

14. MOLECULAR COMPOSITION OF THREE SEDIMENTS FROM HOLE 717C: THE BENGAL FAN¹

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ABSTRACT

We describe the molecular composition of a portion of the solvent-soluble organic material (lipid extract), from three organic rich muds (samples 116-717C-22X-1, 80–86 cm, 116-717C-34X-3, 130–135 cm, and 116-717C-55X-1, 65–70 cm). These samples were taken from Hole 717C, located on the Bengal Fan at a position of 0°55.8'S and 81°23.4'E. Both the palaeoenvironmental and digenetic significance of these lipid distributions have been assessed and found to be consistent with their suspected origins, i.e., turbidites from the upper slope of the western Bay of Bengal and the Ganges-Brahmaputra delta.

INTRODUCTION

Most molecular organic geochemical studies are based upon the concept of biological marker compounds. A biological marker (or "chemical fossil" or "biomarker") is a compound whose occurrence in the geosphere and/or biosphere is indicative of an input from a specific organism or group of organisms (Eglinton and Calvin, 1967; Philp, 1985). Hence, the occurrence of such compounds in sediments is often used to infer the composition of the primary biological input. In addition, the distribution of a series of compounds within a compound class (e.g., Pymnesiophyte alkenones; higher plant *n*-alkanes) has been found, in some instances, to reflect some aspects of the growth conditions experienced by the organism during its life (Brassell et al., 1986a and 1986b; Poynter et al., 1989b).

The molecular marker approach has been applied to a large number of sediments (both ancient and modern), from a diverse range of environments. These studies have shown that the composition of the organic matter present in each environment is often characteristic of both the assemblage of contributing organisms and their contemporary environmental conditions (Didyk et al., 1978; Brassell, 1984; Meyers et al., 1984; ten Haven et al., 1985; Mello et al., 1988). The application of biomarkers to such problems depends upon our understanding of the following:

1. Good taxonomic control. The molecular composition of a large number of contemporary organisms has been investigated; however, there remain a great number yet to be yet characterized.

2. The effect of evolution upon molecular composition. Most studies that utilize biomarkers depend upon the assumption that the molecular composition of ancient organisms is comparable with their present day analogs, i.e., that their evolution has had little effect upon their molecular composition. This assumption is to date largely untested.

3. Selective degradation during transportation from the photic zone to the sediment. A study investigating the composition of the sterol portion of organic matter throughout an

open marine water column has found that relatively refractory components, such as vascular plant sterols (24-ethyl-cholest-5-en-3 β ol), are enriched compared to more labile components such as the common algal sterol 24-methyl-cholest-5-en-3 β ol, as water depth increases (Gagosian et al., 1983; Wakeham et al., 1983).

4. Selective degradation or transformation after incorporation into the sediment, e.g., Mackenzie et al. (1982).

Site 717 is located at the extreme distal end of the Bengal submarine fan, close to the termination of the most recently active fan channel. The major sediment supply to the fan is derived from the uplift of the Himalayas and is fed to the delta front by the Ganges-Brahmaputra river systems. Sediments are channelled very efficiently to the outer margin of the fan by the delta front trough "The Swatch of No Ground" (Emmel and Curray, 1984).

The sediment samples (from Hole 717C) analyzed during this study were as follows: Samples 116-717C-22X-1, 80–86 cm, 116-717C-34X-3, 130–135 cm 116-717C-55X-1, 65–70 cm. These samples have been assigned to lithological Units III, III, and IVD, respectively, and facies F₂/F₃, F₃/F₇, and F₃, respectively (Cochran, Stow, et al., 1988; and D.A.V. Stow, pers. comm.). These lithological units are comprised mainly of mud turbidites with thin interbedded pelagic clays. At least three different sources of turbidites to the site have been provisionally identified as follows: silts and muds from the Ganges-Brahmaputra delta, dark-gray organic rich muds from the upper slope of the western Bay of Bengal, and greenish biogenic turbidites probably from the Afanasiy-Nitikin seamount group. The facies type F₃ corresponds to turbidites from the upper slopes of the western Bay of Bengal, whereas facies type F₂ are turbidites derived from the Ganges-Brahmaputra delta (Cochran, Stow, et al., 1988; and D.A.V. Stow, pers. comm.). While no individual assessment of the samples analyzed was made, further details of the facies types to which they were assigned are given in Stow et al. (this volume). Hole 717C lies beneath 4634 m of water.

