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Turbidites and contourites of the Palaeogene Lefkara Formation, southern Cyprus

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Abstract

Deposition of the Palaeogene to early Neogene calcareous and siliceous deep-water sediments of the Lefkara Formation in Cyprus was successively dominated by pelagic, turbidity current, a return to pelagic and then bottom-current processes. Sedimentation occurred on the distal parts of a carbonate slope-apron to basin plain setting located in the western arm of the Tethys Ocean. The early phase of sedimentation directly overlying ocean crust, ridge-derived volcaniclastics and chemogenic sediments, was dominated by pelagic deposition of marl, marly chalk and radiolarian-rich calcilutite. This was followed by a gradual increase in the influx of biogenic turbidites (forming both chalk and chert deposits) from the north during the Early and Middle Eocene period, primarily as a response to tectonic uplift of the Kyrenia Range. Slower rates of sedimentation returned during the Late Eocene to Early Miocene, together with significant hiatuses in the sedimentary record. Together these reflect the cessation of turbidity current input, continued pelagic deposition and the onset of bottom-current influence on sedimentation. A combination of subtle features and supporting evidence allows the recognition of contourites in all the sections studied, together with the interaction of turbidity current and bottom-current processes in parts of the Lefkara Formation.

Keywords: turbidites; contourites; limestones; Palaeogene; Cyprus

1. Introduction

The Troodos ophiolite and its sediment cover exposed in Cyprus is a well known example of ancient ocean crust, from ultramafic mantle rocks to ocean floor pillow basalts, overlain by oceanic sediments (Moores and Vine, 1971; Robertson, 1990) (Fig. 1). The Lefkara Formation forms part of the early sediment cover ranging from latest Cretaceous to Early Miocene in age (Fig. 2). It is found overlying either pillow lava, hydrothermally formed umbers, previously displaced nappes, or radiolarites formed below the CCD (Robertson and Hudson, 1973, 1974).

The mainly biogenic sediments of the Lefkara Formation were deposited by turbidity current, bottom current and pelagic processes in part of a closing ocean basin. They reflect the environmental evolution of this part of the Tethyan ocean soon after its formation up to the onset of uplift at the first stage of ophiolite emplacement.

Turbidites in the Lefkara Formation were first documented by Robertson (1975, 1976), who also mentioned the possible influence of bottom currents

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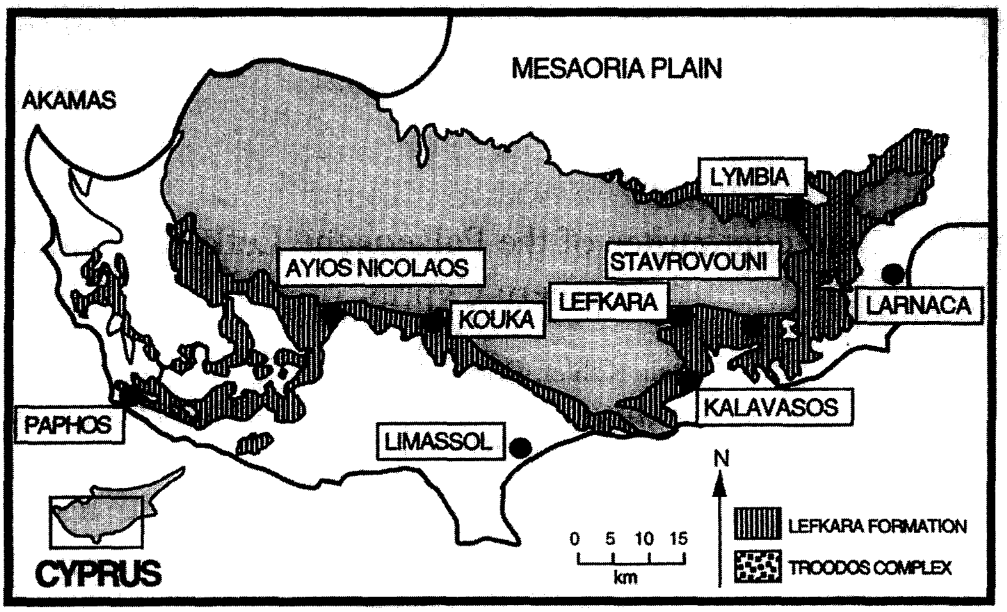


Fig. 1. Simplified geological map of southern Cyprus showing the location of the six sections studied in detail as well as principal towns along the south coast.

during sedimentation. The present study concentrates on the interaction of these two processes with the background pelagic sedimentation along the southern and eastern margins of Troodos. Six sections were studied in detail (Fig. 3), both in the field and in subsequent laboratory analyses. Biostratigraphic dating was carried out for each of the study sections by one of us (GK) as part of a PhD thesis (Kähler, 1994).

In this paper, we present a brief review of lithostratigraphy of the Lefkara Formation, a more detailed account of calciturbidite and calcicontourite facies, and then attempt to relate the pattern of sedimentation to a reconstruction of basin development in time and space, considering both the tectonic evolution of Cyprus as well as global environmental changes.

