneri.

## Analysis of the Organic Matter

Quantitative and qualitative analyzes of the organic matter have been carried out in the different sedimentation environments, characterized mainly by their lithology and their paleontological content. Immaturity is one characteristic of the organic matter found in the different units. Only its content and its state of preservation vary in accordance with the sedimentation environment.

### *Characteristics of the Organic Matter in the Different Formation* (Table 2)

*Calcaire à Gryphées.* This is represented by alternating limestones and marls or calcareous argillites, deposited in a medium energy reducing environment. Considering the northern Grès d'Hettange sandstone member which is part of the Calcaire à gryphées formation, we can note, from south to north, that the quantity of terrigenous material rises progressively and reflects the increasingly marked influence of the Ardennes Range. The presence of coarse bioclasts argues in favor of a weak bathymetry, also reported by other authors (Hallam 1960). The monospecific combinations of encrusted foraminifera indicate an environment in the course of opening in the Hettangian. Progressively, their variety and their abundance increase. The palynological content, in northern Lorraine, reveals a mixture of continental forms and marine forms, with the initial predominance of humic matter, followed progressively by amorphous matter (Hanzo et al. 1990).

The organic carbon contents in these facies show that, in the south, the few samples analyzed in the argilites of the transition zone (at the Rhaetian/Hettangian boundary) have uniformly low TOC contents (about 0.3 %). In the north, the high sedimentation rate zone, the values are higher and more variable (0.5 to 1.8 % from one section to the next). For the Calcaire à gryphées, the data are far more numerous and the ranges of values between north and south are approximately the same. On a given section, at least in a borehole, the variations are wide, ranging from 0.2 to 9 % TOC in the south (at Sandaucourt) and from 0.2 to 5.3 % in the north (at Cattenom). At Cattenom, the TOC contents show an overall increase with the carbonate contents at the top of the formation. They are lower in central Lorraine. In Grès d'Hettange, where coarse-grained terrigenous deposits are considerable, the thick sandstone facies of Hettange and Boust (in the subsident north zone) have low TOC values, lower than at Cattenom with only 2.5 m of sandstone.



Throughout the Calcaire à gryphées, the organic matter is marine, as is clearly demonstrated by the symmetrical shape of the $S_2$ pyrolysis peaks, and immature, but probably poorly preserved, judging from the low HI values (Espitalié et al. 1985; Crumière and Espitalié 1989). However, variations exist. In the north, at Cattenom, the organic matter definides a continental influence at the base of the formation; on the other hand, the organic matter is marine and well preserved at the top (with HI from 200 to 500) (Fig. 3 a). The samples analyzed in Grès d'Hettange, with frequent lignite levels, are very fine shale seams, the only manifestations of marine sedimentation. The organic matter there cannot be characterized because of the low TOC contents and HI. Elsewhere in Lorraine, with the exception of Sandaucourt, which demonstrates units with good organic matter, the HI values are low (less than 150 on average), characteristic either of the deposition of continental organic matter, or of the deposition of marine organic matter weathered to varying degrees. The analysis of the shape of the $S_2$ pyrolysis peaks (Espitalié et al. 1985) shows that they probably concern a marine organic matter weathered in the course of its deposition. This may be connected with the low sedimentation rate of these series, deposited in an environment that did not allow good preservation of the organic matter after its deposition.

*Argiles à Promicroceras.* With the relative rise of the sea level, the sedimentation took place in a calmer environment. The vertical facies distribution is, in fact, progressive, first marly, and then mainly shaly.

Macrofossils are rare, and the very irregularly distributed foraminifera are elongated and costulate individuals, which nevertheless attest to a sufficient oxygen in the aquatic environment. At Cattenom, they are very numerous and highly diversified, and the microflora prove to be rather poorly preserved there, with more and more humic matter, but also dinoflagellate cysts at the base of the series (Hanzo et al. 1990).

The organic carbon contents measured in these facies are low (0.2 to 0.9 % on average). They are generally uniform over a given section. At Cattenom, the transition from the Calcaire à gryphées to the Argiles à Promicroceras is progressive, not only lithologically, but also in terms of organic matter content (1 to 2.3 % in the base marls which also contain the highest organic matter). In this thick series composed of fine-grained terrigenous material, with very low organic matter contents, it is nevertheless in the northern subsidence zone that the highest TOC are located.

To the north, especially at Cattenom, the organic matter is generally of marine origin (symmetrical $S_2$ peaks) but poorly preserved, as indicated by the HI values (Fig. 3 a) which do not exceed 100: with an average of 13 to 60 (except in the neighborhood of the Calcaire à gryphées). As again demonstrated by the $S_2$ peaks, the organic matter of continental origin is visible in some samples. At the center (Essey) and south (Breauvannes and Merrey), the organic matter is even more poorly preserved (HI generally lower than 50), only allowing its terrigenous component to subsist.

*Calcaire Ocreux, Marnes à Numismalis, Calcaire à Davoei.* A regressive trend can be observed, reflected by a detrital carbonate episode, containing a marly insertion in northern Lorraine.

The facies are suddenly very rich in benthic macrofauna (sedimentation rate being low), whereas the evolution of the foraminifera is more progressive. In the Carixian, the microfauna is abundant and well preserved, displaying strong ribs which attest to major action of the waves. In these three formations, the palynological content reveals very few continental forms (spores and pollens) and marine forms (acritarches), which are poorly preserved throughout.

The organic matter contents of the limestone facies, which are more or less uniform throughout a given section, do not really appear to have changed in comparison with the above contents (0.06 to 0.8 % on average). The lowest values are found in central Lorraine. In the Marnes à Numismalis, they rise sharply (1.9 % on the average, with a maximum of 2.7 %).

Throughout the area investigated, the organic matter is very poorly preserved in the Calcaire Ocreux and the Calcaire à Davoei (HI generally below 60). In the Marnes à Numismalis (only in northern Lorraine, at Cattenom), the organic matter, of marine origin, is far better preserved (HI up to 335) (Fig. 3 a, b).

*Argiles à Amalthées, Grès Médioliasique.* The opening of the Basin then increased and the dominant energy is fairly low. This concerns shaly and silty facies, where the quantity and size of the silts are greater than previously (Allouc and Hilly 1979), increasing particularly from the Argiles à Amalthées to the Grès médioliasique.

Macrofossils and various traces of life are numerous in the Argiles à Amalthées, with new, abundant, rapidly evolving forms of foraminifera. At Cattenom, a few samples reveal several spores and pollens, confirming the continental influence aready marked by the extent of the silts, and a few rare acritarches. In the Grès médioliasique, the foraminifera tend to decrease, fol-