METHODS

Deep frozen sediment samples were thawed and homogenized prior to removing an aliquot (ca. 3 g dry weight) for lipid extraction. The samples were extracted by ultrasonication (sonic bath) in five 15-min steps (twice with methanol, once with a 1:1 mixture of methanol and dichloromethane, and twice with dichloromethane). After each step the sample was

¹ Cochran, J. R., Stow, D.A.V., et al., 1990. *Proc. ODP, Sci. Results* 116: College Station, TX (Ocean Drilling Program).

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centrifuged and the clear extract decanted off; all the extracts were combined. A known quantity of internal standard (C36 *n*-alkane; C40 *n*-alkane; cholesterol hexanoate) was added to each sample after the second methanol extraction to allow later quantitative analysis of lipid abundances. The organic extract was washed with aqueous KCl to separate salts and water, and the organic layer removed. The remaining aqueous layer was extracted once more with 5 mL of dichloromethane. These organic extracts were combined and the excess solvent removed by rotary evaporation before being stored in BSTFA at 4°C.

Analysis by gas chromatography was performed on the derived total extract using a Carlo Erba Mega series 5300 fitted with an OV-1 fused silica capillary column (50 m × 0.32 mm i.d.). Hydrogen was used as the carrier gas with a flow rate of 50 cm/s; the temperature program used was as follows: 50°–150°C at 10°C/min and 150°–300°C at 4°C/min. Data were acquired using an online Minichrom data acquisition system.

Subsequent GC/MS analysis was performed using a Carlo Erba Mega Series 5160 gas chromatograph linked to a Finnigan 4500 quadrupole mass spectrometer. The gas chromatograph was fitted with an on-column injector and an OV-1 (cross-linked methylsilicone) fused silica capillary column (50 m × 0.32 mm i.d.) and was temperature programmed from 50°–150°C at 10°C/min and 150°–300°C at 4°C/min. Helium was employed as the carrier gas. The mass spectrometer was operated in the EI mode (ionizing energy 35 eV; ion source temperature 250°C with a scan time (*m/z* 50–600) of 1 s). An INCOS 2300 system was used for acquisition and processing.

Compounds were identified by a combination of their mass spectra compared with literature sources) and their relative retention times.

Bulk composition determinations (organic carbon, carbonate, nitrogen, and sulfur) were performed by the microanalytical services department at Bristol University, run by Mr. M. West. Determinations were made as follows:

1. Total carbon and nitrogen determinations were made using a Perkin Elmer 240C elemental analyzer. The sample was fully combusted and the oxides produced were swept through a series of traps using helium. The weight of CO₂ liberated was determined by measuring the thermal conductivity of the gas stream before and after passage through a CO₂, soda asbestos trap. The weight of nitrogen evolved was determined by measuring the remaining concentration of inert gases after removal of water, carbon dioxide, and other active gases. The remaining nitrogen oxides were reduced to nitrogen by reduction with activated copper, prior to determining the composition of the gas stream by thermal conductivity.

2. Carbonate determinations were made by measuring the weight increase of a CO₂ trap, after passing the gas evolved from the addition of phosphoric acid to the sample through the trap.

3. Sulfur determinations were made by burning a mixture of the sample and sucrose in a platinum/gold holder in oxygen. The sulfur dioxide evolved was collected in a solution of hydrogen peroxide and barium perchlorate which oxidizes the sulfur present to sulfate and then sulfuric acid. The sulfuric acid generated was then determined by titration with base.

RESULTS

Bulk Composition

The bulk composition of each sample in terms of organic carbon, nitrogen, sulfur, and carbonate is shown in Table 1.

Molecular composition and significance

In this preliminary study the three sample extracts were analyzed as total extracts. Consequently it was only possible to identify the major components of each sample. Gas chromatographic traces of the lipid extracts from each of the three samples considered are shown in Figure 1, while peak assignments are given in Table 2. The gross composition of these extracts is shown in Table 3.