2. Lithostratigraphy

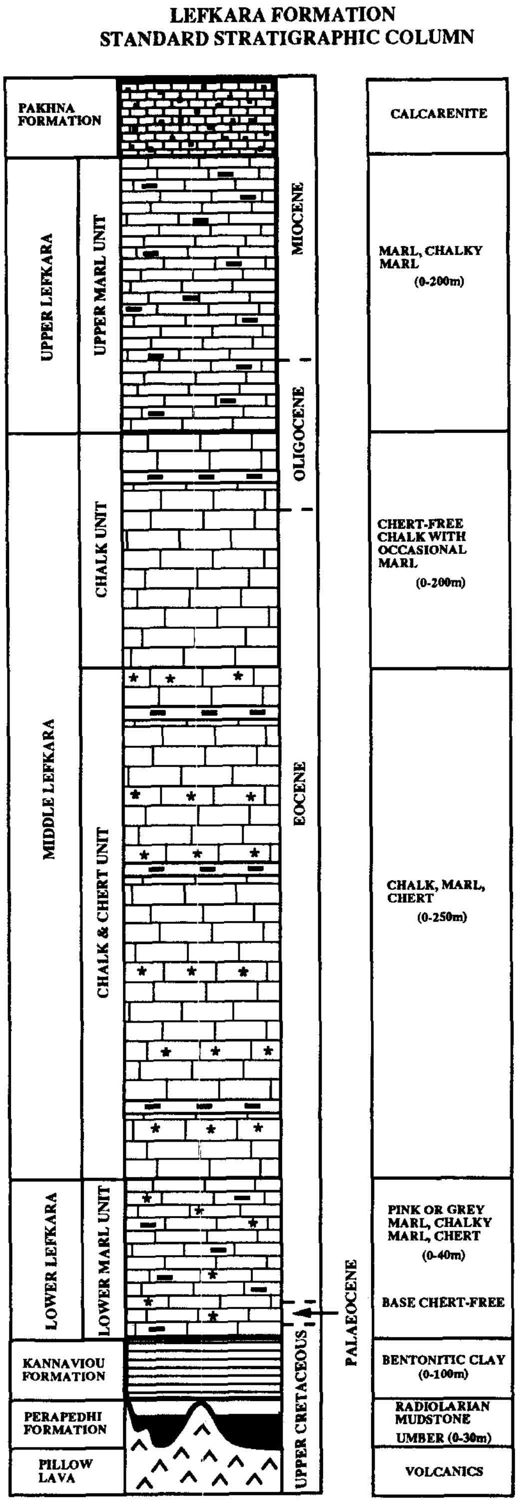
2.1. Lithological units

The Lefkara Formation can be subdivided into four lithological units (Figs. 2 and 3) each of which can be further subdivided into lower and upper subunits (Kähler, 1994). The oldest of these, the *Lower Marl unit* consists of pinkish marls, white chalky marls, rare limestones and cherts in regular, medium to thick beds. There is an increasing proportion of silicified micrite and chert facies from a lower chert-poor subunit to an upper chert-bearing subunit. Burrows and bioturbational mottling are present throughout and turbiditic structures are common in the upper part of some sections.

The overlying *Chalk and Chert unit* is characterised by regularly bedded facies (average bed thickness 9–16 cm), including chalks, marly chalks and thin marls, intercalated with silicified micrites and cherts. Turbidite structures are common only in some sections, particularly in the upper parts of the eastern localities (see below), whereas bioturbation is more common in other sections.

The *Chalk unit* is almost free of cherts, and medium- to thick-bedded (average 20–50 cm). In the western sections the lower part of the unit is composed of turbiditic chalks with structures decreasing towards the top. Otherwise it consists of dominantly thick-bedded to massive chalks or marly chalks with rare or no sedimentary structures in most sections. Near the topmost part of the unit clay seams may be present and beds become progressively thinner.

The *Upper Marl unit* is a succession of chert-free thin-bedded marls and chalky marls which becomes



increasingly calcarenitic towards the top. Only in one section, the Motorway section, the facies differs. Here bedded, laminated and bioturbated chalks are interbedded with thick marly strata.

2.2. Lithofacies

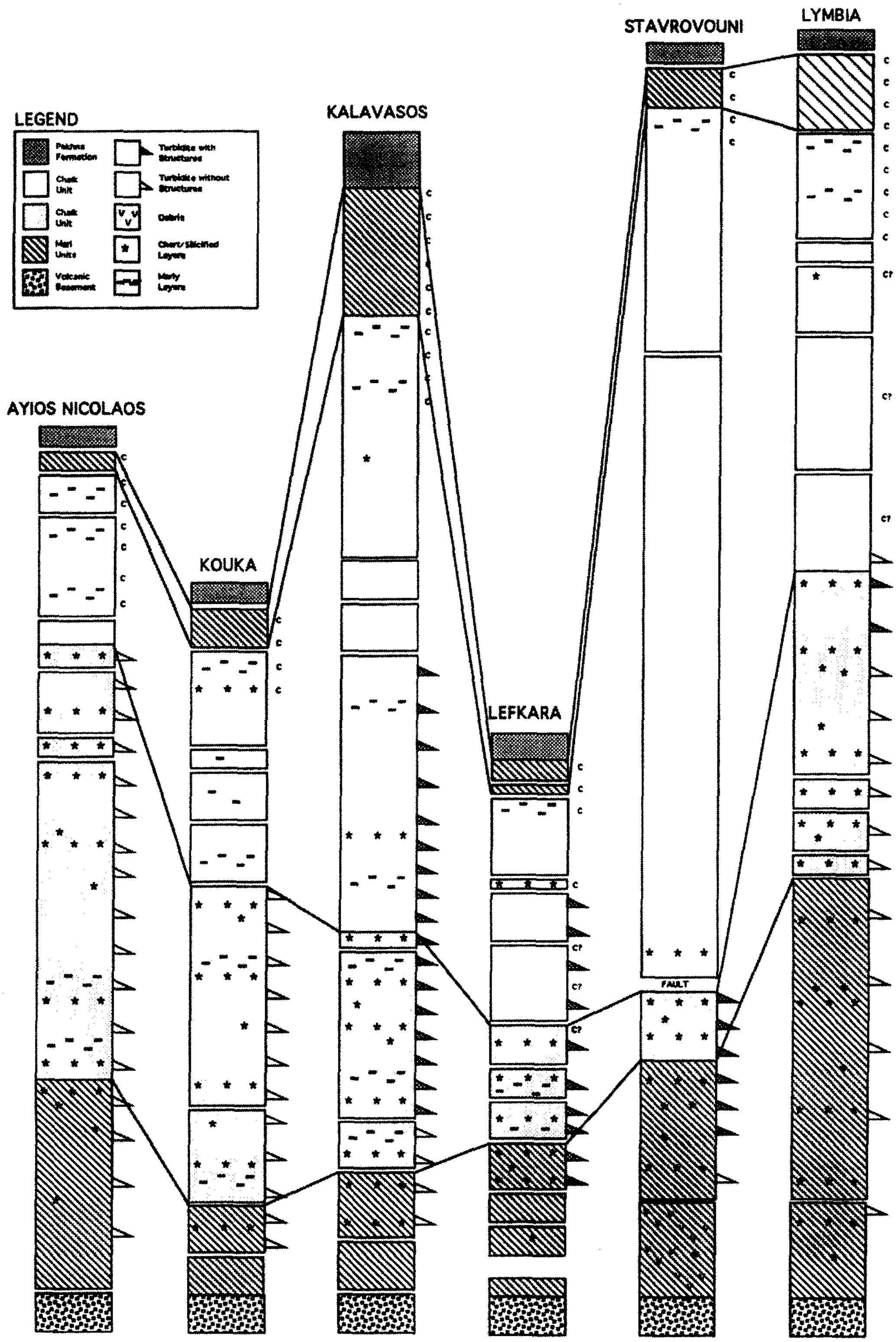
The Lefkara Formation is composed entirely of three end-member facies: chalks, marls and cherts. These occur independently, in association with each other and as various admixtures. The chalks represent primary deposits, whereas the cherts and marls are the result of partial diagenetic modification. Nevertheless, a primary difference in composition is responsible for the development of all three end-members.