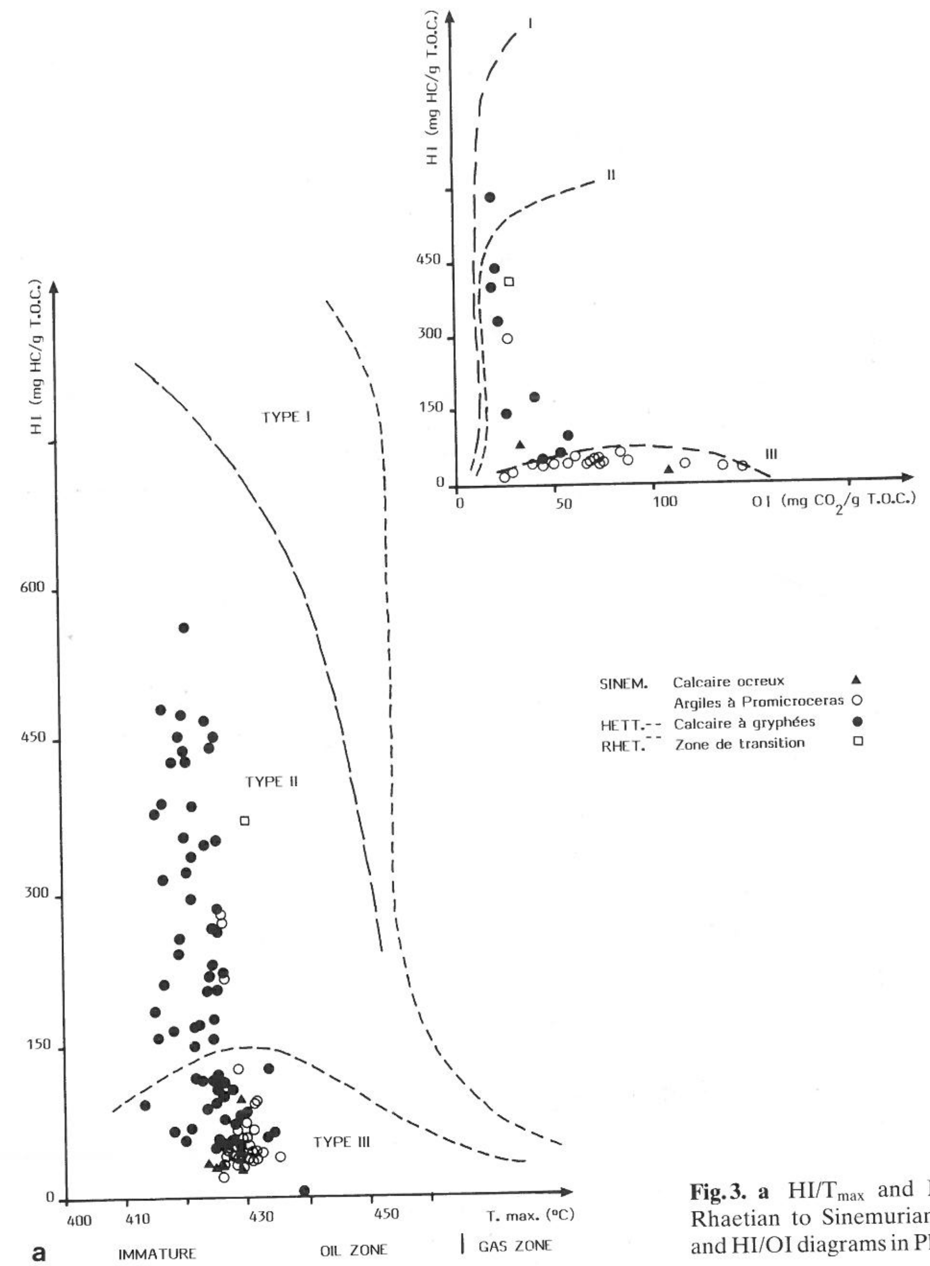



**Fig. 3. a** HI/$T_{max}$ and HI/OI diagrams in formations from Rhaetian to Sinemurian, in Cattenom boreholes. **b** HI/$T_{max}$ and HI/OI diagrams in Pliensbachian formations, in Cattenom

lowed by the extinction of the previous forms, except in northern Lorraine, where the series is thicker.

The preservation of the organic matter in these very silty facies is not good (0.3 to 0.8 % TOC on average). The lowest values are found in northern Lorraine. There is no variation in any given section, apart from a slight decrease in the Argiles à Amalthées, at the top of certain boreholes. Note the extremely low values on the Jeandelaincourt section.

In the Argiles à Amalthées in general, the organic matter exhibits a dominant marine character, except at the top of the Cattenom series, marked by the more pronounced terrigenous deposition of the next formation. The HI values do not exceed 130, revealing a weathered character (Fig. 3b). This preservation decreases further in the boreholes of southern Lorraine. In the Grès médioliasique where the values are less dispersed than in the Argiles à Amalthées, the hydrogen index values do not exceed 145. The continental influences are not clearly marked, probably because of dilution or oxidation of the transported terrigenous materials.

*Schistes Carton and Base of Marnes à Bifrons.* The sea transgressed and reached its maximum extension, depositing shales essentially with so-called bituminous facies.

The environment, with stratified waters, has become euxinic at the sea floor, and is marked by the absence of benthos. Macrofauna are absent and the Domerian foraminifera reveal many extinctions at the base of the Schistes cartons. This environment favors the preservation of organic matter. The observation of the microflora reveals very few pollens, spores, and acritarches at Tranqueville, and very few coccoliths at Bettembourg. This probably results from a dilution by the terrigenous mate-



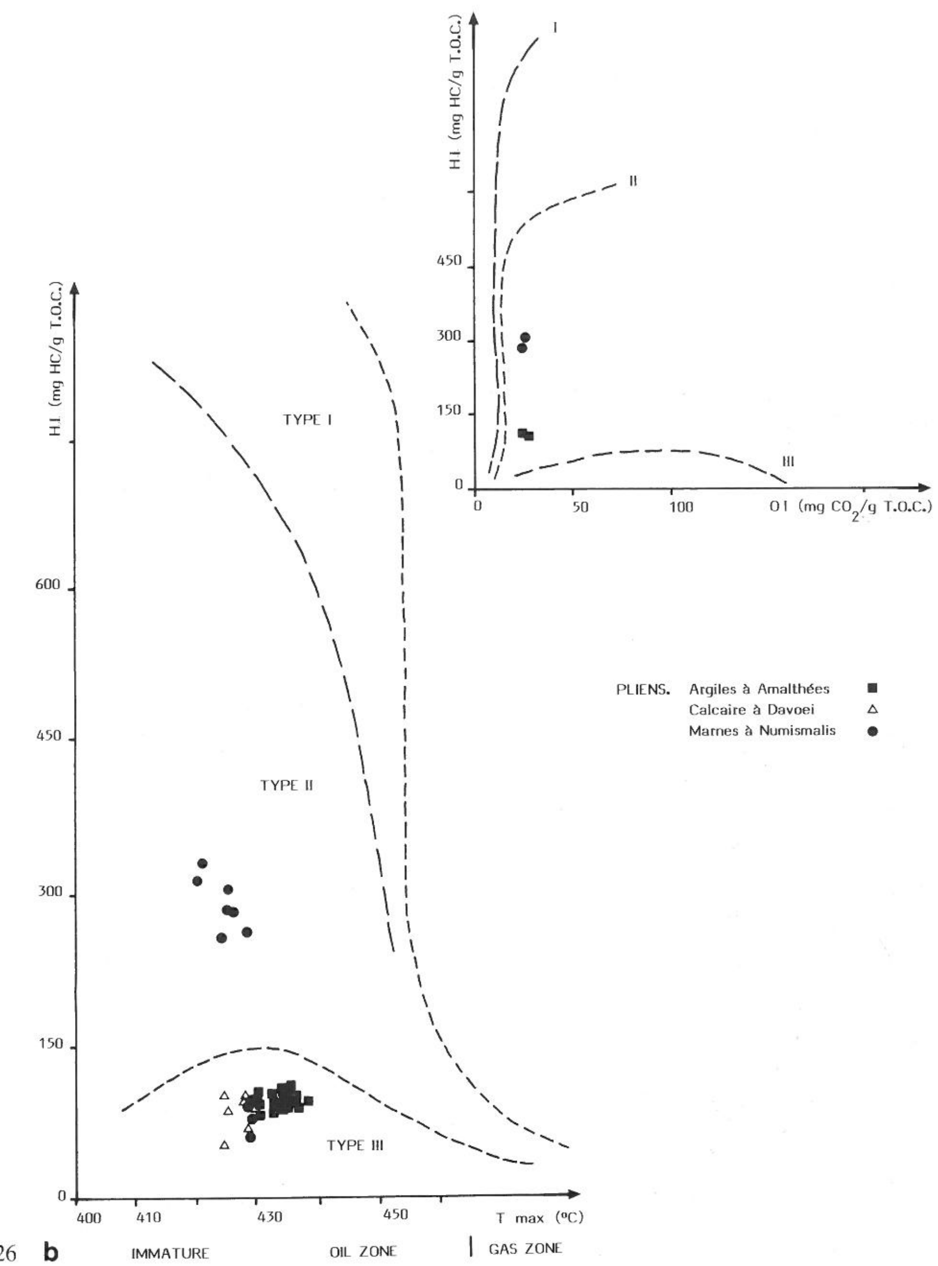



**Fig. 3** *(continued).* Legend see p. 126

rial, because, elsewhere, the Schistes cartons are particularly rich in very well-preserved varieties of coccoliths, thanks to the confined character of the depositional environment (Goy 1979).