Table 1. Concentration of organic carbon, nitrogen, sulfur, and carbonate in each sample in percent relative to sediment dry weight.

Sample	Carbon	Nitrogen	Sulfur	Carbonate
116-717C-22X-1, 80–86 cm	2.68	0.24	0.06	2.95
116-717C-34X-3, 130–135 cm	1.49	0.14	0.42	0.28
116-717C-55X-1, 65–70 cm	1.03	0.14	0.13	0.41

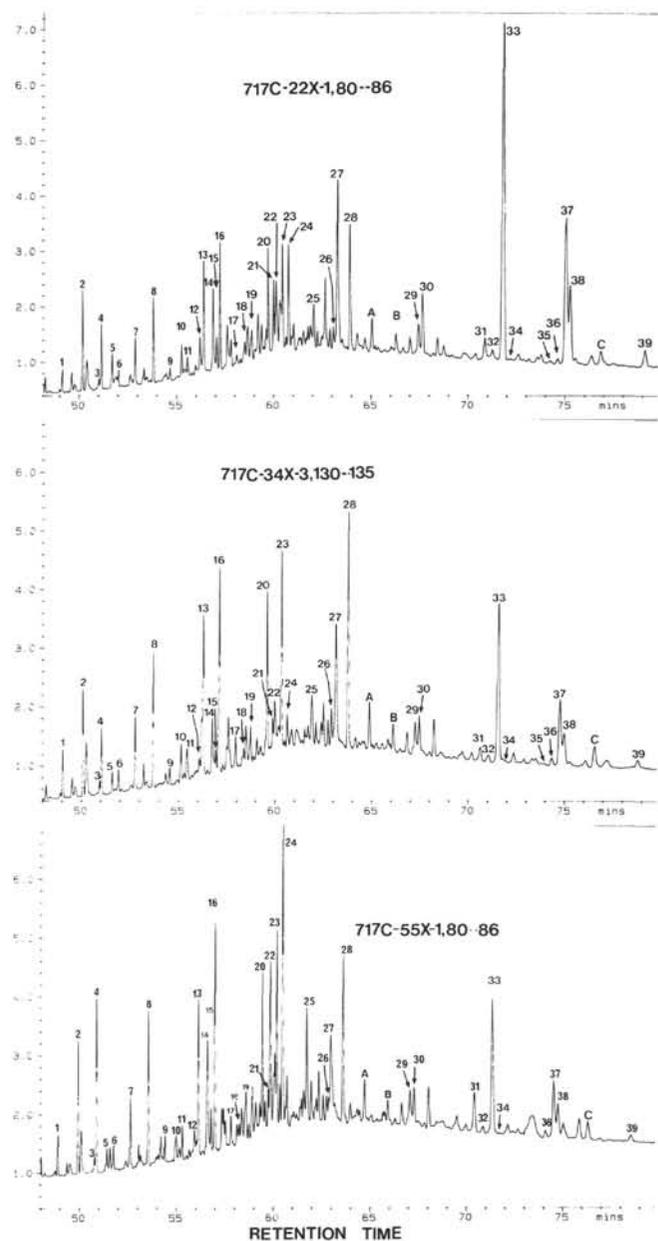


Figure 1. Three gas chromatographic traces of the derived total lipid extracts of the samples considered in this study (see "Methods" section for experimental details). Compound assignments are listed in Table 2.

Table 2. Assignment of the peaks shown in the gas chromatographic traces (Fig. 1), to specific compounds.^a