The micro- and macrofacies of the Lefkara Formation have been described in detail elsewhere and will not be repeated here in depth (Robertson, 1975, 1976; Kähler, 1994). Facies containing silica, distinct sedimentary structures, such as lamination, cross-lamination, grading and microscours, or which are calcarenitic are dominantly packed biomicrites. These are mainly interpreted as calciturbidites. Otherwise, most chalks and marls are sparse biomicrites with a pelagic microfauna. Some of these can be interpreted as fine-grained calciturbidites and many as true pelagites. However, evidence for the influence of bottom currents in parts of the succession allow us to interpret some of the chalks, calcisiltites and calcarenites as contourites.

2.3. Stratigraphy

Detailed biostratigraphic work, based on planktonic foraminifers and radiolarians, reveals a middle Paleocene to Early Miocene age for the Lefkara Formation where studied (Kähler, 1994). Although a Maastrichtian age has been reported for the onset of Lefkara sedimentation by other workers (e.g. Mantis, 1970), such Late Cretaceous sediments are rare and only patchily distributed in Cyprus.

Fig. 2. Standard stratigraphic column for Cyprus showing the Lefkara Formation age, units, principal lithologies and thickness variation.


LEGEND
Pakhna Formation
Chalk Unit
Chalk Unit
Marl Units
Volcanic Basement
Turbidite with Structures
Turbidite without Structures
Debris
Chert/Silicified Layers
Marly Layers
AYIOS NICOLAOS
KOUKA
KALAVASOS
LEFKARA
STAVROVOUNI
LYMBIA
FAULT

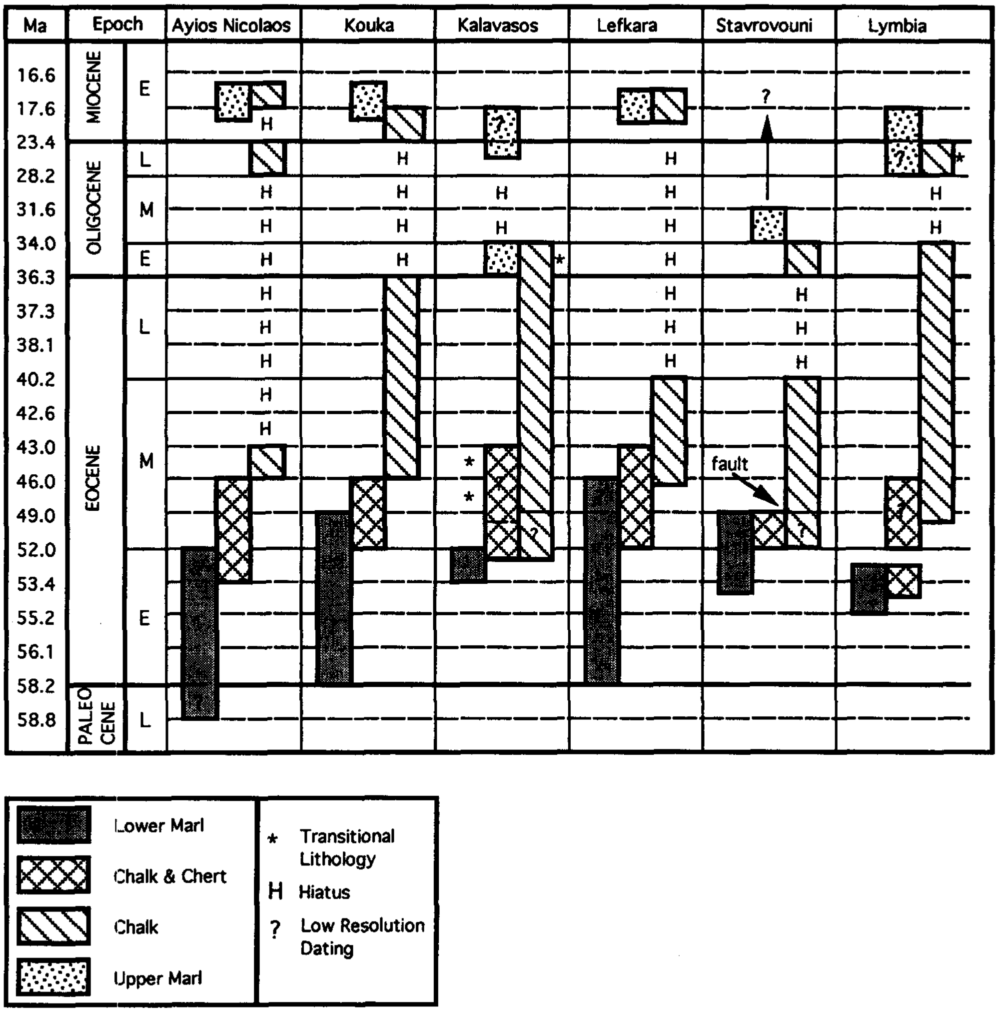


Fig. 4. Stratigraphic correlation of the four lithological units within the Lefkara Formation between the six study sections, based on careful biostratigraphic analysis by Kähler (1994). Note the marked diachroneity of units.