These facies are very rich in organic matter, sometimes up to 12.5 %, with averages of 2.4 to 8.5 %, with the maximum in the north, the highest sedimentation rate zone, and the minimum at Jouy aux Arches (north central Lorraine). On a given section, the range of values is sometimes rather wide, varying by a factor of 2 at Tranqueville, for example.

The organic matter is clearly marine and well preserved, with HI values up to 720 (Fig. 4) (271 to 720, with a random distribution). Nevertheless, some facies reveal the effect of weathering at the outcrop.

*Marnes à Bifrons, Couches à Crassum, Marnes à Voltzi, and Grès Supraliasique.* The environment progressively becomes more open and the deposits more oxygenated. They yield shales with carbonate laminites, with increasing energy in the environment, and enrichment in silts and carbonates in the Grès supraliasique.

The foraminifera demonstrate a deep renewal, up to the Grès supraliasique, where they disappear. At Tranqueville, the microflora, generally poorly preserved, reveal very few spores and pollens. Acritarches and dinoflagellate cysts exist from the Marnes à Voltzi onward. At their top, the Tasmanaceae indicate the generally regressive character of the sequence.

The organic carbon contents decrease, with an average of 1.2 to 0.8 %. The limestone facies are less rich than the shale facies. The Grès supraliasique facies are marked by decreasing organic matter content up to the Minette unit,

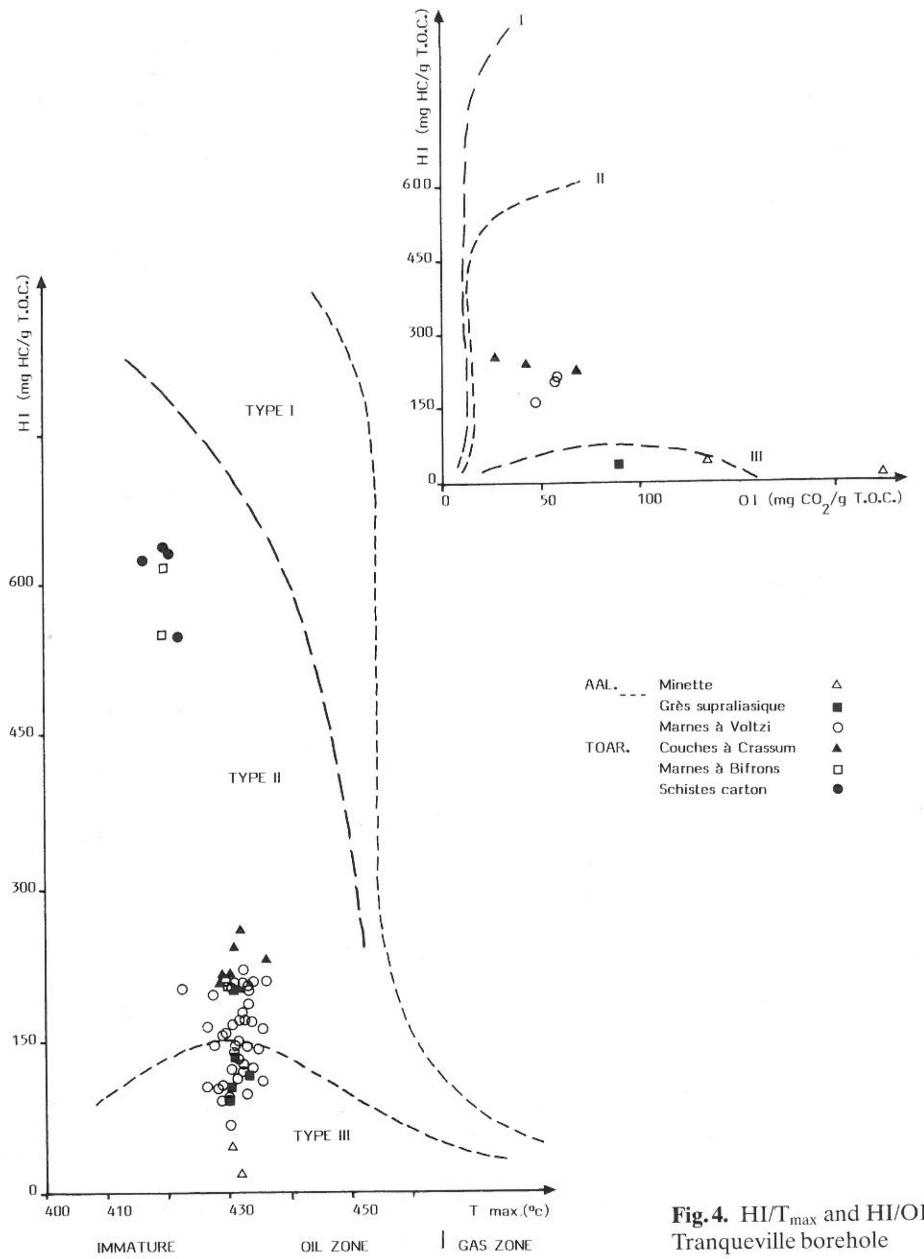



**Fig. 4.** HI/$T_{max}$ and HI/OI diagrams in Toarcian formations, in Tranqueville borehole

0.6 and 0.4% average TOC, respectively. From the base of the Toarcian to the Aalenian, the decline in the organic carbon contents is progressive.

The hydrogen index drops progressively from the Marnes à Bifrons to the Marnes à Voltzi and from the Grès supraliasique to the Minette (100 to 44). On the whole, the organic matter is rather of marine origin, or possibly of continental origin masked by weathering. In fact, the continental influence is progressively demonstrated as one rises in the series, with an increasingly poorly preserved organic matter.

Figures 5, 6 and 7 (pp. 129–132) show the organic geochemistry results in the three regions of Lorraine. Table 3 (pp. 135, 136) gives the relevant data in all the formations: average values of the geochemical parameters.

## *Complement to the Study of the Source Rocks of the Paris Basin*

A comparison of the source rocks of Lorraine and of the overall Paris Basin provides chronostratigraphic details concerning the source rock units, and helps to extrapolate, on the eastern margin of the Basin, the geochemical curves already available.

The chronostratigraphic subdivision is not always easy at the center of the Basin, considering the additional thickness of the sediments in comparison with the eastern margin of the Basin. Nevertheless, the Calcaire à gryphées facies, although with a more marly predominance at the center than to the east, date from the Hettangian/Lower Sinemurian (Poujol 1961). At the center of the basin, it is more difficult to fit the Marnes à Numismalis than in the east, where the facies is of Lower Carixian age. The Schistes carton and the base of the Marnes à Bifrons, to the East, date from the Lower and pro parte Medium Toarcian. At the center of the basin, only the lithologic term of the Schistes carton is used for these two formations, and it is highly probable that the corresponding ammonite zones are the same in the east and at the center of the basin.

The TOC isocontent curves are plotted in Fig. 8 (p. 133), and supplement the existing maps (Espitalié et al. 1987a). Whereas the source rocks are the same in the east and at the center of the Paris Basin, they are nevertheless even richer in organic matter at the center than in the east. This enrichment can be associated with a much greater subsidence rate in the Paris area than in Lorraine, and with predominantly more shaly facies at the center than in the east. At similar sedimentation rate, the organic matter is better preserved (or less diluted) at the center than in the east of the basin, because not affected by the Ardennes coarse terrigenous supply.