Peak	Compound assignment
1	C27 <i>n</i> -alkane
2	C24 <i>n</i> -alkanol
3	C28 <i>n</i> -alkane
4	Squalene
5	C24:0 Fatty acid
6	C25 <i>n</i> -alkanol
7	C29 <i>n</i> -alkane
8	C26 <i>n</i> -alkanol
9	C30 <i>n</i> -alkane
10	C26:0 Fatty acid
11	C27 <i>n</i> -alkanol
12	Cholesta-5,22-dien-3 β -ol
13	C31 <i>n</i> -alkane
14	Cholest-5-en-3 β -ol
15	5 α (H)-cholestan-3 β -ol
16	C28 <i>n</i> -alkanol
17	C32 <i>n</i> -alkane
18	C28:0 Fatty acid
19	C29 <i>n</i> -alkanol
20	C33 <i>n</i> -alkane
21	24-ethyl-cholest-5-en-3 β -ol
22	5 α (H)-24-ethyl-cholestan-3 β -ol
23	C30 <i>n</i> -alkanol
24	4 α ,23,24-trimethylcholest-22-en-3 β -ol
25	C31 <i>n</i> -alkanol
26	C35 <i>n</i> -alkane
27	C30 alkane-1,15-diol and alkan-15-on-1-ol
28	C32 <i>n</i> -alkanol
29	C32 alkane-15-on-1-ol
30	C32 alkane-1,15-diol
31	C31 Hopanol
32	C37:3 methyl ketone
33	C37:2 methyl ketone
34	C37:2 methyl ester
35	C38:3 ethyl ketone
36	C38:3 methyl ketone
37	C38:2 ethyl ketone
38	C38:2 methyl ketone
39	C39:2 ethyl ketone
A	C36 <i>n</i> -alkane (Internal standard)
B	Cholesteryl He xanoate (Internal standard)
C	C40 <i>n</i> -alkane (Internal standard)

^a The following nomenclature was used to describe compound structure: CX:Y; where X refers to the number of carbon atoms in the alkyl chain and Y the number of double bonds present; structures where a Y term is not shown, are not normally expected to contain double bonds.

Hydrocarbons

The hydrocarbons (within the section of the gas chromatographic trace studied) were dominated by a series of C27 to C35 *n*-alkanes having a strong odd/even chain length preference. Such distributions are generally thought to reflect an input from terrestrial higher plants, e.g., Eglinton et al. (1962), Eglinton et al. (1967), Kolattukudy (1976). Such compounds can be introduced into the marine environment by either fluvial (Prahl and Pinto, 1987; Prahl and Carpenter, 1984) or eolian (Simoneit et al., 1977) mechanisms. In view of their location in this instance adjacent to the Bengal Fan, it is anticipated that the major mechanism here is fluvial.

In addition to the "higher plant" *n*-alkanes it is anticipated that other common branched or polycyclic hydrocarbons may be present in these samples. In particular, it is reasonable to expect that ster-4-enes and ster-5-enes may be present as a result of the early diagenetic modification of the steroid or steroidal ketone precursors (Mackenzie et al., 1982). Their lack of detection in this in this study is probably governed by

Table 3. The absolute concentration of selected biomarker sums and the relative abundance of those sums, with respect to organic carbon.^a

Abundance ($\mu\text{g/g}$)	116-717C-22X-1 80-86 cm	116-717C-34X-3 130-135 cm	116-717C-55X-1 65-70 cm
<i>n</i> -alkanes	2.87	2.21	2.52
<i>n</i> -alcohols	4.90	3.49	4.90
Dinosterol	0.05	0.02	0.14
Alkenone	13.10	3.49	3.64
alkane-1,15 compounds	3.36	1.30	1.28
(Relative abundance per mil organic carbon)			
<i>n</i> -alkanes	0.107	0.082	0.094
<i>n</i> -alcohols	0.183	0.130	0.183
Dinosterol	0.002	0.001	0.005
Alkenone	0.489	0.130	0.136
alkane-1,15 compounds	0.125	0.048	0.048

^a Abundance in $\mu\text{g/g}$ sediment (dry weight); relative abundance in parts per thousand of organic carbon (per mil, ‰). The sums were as follows; the sum of the C27, C29, and C31 *n*-alkanes; the sum of the C24, C26, and C28 *n*-alkanols; dinosterol; and the sum of the C37, C38, and C39 (di- and tri-, methyl and ethyl) ketones.

their implicit low abundance in the sample and the sensitivity of the analytical method.

Alkanols

A series of alkanols were identified in these samples having carbon numbers between C24 to C32. This series showed an even/odd carbon number preference with a carbon number maximum at C28. Such a distribution is thought to reflect an input from terrestrial higher plants, e.g., Eglinton et al. (1967); Kolattukudy (1976). Their occurrence, in association with the "higher plant" *n*-alkanes, provides secondary evidence that this is the source and underlines the importance of the terrestrial input to these sediments.