Generalising the results obtained by Kähler (1994), the Lower Marls are Early Eocene to early Middle Eocene in age, the Chalk and Chert unit is Early to Middle Eocene, the Chalk unit ranges from Middle Eocene through Oligocene and into the Early Miocene (in some sections), and the Upper Marl unit is Oligocene or Early Miocene (Fig. 4). However, there is a marked diachronous onset of the different units in the different sections studied, coupled with periods of slow or non-deposition, also shown in Fig. 4. Sedimentation rates calculated from this study are typically from 1 to 5 m/Ma, but range up to 20 m/Ma and down to 0.2 m/Ma.

Fig. 3. Schematic summary logs for the six study sections showing the four lithological units above volcanic basement and their lithostratigraphic correlation. (Note that this differs from the biostratigraphic correlation shown in Fig. 4.) The occurrence of contourites (*c*) and turbidites are indicated to the right of each section. Breaks in the logs represent actual breaks in the sections. For location see Fig. 1.

3. Regional characteristics

Six sections through the Lefkara Formation were selected for detailed study (Fig. 3). The main features of each section are briefly reviewed below.

3.1. Kalavasos

All four lithological units are recognised at Kalavasos, and the Lower Marls are found directly overlying pillow lavas in the valley northwest of the village. The Chalk and Chert and Chalk units are both relatively thick with common turbidites. These vary upwards from thick-bedded calcarenite–calcilutite turbidites with basal Bouma A- and B-divisions, through medium- and thin-bedded base-absent turbidites. The coarser-grained lower divisions, in particular, are typically silicified (Fig. 5c). Bioturbation indicative of slow pelagic sedimentation increases upwards and is dominant in the thick-bedded Upper Chalk and Upper Marl units.

3.2. Lefkara

The Lefkara section is the type locality of the Lefkara Formation, displaying a relatively thick and complete succession but one that is somewhat complicated by tectonic disturbance. Turbidites are first recognised towards the top of the Lower Marls as thick, highly silicified, Bouma A–F beds, with up to cm-sized clasts in some basal divisions (Fig. 5b). The interbedded bioturbated chalks are also thick, indicating comparatively long periods of interturbiditic pelagic sedimentation. Thick cherts, interpreted as turbidites, characterise the lower part of the Chalk and Chert unit, and thinner-bedded base-absent turbidites are more common upwards. Bioturbated pelagites become common in the Chalk unit and above, with rare thin turbidites and possible evidence of bottom-current reworking towards the top of the Chalk.

3.3. Stavrovouni

The section south of Stavrovouni Forest is missing both the lower part of the Lower Marls and most of the Chalk and Chert units, the latter most likely by faulting. However, the remaining succession is closely comparable to those found at Lefkara and Kalavasos, with a siliceous turbidite-dominated lower part and pelagic chalk-dominated upper part.

3.4. Lymbia

There is a thick, complete and well-exposed succession of Lefkara Formation overlying pillow basalts along the Nicosia–Larnaca motorway between Lymbia and Aradhipou. There is an upward increase in chert through the Lower Marls to an acme of thick turbiditic chert beds at the Lower Marl–Chalk transition. The cherts then become thinner and rarer upwards and turbidites where recognised are also thin and base-absent. Most of the Chalk unit comprises thick-bedded massive chalks with indistinct lamination and intense bioturbation more characteristic of contourites. The overlying 'Upper Marl' equivalent has laminated and bioturbated calcarenite horizons intercalated with the background marls. These are interpreted as calcarenitic contourites.

3.5. Kouka

A relatively complete Lefkara section is exposed along the roadside south of Kouka village and the contact with underlying basalts is seen about 1 km to the north. The sediments throughout are medium- to thick-bedded, bioturbated and burrowed, mainly chalks and marls, with fewer thinner cherts than in the sections described above and only rare turbiditic structures evident. Evidence for calcilutitic contourites and thin reworked siliceous contourites is present near the top of the Chalk unit.

3.6. Ayios Nicolaos

In the Ayios Nicolaos section exposed along the roadside northeast of the village, all lithological units are well represented, although structurally disturbed in parts. The basal Lower Marls are deposited on bentonitic clays above pillow basalts. In general, the succession is very similar to that at Kouka, with a predominance of thick-bedded, bioturbated pelagic chalks and marls, but having thinner-bedded cherts and poorer turbidite structures. Intercalated marls and clay seams towards the top of the Chalk unit are interpreted as the result of winnowing action by bottom currents.

4. Calciturbidites: nature and distribution

From the foregoing it can be seen that turbidites are most common in the SE study sections, at Kalavasos, Lefkara and Stavrovouni, and that they also appear to show the same general trends in deposition with time (Fig. 3). There is a gradual increase in the number of chert beds from near the base of the Lower Marls, followed by an incoming of thick high-energy turbidites or pure chert beds separated by relatively long pelagic intervals. These are overlain by high-frequency, lower-energy, base-absent turbidite events with less pelagic intercalation. Upwards there is a fining and thinning of turbidite strata, a decrease in frequency and thickness of the calcarenite A-, B-, and C-divisions, and an increase in bioturbated pelagic F-divisions, reflecting a decrease in the frequency, velocity and/or density of turbidity currents.