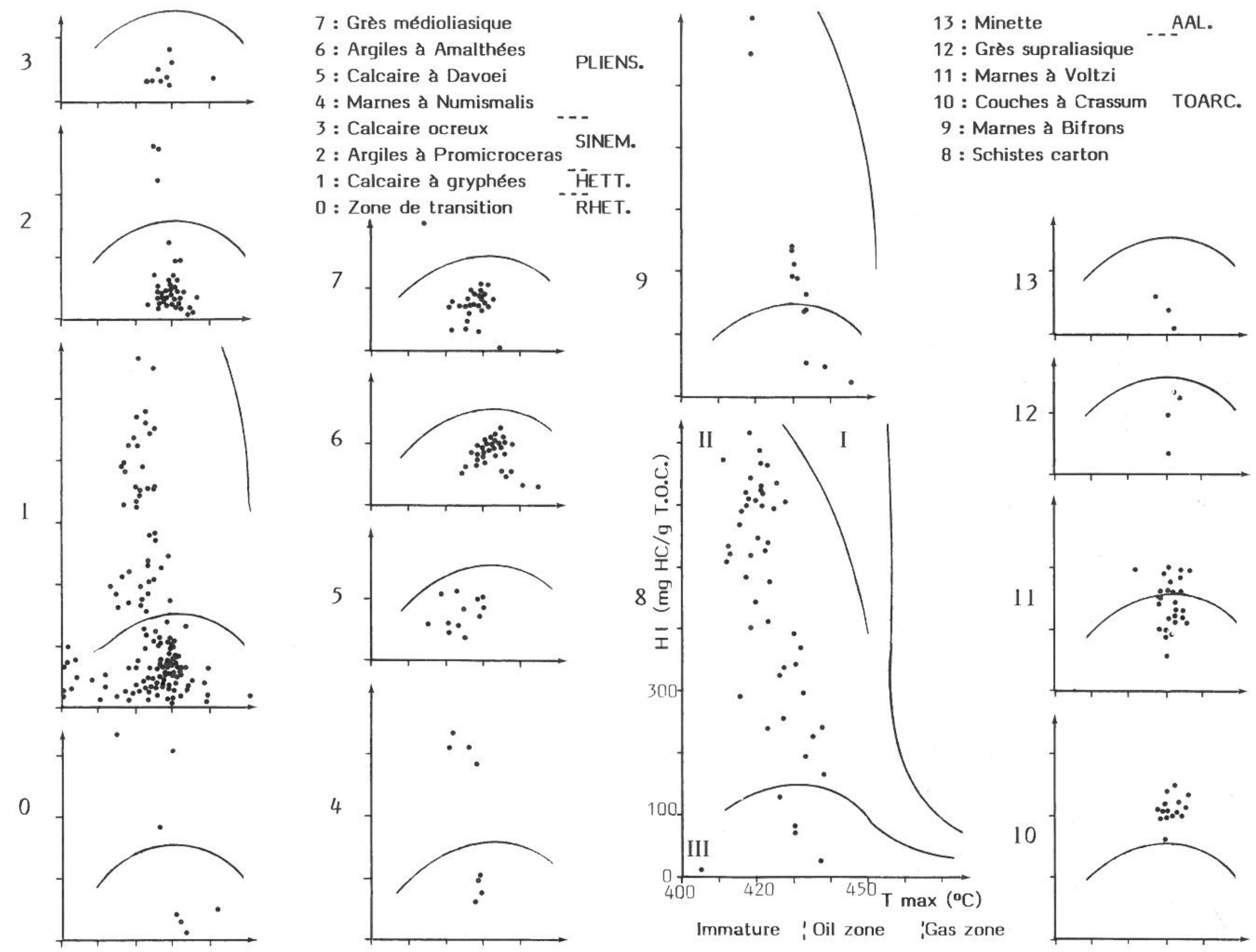



**Fig. 5.** Organic geochemistry of Lorraine Lower Jurassic: classification of different formations, according to HI/$T_{max}$ diagrams

## Relationship Between Organic Matter and Sedimentation

Some sedimentological and paleontological factors may or may not be favorable to the preservation of organic matter, in terms of quantity and quality (Fig. 9, p. 133).

### *The Levels Rich in Organic Matter Depend on Three Main Types of Geological Event*

*Variations in Sea Level.* In fact, the three Lias units richest in organic matter correspond to low to medium energy environments, i.e., to incipient lithologic sequences, irrespective of the lithologic predominance: limestones and marls of the first (Calcaire à gryphées) and marls or shales in the next two (Marnes à Numismalis and then Schistes carton).

During these transgressive and regressive cycles, the transgressive pulsations are especially favorable to large quantities of organic matter, principally when the transgression reaches its peak (Schistes carton). The exception is when the input of coarse-grained terrigenous diluted the organic matter (Argiles à Amalthées).

Figure 10 (p. 130) shows some characteristics of the units which are richer in organic matter.

*Sedimentation Rate.* Northern Lorraine, located in the prolongation of the maximum subsidence axis of the Paris Basin, contains the highest TOC values, irrespective of the formation concerned. However, in other zones such as Sandaucourt, high values may be discriminated.

Consequently, high sedimentation rate is also a favorable factor to good organic matter contents.

*Confinement of the Environment.* The overall character of the Liassic series is that of a reducing environment. For the Schistes carton, the bottom was even clearly confined, and this may explain the high organic matter contents in these facies, throughout Lorraine, due to good preservation of the deposited material.

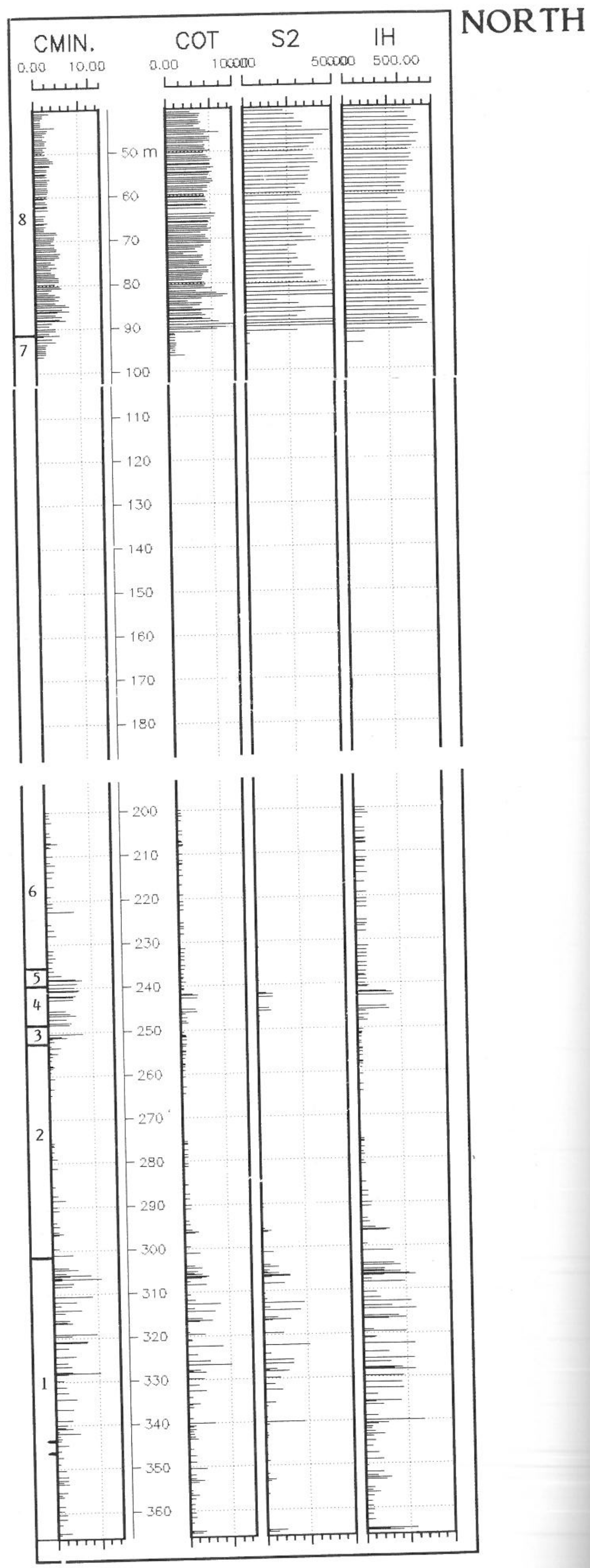
Some factors, on the contrary, diminish the effects that favor the preservation of organic matter. Thus if the coarse terrigenous material (silts and sands) is excessive, the organic matter tends to be diluted or weathered, and this could occur if the waters contain oxygen. This, in fact, occurs in the Grès d'Hettange unit, which is inserted in the Calcaire à gryphées in northern Lorraine, a zone that has nevertheless a high sedimentation rate. This also applies to the Argiles à Amalthées, which nevertheless happens to be in a long-term transgressive phase.