Fatty acids

A series of long-chain fatty acids were recognized in these samples, having carbon numbers between C24 and C30. This series showed a strong even/odd carbon number preference with a carbon number maximum near C26/28. Again such a distribution is thought to reflect an input from terrestrial higher plants (Eglinton et al., 1967; Kolattukudy, 1976). The occurrence of the fatty acids were not considered quantitatively, as trimethylsilyl esters of fatty acid compounds are not particularly stable and may decompose prior to the analysis. However, once again the occurrence of these compounds is thought to underline a terrestrial component in these samples.

Steroidal alcohols

Several sterols were identified in this study including cholesta-5,22-dien-3 β ol, the ubiquitous cholest-5-en-3 β ol, and cholestan-3 β ol. The origin of the cholest-5-en-3 β ol found in these sediments is likely to be mixed, since this compound is produced by both zooplankton and phytoplankton (Volkman et al., 1986). Phytoplankton sources include: dinoflagellates; some species of prymnesiophyceae; and to a limited extent diatoms; in addition, cyanobacteria have also been found to produce this sterol (Volkman et al., 1986, and references therein). Consequently, the information afforded by this sterol must be considered limited. 5 α (H)-cholestan-3 β -ol is presumably derived in part from the diagenetic reduction of cholest-5-ene-3 β ol (via ketone intermediates; Gaskell and

Eglinton, 1975; Nishimura and Koyama, 1977; and Mackenzie et al., 1982). There is however, no clear increase in the abundance of the $5\alpha(H)$ -cholestan- 3β -ol relative to the cholest-5-en- 3β -ol with depth. This is evidence that, either diagenesis is not the source of this stanol in this case, or that some other change in the primary sterol input must vary so as to conceal the diagenetic process. Direct inputs of $5\alpha(H)$ -cholestan- 3β -ol are known (e.g., Robinson et al., 1984).

In addition, several C29 24-ethyl substituted sterols are present, including 24-ethylcholest-5-en- 3β -ol and 24-ethyl $5\delta(H)$ -cholestan- 3β -ol. The 24-ethylcholest-5-en- 3β -ol is a major sterol in vascular higher plants (Goad and Goodwin, 1972). However, its occurrence in the bio/geo-sphere is not limited to this source (e.g., Volkman et al., 1986; and references therein). In this instance its source is likely to be predominantly vascular plants, in view of the abundance of other typical higher plant compounds, e.g. the "higher plant" *n*-alkanes and *n*-alkanols.

It is noted that the ratio of the C29 24-ethyl stanol to the corresponding sterol increases with depth from, 0.9 at 170 m, to 2.1 at 288 m, to 4 at 484 m. Presumably, as with the reduction of cholest-5-en- β -ol to $5\alpha(H)$ -cholestan- 3β -ol (Gaskell and Eglinton, 1975; Nishimura and Koyama, 1977; Mackenzie et al., 1982), the $5\alpha(H)$ -24-ethyl-cholestan- 3β -ol may be derived in part from the diagenetic alteration of the 24-ethyl-cholest-5-en- 3β -ol. However, why a systematic change in the C29 stanol/sterol ratio should be observed while the equivalent C27 ratio behaves erratically is not clear. It seems unlikely that the addition of a single CH₂ group on such a remote side chain should influence the reduction of the double bond on the sterol "B" ring. In view of this and the limited number of analyses completed to date, it is not possible to state whether this observation is to be explained in terms of diagenesis or of the sterol composition of the precursor biological input.

Finally, a single 4-methyl sterol ($4\alpha,23,24$ -trimethylcholest-22-en- 3β -ol or dinosterol) has been recognized in each of the three samples considered. In contrast to the suspected multiple origins of many sterol biomarkers the occurrence of sterols methylated at the C4 position (with one exception) is thought to be restricted to dinoflagellate sources (Boon et al., 1979; Robinson et al., 1984). The one exception is the bacterium *Methylococcus capsulatus*, which contains both 4-methyl and 4,4-dimethyl sterols; these can easily be distinguished from dinoflagellate sources since they contain a double bond between the 8–14 carbon atoms (Harwood and Russell, 1984).