This trend is mirrored by the Lymbia Motorway section, although turbidite structures are less clear, the chert overprint more dominant and bioturbated intervals generally thicker. In the western sections, at Ayios Nicolaos and Kouka, the turbidites occur during the same lithostratigraphic interval but are much less clear due to lack of structures and are interpreted as more distal in character.

Biostratigraphic dating allows us to date the onset of definite turbidite influx to the top of the Early Eocene (53 Ma), although thin chert horizons are observed from the base of the Early Eocene (57 Ma) and might therefore suggest a slightly earlier onset in most sections. The youngest definite turbidite deposits are dated at approximately 42 Ma from the top of the Middle Eocene in the eastern sections, and we assume a similar termination throughout the region.

In general, the turbidites observed in the Lefkara Formation (Fig. 5) are more typical of calciturbidites than siliciclastic turbidites and compare favourably with the models developed by Stow et al. (1984), Stow (1986) and Eberli (1987, 1991). They have poorly sorted A- and B-divisions, in this case including lithic clasts, intraclasts and benthic foraminifers, and an absence of water-escape structures and sole marks. Although there is typically a thick fine-grained interval overlying the coarser A-, B- or C-division, lamination is indistinct in the D-division and it is very difficult to distinguish between the turbiditic E- and pelagic F-divisions. Both Stow et al. (1984) and Eberli (1991) suggest that this is in part due to the lack of electrostatic adhesion between carbonate particles in dilute suspensions, so that the finer portions of turbidity currents will mix upwards into the water column and settle very slowly with the background pelagic fallout.

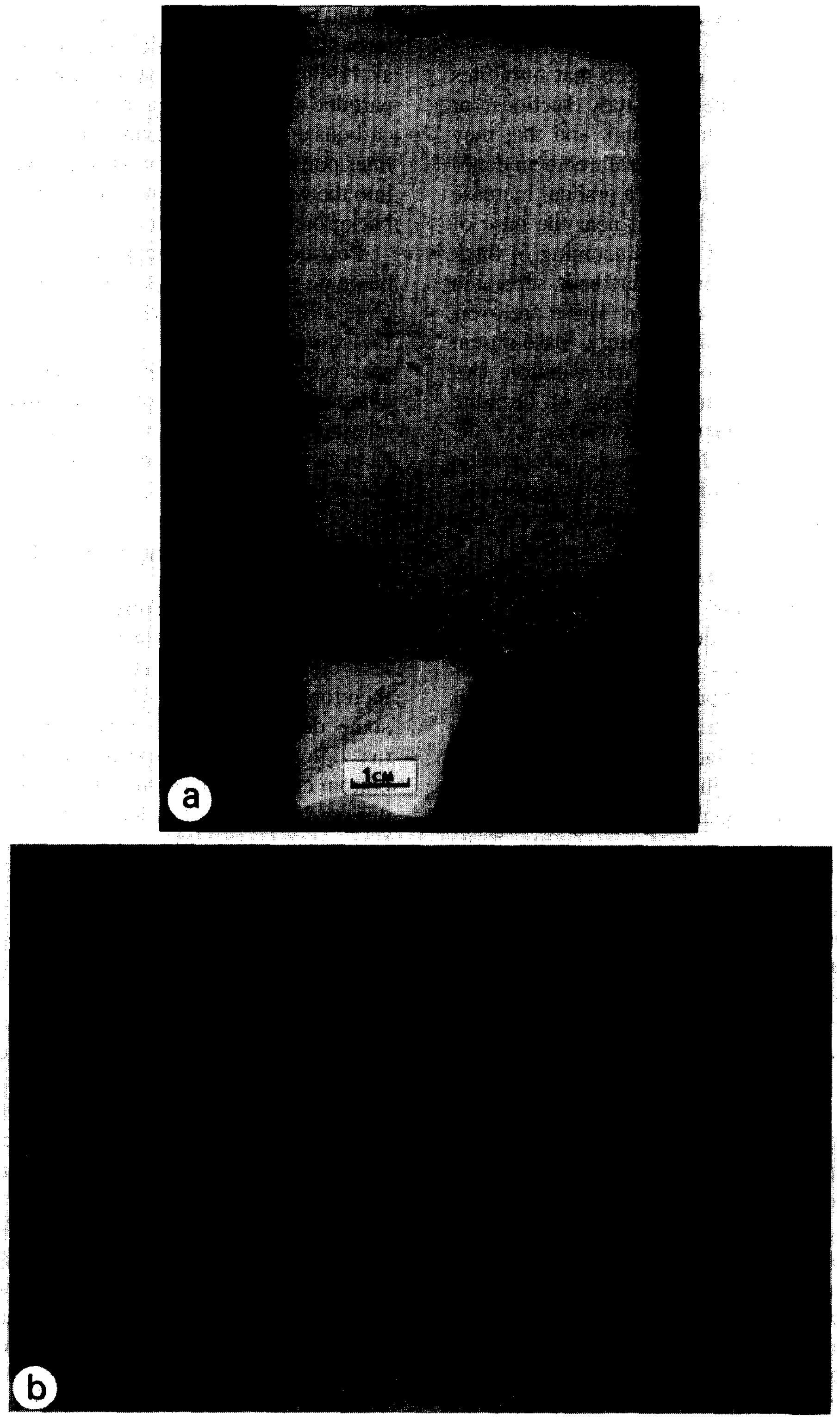
Post-depositional modifications are common in biogenic turbidites, in particular the partial or complete silicification of the coarser-grained divisions. In extreme cases, the resulting chert layers may preserve little or nothing of the original texture, composition and sedimentary structures. Most of the cherts in the Lefkara Formation are here interpreted as of turbidite origin, although definitive evidence is not always present.

5. Calcicontourites: nature and distribution

As with fossil contourites everywhere (see Stow et al., 1998), the evidence for their occurrence is less clearly defined than for turbidites, and it is therefore necessary to justify our interpretation in some detail. There are several lines of reasoning (as follows) for suggesting that the influence of bottom currents on sedimentation became significant during deposition of at least parts of the Chalk and Upper Marl units (Fig. 6). This is most evident for the Lymbia Motorway section (Fig. 7) but is also apparent elsewhere.