### The Quality of the Organic Matter (Type, Maturity, and State of Preservation) Varies in Time and Space

It is always an immature matter, given the shallow burial of the series (less than 1000 m).

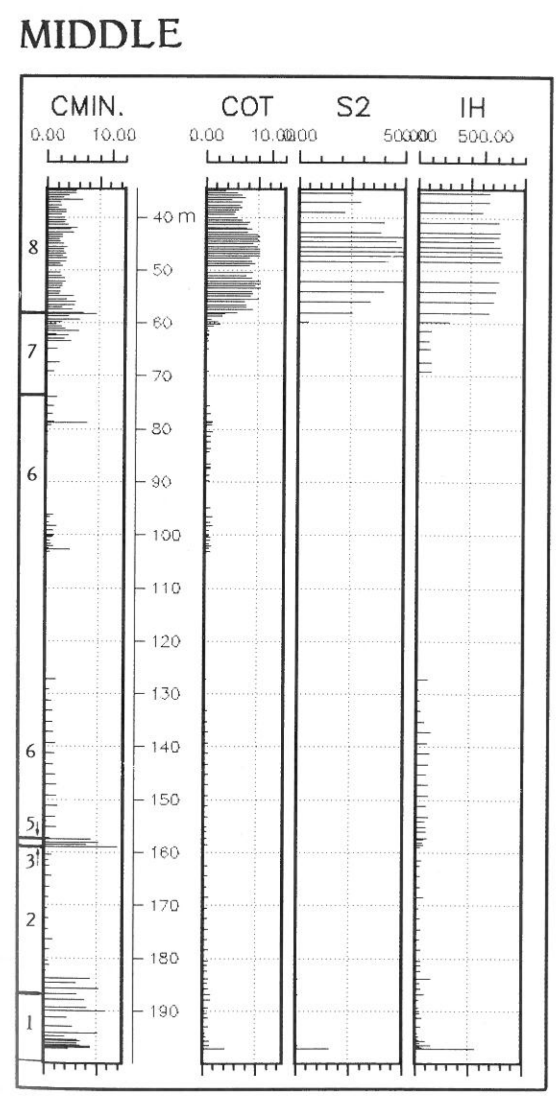
It is predominantly marine in the rich units, whereas the terrigenous influence is increasingly felt in the poorer units, depending on the quantities and types of deposit supplied by the emerged lands in the north. This occurs at every end of a sequence, in the Calcaire ocreux, the Calcaire à Davoei, and the Grès médioliasique/Minette.

The state of preservation of the organic matter is variable. It is fairly good in the rich levels but increasingly poor as the continental influence increases (the hydrogen index drops, not counting matrix effects). These observations are sometimes confirmed by the poor state of the microflora. This probably results from a weathering inherent in the transport by currents and/or the existence of an oxygenated sea floor, as attested by the benthic fauna, at least in the central and southern areas of less sedimentation rate. This is the case of the regressive phases.






| | | |
|---|---|---|
| 12 Grès supraliasique | | TOARCIAN |
| 11 Marnes à Voltzi | | |
| 10 Couches à Crassum | | |
| 9 Marnes à Bifrons | | |
| 8 Schistes carton | | |
| 7 Grès médioliasique | Domerian | PLIENSBACHIAN |
| 6 Argiles à Amalthées | | |
| 5 Calcaire à Davoei | Carixian | |
| 4 Marnes à Numismalis | | |
| 3 Calcaire ocreux | Lotharingian | SINEMURIAN |
| 2 Argiles à Promicroceras | Sinemurian | |
| 1 Calcaire à gryphées ± Grès d'Hettange | | HETTANGIAN |