Feeding experiments, in which radiolabeled dinosterol was fed to a crustacean, an annelid, and a mollusc, have shown this compound can pass quantitatively through the guts of these organisms. This is in contrast to various other sterols which were rapidly assimilated (Bradshaw, 1988). Further evidence for the refractory nature of this compound comes from the observation that it has been observed to become enriched (with respect to total sterols) in samples collected from increasingly deepening water (Gagosian et al., 1983a; Wakeham et al., 1983).

Collectively, these findings signify dinosterol to be a biomarker of the first order. We interpret its occurrence in these samples as reflecting a significant dinoflagellate input to all three samples, the input being highest during the original deposition (pre-turbidite) of the sediment sample 116-717C-55X-1, 60–65 cm.

Long Chain Alkenones And Alkenoates

Long chain di- and tri-unsaturated ketones (de Leeuw et al., 1980; Rechka and Maxwell, 1988) have been recognized in

each of the three sediments considered in this study, being most abundant in the shallowest sample. These compounds have been found to be a major component in some species of Prymnesiophyte algae (Volkman et al., 1980; Marlowe 1984), and hence, are thought to be indicative of such an input. Their stability in the biogeosphere is as yet little studied. However, the fact that these compounds are frequently found to be major components in a variety of oceanic sediments deposited throughout a wide age range, is indicative of their being relatively stable (Farrimond et al., 1986, and references therein). Furthermore, their stability relative to each other (tri- vs. di-), has been demonstrated for sediments deposited during the last 600 ka, e.g., the ratio of the C37 di- and tri-unsaturated compounds has been observed to behave in a predictable way in sediments deposited after this date (Poynter et al., 1989a). Despite this, the suggestion that the contribution of Prymnesiophyte algae to the youngest sediment was greater than to the older sediments, is as yet unjustified.

Alkane-1,15-Diols And Alkan-15-on-1-ols

The co-eluting C30 alkane-1,15-diol and C30 alkane-15-on-1-ol and the corresponding C32 compounds have been recognized in each of the three samples considered in this study. The biological origins of these compounds remain unclear, as they have been found in a variety of sediments, including those from the Black Sea (de Leeuw et al., 1981), the hypersaline Tyro Basin in the eastern Mediterranean (ten Haven et al., 1987), and a coastal area at the mouth of the St. Lawrence estuary (Nichols and Johns, 1986). Recently cyanobacteria have been proposed as a source for the alkane-1,15-diols (Morris and Brassell, 1988).

DISCUSSION

The molecular composition of these samples, in terms of the compounds detected, is surprisingly similar to that of many other marine sediments, including those from the following regions: the Cape Blanc upwelling off western Africa (Poynter et al., 1989a); the Sierra Leone region (Marlowe, 1984, Brassell et al., 1986) and Guinea Basin region (Poynter 1989) from the tropical Atlantic; the Peru upwelling region (Farrimond et al., in press); and a Mediterranean sapropel (ten Haven et al., 1986 and 1987). The dominant "marine" lipids recognized in the above samples includes the long chain alkenones and the alkane-1,15-diol/alkane-1-ol-15-one type compounds. Dinosterol may or may not be a dominant compound. If produced it is selectively preserved, but it may not always be a major input.

The principal differences between the above sites is generally the extent of the "higher plant" component present. In the case of the Peru upwelling "higher plant" waxes are barely detectable, the major "marine" lipids being the alkenones and the alkane-1,15-diols.

The above observation (i.e., that the composition of the lipid-soluble component of low to middle latitude marine sediments remains relatively constant), can be taken as evidence that the lipid composition of such sediments are partially dependent upon the composition of the contributing biota. Indeed, it would seem that a major factor influencing the composition of the sedimentary lipid fraction is the stability of the molecules during transit to the sediment. This notion is by no means original (consider the changing composition of the sterol fraction mentioned earlier), although it may have been underestimated. Highly selective preservation may partially explain the predominance of "Prymnesiophyte" alkenones in sediments underlying upwelling waters where *Prymnesiophyte* production is suppressed by diatoms (Poynter et al., 1989b; Farrimond et al., in press).