5.1. Sedimentary structures

Most of the Chalk unit in the Lymbia Motorway section is composed of massive chalks that are extensively bioturbated but contain only few faint sedimentary structures. These include more distinct burrowed horizons, some medium-thick laminae and more common thin, indistinct, discontinuous laminae. There is no cross-lamination, and no well-developed grading or structural sequence characteristic of the fine-grained turbidites observed in the other sections. These features, together with their occurrence in weakly developed cyclic sequences, seem to be best interpreted as being produced by bottom currents acting on fine-grained pelagic and/or turbiditic sediments, and are very similar to the muddy con-


1CM
a
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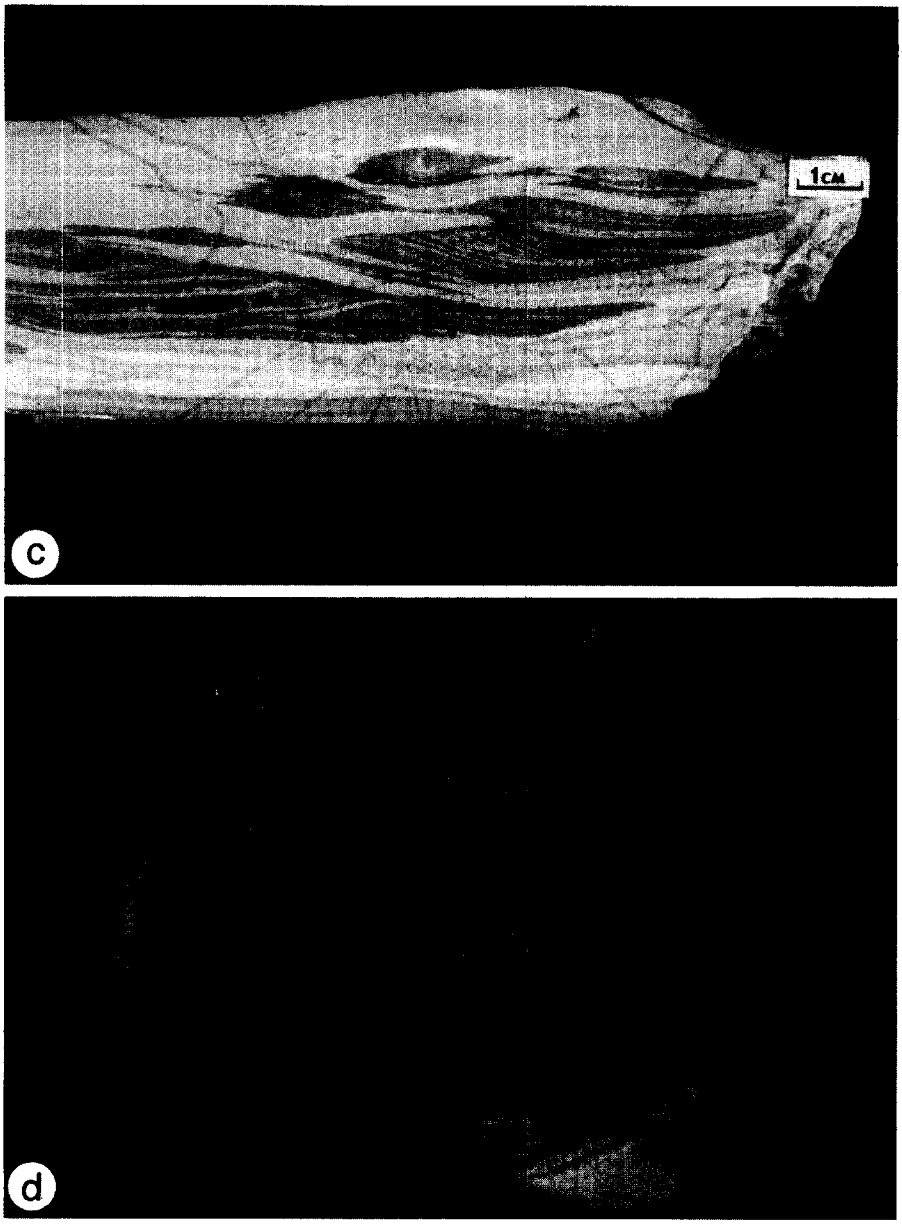
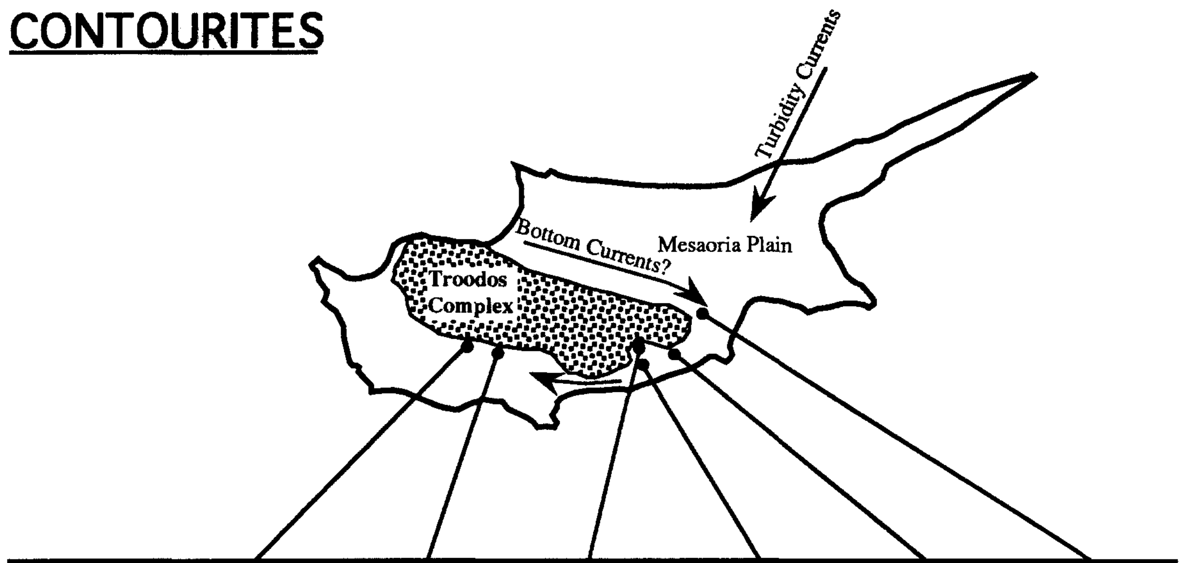