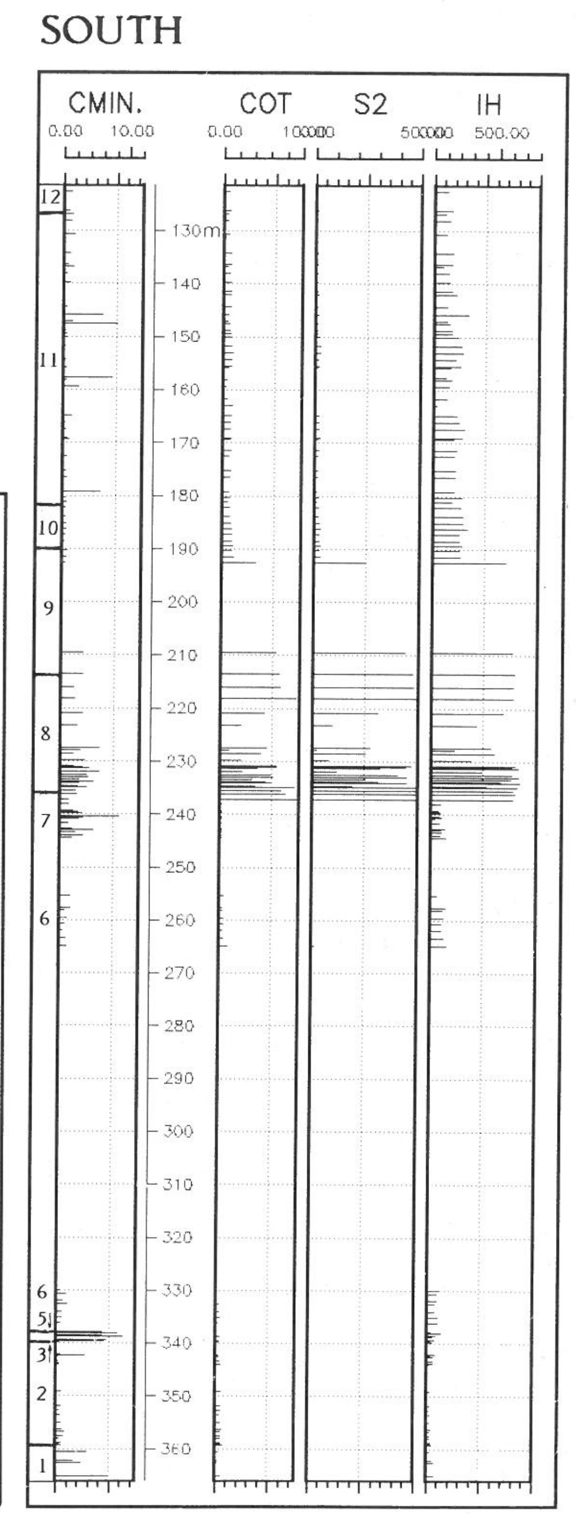




**Fig. 6.** Organic geochemistry of Lorraine Lower Jurassic, on synthetic cross sections in north, center and south

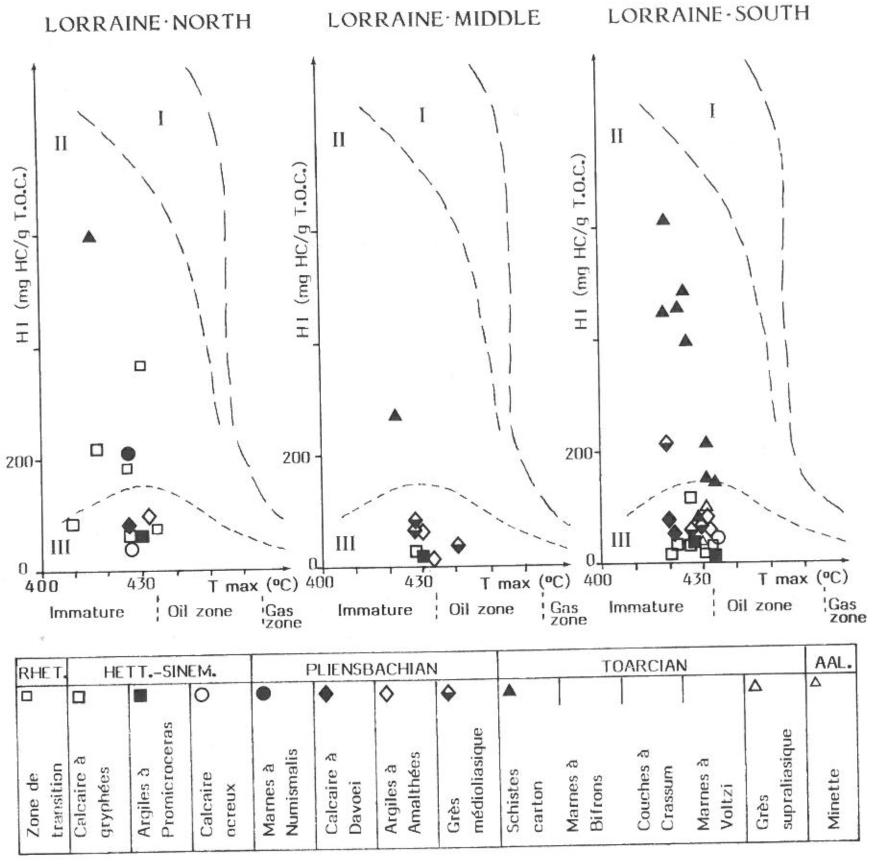



**Fig. 7.** Organic geochemistry of Lorraine Lower Jurassic: classification of different formations, according to HI/$T_{max}$ diagrams, based on average values per section

## Conclusions

In the Lias of Lorraine, three units rich in organic matter exist, independent of their lithology: limestones, marls, or argilites, which express the local variations of paleoenvironment in a context of transgressive pulsations.

### *Calcaire à Gryphées*

The Calcaire à gryphées (Hettangian, Lower Sinemurian) marks the inception of the Jurassic marine onlap, a transgressive phase favorable to the organic matter, but lessened by the oxygenation caused by the currents and by the abundance of coarse terrigenous material in certain units (Grès d'Hettange).

### *Marnes à Numismalis*

The Marnes à Numismalis (Lower Pliensbachian) also mark the inception of a sequence, hence in a transgressive phase (slightly more than above), and the high sedimentation rate further favors the preservation of organic matter, especially in the absence of the coarse terrigenous influence connected with the Ardennes.

### *Schistes Carton and the Base of the Marnes à Bifrons*

The Schistes carton and the base of the Marnes à Bifrons (Lower Toarcian) exhibit many characteristics favorable to high organic matter contents. They correspond to the peak of the Liassic transgression. They display a confinement of the sea floor, which makes this formation the most important from the standpoint of organic matter. The fine-grained terrigenous material predominates.

At the beginning of the sequence, the immature, marine organic matter is relatively well preserved. By contrast, it then evolves towards a poorly preserved matter, still marine, but with a continental influence increasing progressively upwards.

As to the relationship between the organic matter and the sedimentation, a link is observed with the transgression/regression cycles.

Source rocks are associated with the transgressive pulsations, chiefly at the maximum transgression (Schistes carton). That may be due to a higher planktonic biomass contents at the time, or the case may simply be one of better preservation after the deposition (confined environment).

On the contrary, associated with the regressions are the units poorest in organic matter, which are often badly