Significance of the distribution of the molecular components within each lipid extract

The distributions of some of the compounds (within a compound class and/or from a specific biological source) have been determined and expressed as parameters (Table 4). Possibly the best known of these parameters is the U_{37}^k index used to describe the unsaturation of the "Prymnesiophyte" alkenones (Brassell et al., 1986a and b). This parameter, which utilizes variables from both within a compound class (alkenones) and from a specific origin (*Prymnesiophytes*), is thought to be strongly dependent on the growth temperature of the specific source organism.

Based upon the calibrations of Prah et al. (1988) and Poynter (1989), the U_{37}^k values found for the present sediments correspond to water temperatures in the range 26°–28°C. While such values are eminently reasonable considering the sample location, it is doubtful that these U_{37}^k values are merely a reflection of sea-surface water temperature. The unpublished results of Grimalt (Site M16415-2) and Poynter (Hole 658A) show that samples older than approximately 900 ka, deposited under relatively cool water masses have U_{37}^k values which (based on the calibration studies) correspond to warmer waters (ca. 28°C). This apparent shift is perhaps more likely to be an effect of evolution than of diagenesis. However, further discussion of these observations is outside the scope of the present paper.

The "higher plant" *n*-alkane ACL parameter describes the average number of carbon atoms per molecule based on the abundance of the C27, C29, and C31 "higher plant" *n*-alkanes. This parameter is defined by the following formula.

$$n\text{-alkane ACL} = \frac{27 \times [C27] + 29 \times [C29] + 31 \times [C31]}{[C27] + [C29] + [C31]}$$

where [C \times] is the concentration of the *n*-alkane containing \times carbon atoms.

It has been found that the modal carbon number of a higher plant *n*-alkane distribution is broadly related to latitude (Simoneit et al., 1977; Poynter et al., 1989a), with higher modal carbon numbers occurring at lower latitudes. A further, more critical, analysis of the distribution of the above parameter (*n*-alkane ACL), has linked this relationship to the geographical distribution of fluvial and eolian inputs and source regions (Poynter 1989). The range of values determined in the present study is close to the observed upper limit, i.e., Saharan Air Layer dust from the Saharan/Sahel boundary had values

falling in the range 29.9–30.1. Note, for comparison, material transported south by the northeasterly trade winds was found to have values in the region 29.3–29.5. Based on the above, the values determined for this site (29.8–30.0) are indicative of a warmer (tropical) source region. This is consistent with the likely source, i.e., the Ganges-Brahmaputra river system. However, because in this instance we are dealing with much older *n*-alkane distributions (1–6 Ma) than those considered previously (0–400 ka), we should be prepared to accept the possibility that the results may have been influenced in some unknown way by evolution.

The (alc/(alc + alk)) ratio describes the proportion of C24, C26, and C28 *n*-alkanols in the sum of the (C24, C26, and C28 *n*-alkanols and C27, C29, and C31 *n*-alkanes). This parameter may provide a measure of the extent of degradation to which these compounds have been exposed. The rationale behind this is as follows:

1. It is assumed that, in terms of the bulk input of terrigenous material (averaged from many species of plant) into a sedimentary environment, the ratio of higher plant *n*-alkanes to *n*-alkanols in the epicuticular leaf waxes is approximately constant.

2. These compounds presumably have unknown yet definable degradation constants in the marine environment. The values of this parameter are likely to be dependent upon the chemistries of these compounds, for example the presence and absence of the hydroxyl functional group.

3. If these two assumptions hold, then the ratio of these two classes of compounds should depend on the extent of degradation. In a degraded sample the ratio of the functionalized *n*-alkanols to the unfunctionalized *n*-alkanes should have decreased because, while both compounds may be degraded, the functionalized compound will probably have the highest rate constant.

The rationale behind the application of this tool has been hinted at in the past (ten Haven et al., 1986 and 1987), i.e., the ratio of the *n*-alkanols to *n*-alkanes was found to differ in a series of sapropelic and non-sapropelic samples from the Mediterranean Sea. The mechanism offered to account for this difference was that the non-sapropel terrigenous material, having a higher eolian content, was more degraded (uv photo-oxidized) than that in the sapropelic sample, the latter having a predominantly fluvial source.