Fig. 5. Photographs of typical sediment facies within the Lefkara Formation. (a) Part of graded calciturbidite over bioturbated pelagic calcilutite. Poorly sorted (A-division) with volcanic and sedimentary lithoclasts. (b) Detail of part of base of calciturbidite figured in (a). The larger clasts are 3–4 mm long. (c) Part of silicified calciturbidite showing C- and D-divisions. (d) Thin calcarenitic turbidite (with dark volcanic and sedimentary clasts) overlain by bioturbated calcilutite. The sharp, slightly erosive top is believed to indicate bottom-current reworking of the turbidite, and the overlying calcilutite may be partly contouritic.

tourites described from present-day drifts (Stow and Lovell, 1979; Faugères and Stow, 1993) and to the calcicontourites described from some ancient successions (Bein and Weiler, 1976; Duan et al., 1993).

The gradual fading of turbidite structures above the Chalk and Chert unit and the onset of faint contourite structures seem to indicate an interplay between these two processes at least in the transition



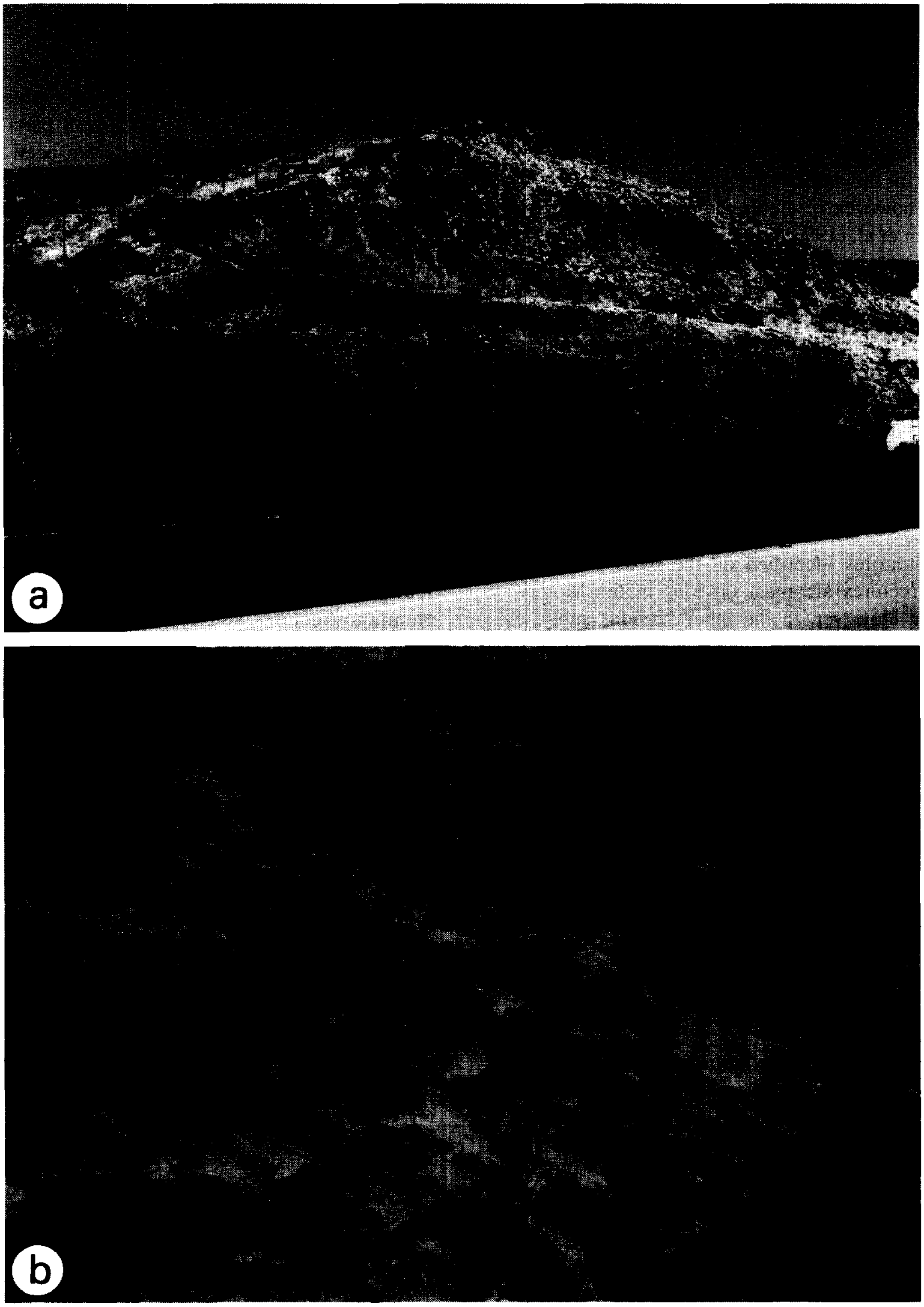
Section / Character	Ayios Nicolaos	Kouka	Lefkara	Kalavasos	Stavrovouni	Lymbia
Macrofacies	Chalk Marl	Chalk Marl Chert	Chalk Marl Chert?	Transitional Chalk, Marl	Chalk with increasing Marl Content	Structured Chalk Marl
Approx Basal Age	18Ma	18-37Ma	18Ma	36Ma	36Ma	36Ma
Oligocene Lithofacies	Chalk	Chalk	Chalk	Upper Marl	Upper Marl	'Upper Marl'
Reworked Radiolarians	Yes	Yes	Yes	No	No	No
Earlier Structures	No	No	Yes	No	No?	Yes

Fig. 6. Principal characteristics of the parts of the six study sections that are dominated by contourites.

zone, with the uppermost turbidites most likely being reworked by bottom currents (Stanley, 1993).