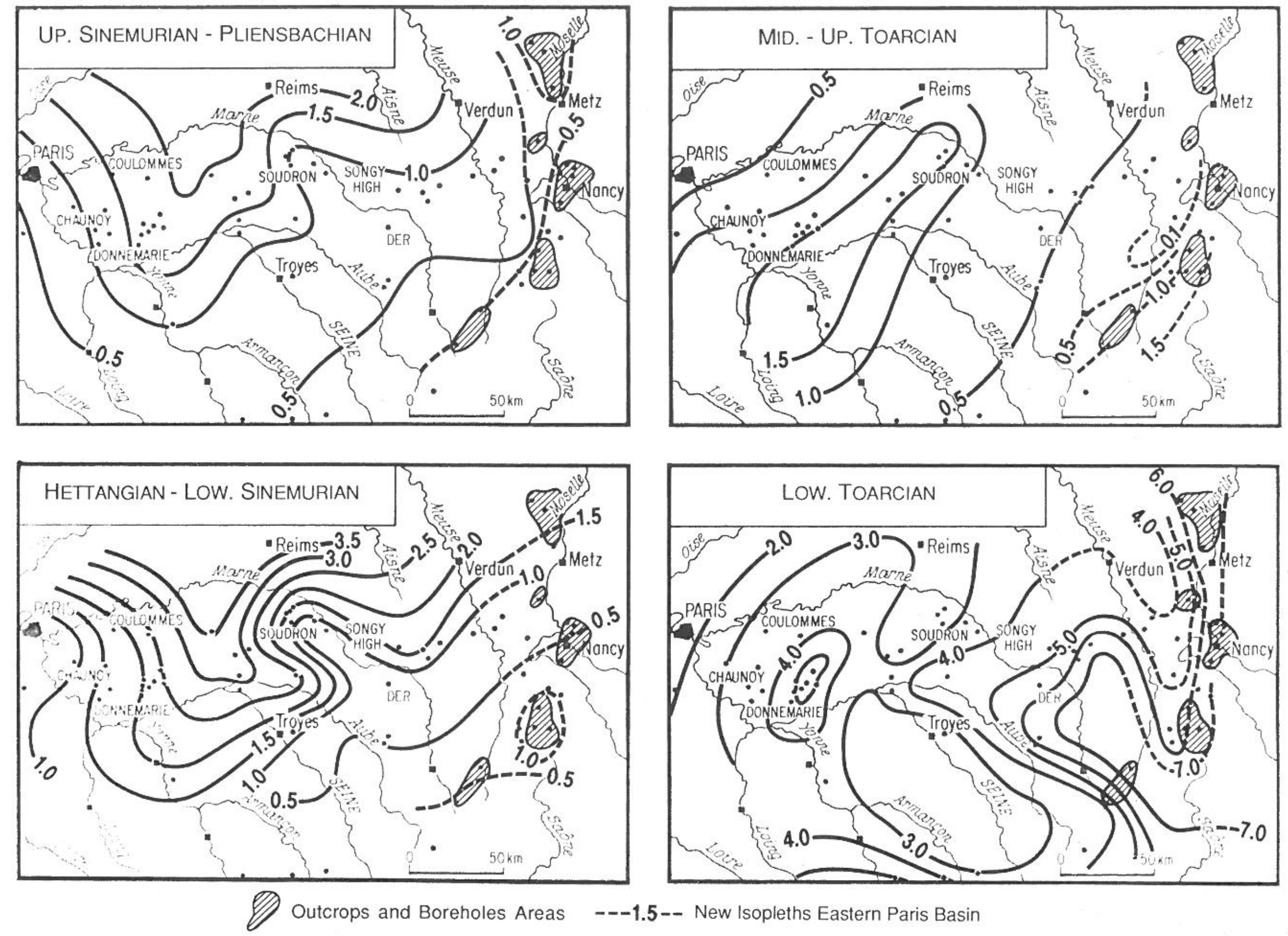



**Fig. 8** *(above)*. Isopleth maps of TOC in Paris Basin

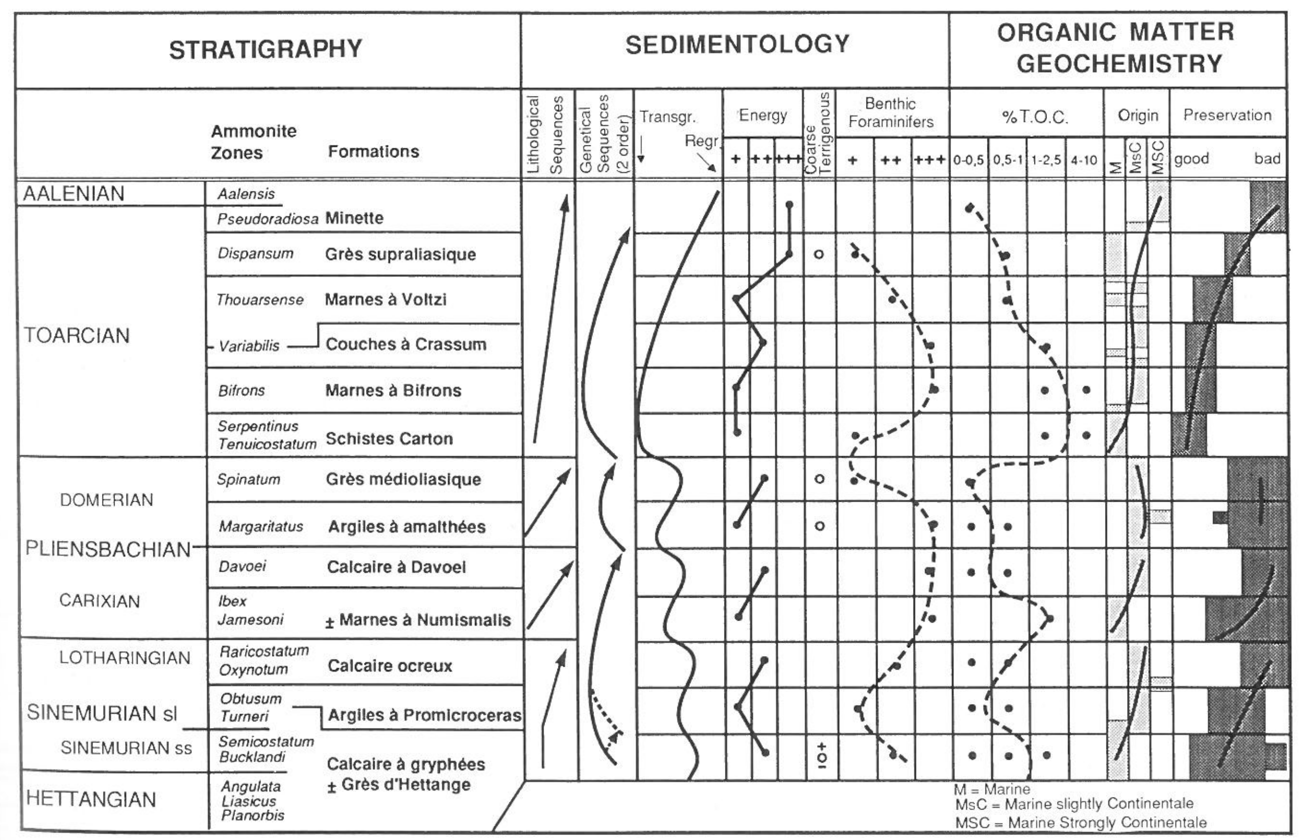



**Fig. 9** *(below)*. Summary of data on sedimentation environment and on organic matter

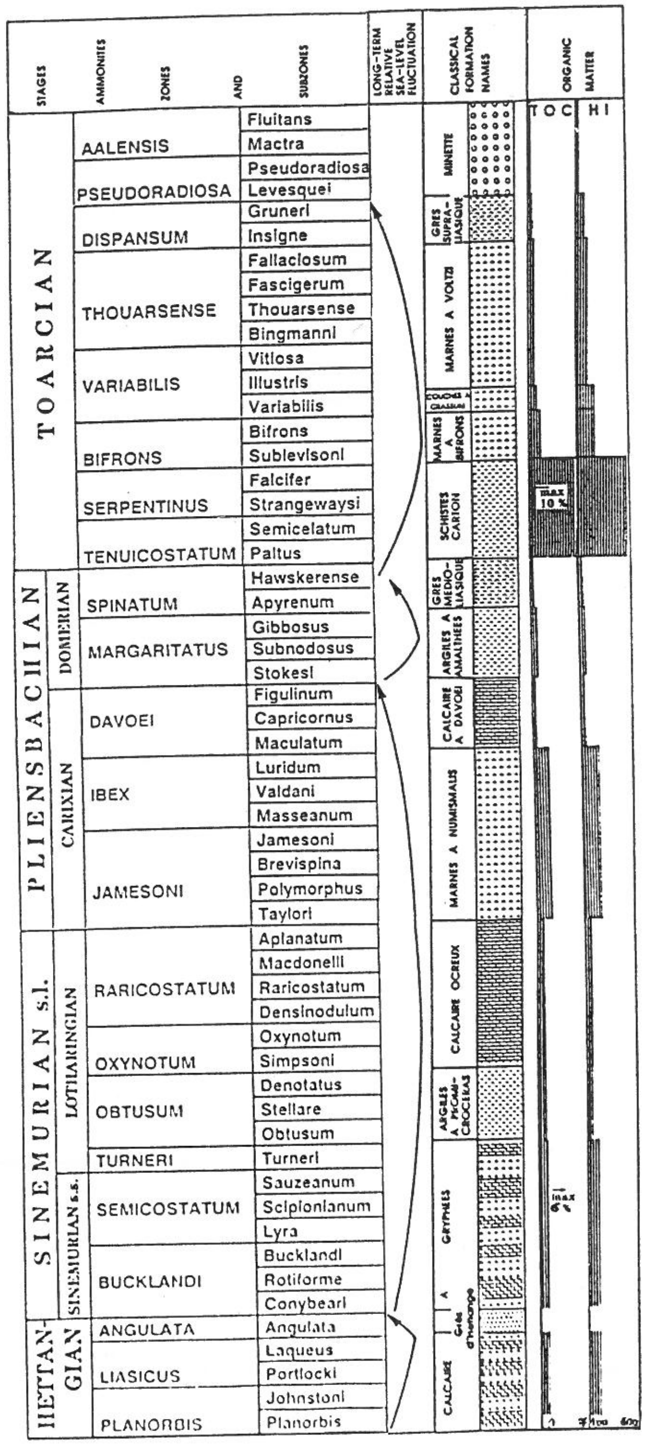



**Fig. 10.** Units of Lorraine Lower Jurassic, richer in organic matter. (After Hanzo et al. 1992)

preserved (oxidizing environment) and exhibit pronounced continental influences.

This work also enabled us to:

- date accurately (in the Lower Carixian) the rocks rich in organic matter of the Middle Lias, frequently found in the boreholes of the Paris Basin,
- complete eastward the geochemical TOC isocontent curves obtained by the same authors, based on petroleum boreholes.