In a recent study (Poynter, 1989) evidence has been presented that suggests that two major factors controlling the preserved ratio of these two classes of compounds are in fact the water depth and the sediment accumulation rate. The details of how this relationship was assessed are outside the scope of the paper but in summary it follows very closely the logic presented by Sarnthein et al. (1987) describing the observed relationship between export primary production and organic carbon concentration in sediment.

The (alc/(alc + alk)) values observed at Site 717 lie in the range 0.61–0.66. In a previous study considering samples from the west African Coast and Guinea Basin (Poynter et al., 1989), the highest values measured lie in the region 0.45–0.60, these values correspond entirely to sediments deposited in less than 1000 m of water. Consequently the extremely high values found at Site 717 in sediments lying in 4634 m of water appear contradictory. This observation is, however, consistent with the turbiditic origin of these sediments, in that they were originally deposited in shallow water and then transferred rapidly to the present site as a density flow without experiencing the normal process of degradation occurring during transit to the deep water.

Table 4. A selection of parameters used to describe some key aspects of the composition of the characterized portion of the sedimentary lipid component.^a

Parameter	116-717C-22X-1 80–86 cm	116-717C-34X-3 130–135 cm	116-717C-55X-1 65–70 cm
U_{37}^k Index	0.967	0.958	0.964
Alkane ACL	29.97	29.80	29.86
Alc/(Alk + Alc)	0.63	0.61	0.66
Terr/(Mar + Terr)	0.32	0.54	0.59

^a The significance of each parameter is described in the text. However, they are summarized as follows:

1. The U_{37}^k index is thought to be related to the sea surface water temperature experienced by the precursor organism (Brassell et al., 1986a and 1986b).

2. The "higher plant" alkane ACL (average chain length) is similarly related to the growth conditions experienced by the precursor.

3. The proportion of "higher plant" *n*-alkanols in the sum of the *n*-alkanes and *n*-alkanols {alc/(alc + alk)} is thought to be related to the extent of degradation to which the organic material has been exposed.

The terr/(mar + terr) index refers to the sum of the stable "higher plant" *n*-alkanes over the sum of all the lipids considered in this study. Implicit in the use of this parameter is the assumption that the ketones, the alkane-1,15-diols and dinosterol are all solely marine in origin. This assumption must, however, be open to question since although marine sources have been assigned to these compounds, freshwater sources are also known (e.g., Robinson et al., 1984). Furthermore, given that these compounds do have a marine source, the ratio of these few lipids may not necessarily bear any relationship to the terrestrial/marine origin of the sedimentary organic matter because, (1) the lipids considered take no account of several main components of marine productivity (e.g., diatoms); and (2) the differing chemistries of these lipids and bulk organic carbon in the water column may complicate any simple relationship between these components. In view of this, the parameter is presented but no conclusions are drawn from it.

CONCLUDING REMARKS

The similarity of the portion of the lipid extract characterized in this study with that characterized in previous studies of marine sediments, is consistent with the view that the dominant factor is the relative resistance to degradation of the molecular input. Consequently the quantitative importance of lipid-producing organisms in controlling the eventual sedimentary composition of the organic matter is diminished, i.e., if only minor production of a particularly stable compound occurs, it will be enriched in the sediment record (relative to other lipids) due to the concomitant process of biodegradation.

The within compound class and/or within biological source composition of many of the compounds considered is consistent with the geographical location of the site. Specifically, attention is drawn to the following:

1. The U_{37}^k index corresponds to a sea-surface water temperature of between 26° and 28°C.
2. The *n*-alkane ACL corresponds to a low-latitude (or equatorial) higher plant source.
3. The ratio of the *n*-alcohols to the sum of the *n*-alkanes and *n*-alcohols corresponds to shallow-water deposition. The occurrence of such a value at a deep-water site is consistent with a turbiditic deposition.

Finally, it should be realized that, while the above values conveniently fit previously determined models, these models were usually determined for much younger sediments and may not be directly transferable.

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