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**Table 3.** Organic geochemistry of Lorraine Lower Jurassic: average values in all formations (of outcrops and boreholes)

| | HETT. | SINEMURIAN: SIN. ss. | SINEMURIAN: LOTH. | | PLIENSBACHIAN: CAR. | | PLIENSBACHIAN: DOM. | | TOARCIAN | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Calcaire à gryphées | Argiles à Promicro. | Calcaire ocreux | Marnes à Numismalis | Calcaire à Davoei | Argiles à Amalthées | Grès médioliasi. | Schistes carton | Marnes à Bifrons | Couches à Crassum | Marnes à Voltzi | Grès supraliasique | |
| Lorraine-north | 1.24 | 0.85 | 0.83 | 1.92 | 0.6 | 0.7 | | 6.97 | | | | | T.O.C. |
| | 0.12 | 0.03 | 0.03 | 0.11 | 0.05 | 0.04 | | 1.25 | | | | | $S_1$ |
| | 3.31 | 0.68 | 0.38 | 5 | 0.55 | 0.74 | | 43.3 | | | | | $S_2$ |
| | 417 | 429 | 427 | 426 | 427 | 433 | | 416 | | | | | T max |
| | 155 | 61 | 43 | 217 | 87 | 98 | | 588 | | | | | H.I |
| | 28 | 68 | 70 | 27 | | 32 | | 31 | | | | | O.I |
| Lorraine-middle | 0.12 | 0.35 | 0.06 | / | | 0.32 | 0.35 | 6.17 | | | | | T.O.C. |
| | 0.02 | 0 | 0 | / | | 0.03 | 0.01 | 0.14 | | | | | $S_1$ |
| | 0.04 | 0.08 | 0.02 | / | | 0.47 | 0.18 | 38.2 | | | | | $S_2$ |
| | 428 | 430 | | / | | 431 | 429 | 423 | | | | | T max |
| | 30 | 23 | 23 | / | | 19 | 74 | 566 | | | | | H.I. |
| | 361 | | | / | | | 924 | 35 | | | | | O.I. |
| Lorraine-south | 0.6 | 0.61 | 0.44 | / | 0.23 | 0.48 | 0.53 | 5.53 | 1.78 | 1.25 | 0.87 | 0.64 | T.O.C. |
| | 0.05 | 0 | 0.01 | / | 0.02 | 0.03 | 0.03 | 0.57 | 0.56 | 0.06 | 0.03 | 0.04 | $S_1$ |
| | 0.99 | 0.21 | 0.2 | / | 0.16 | 0.39 | 1.09 | 32.1 | 6.73 | 2.72 | 1.33 | 0.73 | $S_2$ |
| | 424 | 430 | 433 | / | 421 | 430 | 428 | 424 | 423 | 431 | 431 | 431 | T max |
| | 40 | 34 | 50 | / | 66 | 73 | 85 | 497 | 212 | 217 | 151 | 100 | H.I. |
| | 158 | 38 | | / | | 341 | 113 | 66 | | 46 | 56 | | O.I. |
| LORRAINE | 0.7 | 0.6 | 0.4 | 1.9 | 0.4 | 0.5 | 0.4 | 6.2 | 1.8 | 1.2 | 0.9 | 0.6 | T.O.C. |
| | 0.06 | 0.01 | 0.02 | 0.11 | 0.03 | 0.03 | 0.02 | 0.65 | 0.56 | 0.06 | 0.03 | 0.04 | $S_1$ |
| | 1.45 | 0.3 | 0.2 | 5 | 0.4 | 0.5 | 0.6 | 37.9 | 6.7 | 2.7 | 1.3 | 0.7 | $S_2$ |
| | 423 | 430 | 430 | 426 | 424 | 431 | 429 | 421 | 423 | 431 | 431 | 431 | T max |
| | 75 | 39 | 42 | 217 | 76 | 63 | 80 | 550 | 212 | 217 | 151 | 100 | H.I. |
| | 182 | 53 | 70 | 27 | | 186 | 519 | 44 | | 46 | 56 | | O.I. |

T.O.C. : % ; $S_1$ et $S_2$ : mg HC/g rock ; Tmax : °C ; H.I. : mg HC/g T.O.C. ; I.O : mg $CO_2$/g T.O.C.


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**Table 3** *(continued)*

| | | HETT. – SIN. ss. | LOTH. | | CAR. | | DOM. | | TOARCIAN | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SINEMURIAN | | | PLIENSBACHIAN | | | | | | | | |
| Region | | Calcaire à gryphées | Argiles à Promicro. | Calcaire ocreux | Marnes à Numismalis | Calcaire à Davoei | Argiles à Amalthées | Grès médioliasi. | Schistes carton | Marnes à Bifrons | Couches à Crassum | Marnes à Voltzi | Grès supraliasique |
| Lorraine-north | T.O.C. | 1.41 | 0.85 | 0.83 | 1.92 | 0.6 | 0.7 | | 6.47 | | | | |
| | $S_1$ | 0.13 | 0.03 | 0.03 | 0.11 | 0.05 | 0.04 | | | | | | |
| | $S_2$ | 3,83 | 0.68 | 0.38 | 5 | 0.55 | 0,74 | | 41 | | | | |
| | T max | 421 | 429 | 427 | 426 | 427 | 433 | | | | | | |
| | H.I. | 172 | 61 | 43 | 217 | 87 | 98 | | 582 | | | | |
| | O.I. | 28 | 68 | 70 | 27 | | 32 | | | | | | |
| Lorraine-middle | T.O.C. | | | | | | | | 7.01 | | | | |
| | $S_1$ | | | | | | | | | | | | |
| | $S_2$ | | | | | | | | 43.8 | | | | |
| | T max | | | | | | | | | | | | |
| | H.I. | | | | | | | | 625 | | | | |
| | O.I. | | | | | | | | | | | | |
| Lorraine-south | T.O.C. | 0,9 | 0.61 | 0,44 | | 0.23 | 0.48 | 0.57 | 5.47 | 1.78 | 1.25 | 0.87 | 0.64 |
| | $S_1$ | 0,05 | 0 | 0.01 | | 0.02 | 0.03 | 0,04 | 0.5 | 0,56 | 0.06 | 0.03 | 0.04 |
| | $S_2$ | 2,57 | 0.21 | 0.2 | | 0.16 | 0.4 | 1.3 | 32.1 | 6.73 | 2.72 | 1.33 | 0.73 |
| | T max | 427 | 430 | 433 | | 421 | 430 | 428 | 425 | 423 | 431 | 431 | 431 |
| | H.I. | 76 | 34 | 50 | | 66 | 73 | 91 | 506 | 212 | 217 | 151 | 100 |
| | O.I. | 44 | 38 | | | | 341 | 113 | 67 | | 46 | 56 | |
| LORRAINE | T.O.C. | 1.16 | 0.7 | 0.6 | 1.9 | 0.4 | 0.6 | 0.6 | 6.3 | 1.8 | 1.2 | 0.9 | 0.6 |
| | $S_1$ | 0.09 | 0.02 | 0.02 | 0.1 | 0.03 | 0.03 | 0.04 | 0.5 | 0.6 | 0.06 | 0.03 | 0.04 |
| | $S_2$ | 3.2 | 0.4 | 0.3 | 5 | 0.4 | 0.6 | 1.3 | 39 | 6.7 | 2.7 | 1.3 | 0.7 |
| | T max | 424 | 430 | 430 | 426 | 424 | 431 | 428 | 425 | 423 | 431 | 431 | 431 |
| | H.I. | 124 | 47 | 46 | 217 | 76 | 85 | 91 | 571 | 212 | 217 | 151 | 100 |
| | O.I. | 36 | 53 | 70 | 27 | | 186 | 113 | 67 | | 46 | 56 | |

T.O.C. : % ; $S_1$ et $S_2$ : mg HC/g rock ; Tmax : °C ; H.I. : mg HC/g T.O.C. ; I.O. : mg $CO_2$/g T.O.C.