In the stratigraphic level where Upper Marls are developed in the other sections, the Lymbia Motorway section shows an entirely different facies. Here the bedded chalks at the top of the Chalk unit appear calcarenitic due to a higher amount of sand-sized planktonic foraminifers. Higher up, thick marl strata are intercalated and many of the chalk beds are entirely parallel-laminated, cross-laminated and strongly burrowed throughout. No grading or turbiditic structural sequences are observed. The

Fig. 7. Photographs of Lymbia Motorway section sediment facies. (a) Volcanic basement (dark rocks, lower left) overlain by mainly pelagic marly chalk and calcilutite facies. (b) Calcicontourite facies (calcilutites and calcisiltites) from the Chalk unit, Lymbia section.


a
b

coarser-grained strata show many characteristics of sandy contourites from both modern systems (Stow and Lovell, 1979; Faugères and Stow, 1993) and calcarenitic contourites from ancient successions (Bein and Weiler, 1976; Duan et al., 1993) reflecting a higher current velocity compared to the structures found in the underlying chalks. The interbedded marls, however, resemble the calcilutitic contourites of Duan et al. (1993) and therefore a dominant weak to moderate current strength.

The observed coarser lithology of several strata between the marls and a microfacies rich in foraminifers without lamination but increased fragmentation of the bioclasts indicate either an episodic removal of finer material by the winnowing action of bottom currents, or the addition of coarser particles by current transport. In either case, the cyclic alternation of coarser and finer intervals suggests regular variations in bottom-current intensity (Stow et al., 1986).

Contourites identified on the basis of sedimentary structures are most obvious in the Motorway section. However, in the other sections subtle evidence for contourites is also present near the top of the succession. Regular-bedded cherts, partly with lamination and cross-lamination, occur in the Kouka and (possibly) Lefkara sections near the top of the Chalk unit. These are most likely formed by bottom currents with the siliceous layers being the result of winnowing and relative enrichment of radiolarians (Decker, 1991; Sarnthein and Faugères, 1993). Furthermore, regularly intercalated marl beds at the top of the Chalk unit in the Ayios Nicolaos section and diagenetically enhanced clay seams in the matrix of flaggy chalks, found only near the top of the Chalk unit, may reflect winnowing effects by relatively low-velocity bottom currents.

5.2. Composition and microfacies

There are only very subtle variations in composition throughout the Lefkara Formation, so that the distinction between different facies or processes is not clearcut (Kähler, 1994). Turbidites are best distinguished on the basis of a common allochem component, including reworked pelagic and rarer shallow-water benthic microfossils, lithic clasts and intraclasts, and rare detrital quartz and glauconite. These are absent from pelagic facies and extremely rare in contourites.

General trends in quartz and clay content are superimposed on a background carbonate content that is mostly greater than 80%. The upper parts of the succession, in which contourites have been identified, show a slightly enhanced detrital quartz–clay content, relatively less palygorskite and an increase in illite and chlorite in some sections. Although increased bottom-current circulation is probably not the only cause of these differences, their distinction from the turbidite-dominated lower units is evident.

Thin-section study has allowed the recognition of eight microfacies types within the Lefkara Formation (Kähler, 1994), six of which are clearly defined by their different turbidite divisions. These relatively coarser-grained turbidites are characterised by dominantly packed biomicrites (>50% bioclasts) with variable microstructures, radiolarians and silicification, whereas the finer-grained turbidites (two microfacies) and most contourites are defined by sparse biomicrites (10–50% bioclasts), with or without microstructures, solution seams and radiolarians. The pelagites are also sparse biomicrites but lack any structures, radiolarians or silicification. Coarser-grained contourites, some of which have formed by the reworking of turbidites, tend to show a microfacies very similar to turbidites together with evidence of winnowing.

5.3. Palaeocurrent direction

Palaeocurrent measurements reported by Robertson (1976) revealed mainly NE–SW downslope-oriented flows for Lefkara Formation turbidites, consistent with their derivation from the Kyrenia Range to the north. However, towards the top of the succession in the Lefkara section, highly variable flow directions are reported with a significant component perpendicular to the palaeoslope. This would support alongslope reworking of turbidite tops by bottom currents.

5.4. Hiatuses and reworking

Closely spaced sampling for biostratigraphic analysis at all six sections has revealed the presence of a number of hiatuses or periods of much reduced sedimentation (Fig. 4). These are most intense and widespread within the Oligocene section, but also occur in the Late Eocene and Early Miocene.

Together with the increased occurrence of hiatuses and very slow rates of sedimentation, in some sections increased reworking of planktonic foraminifers and, more significantly, of radiolarians, are found in sediments from Oligocene time onwards (Fig. 6). This is most obvious in the Ayios Nicolaos section, slightly less evident in the Kouka section, and from the Middle Eocene onwards in the Lefkara section. In these localities bottom currents appear to have redeposited material that has been eroded from older strata. In contrast, the Kalavasos, Motorway, and Stavrovouni sections, are lacking in significant bioclast reworking. Here, either exclusively contemporaneous material was redeposited or only erosion but no redeposition took place. A similar displacement and accumulation of radiolarians by bottom currents has been described previously for Eocene contourite deposits in the Atlantic (Sarnthein and Faugères, 1993), and the Jurassic Ruhpolding Formation of the Austro-Alpine region (Vecsei et al., 1989).

5.5. *Timing of contourite deposition*

Strong evidence for contourite deposition dates from Early Oligocene (approximately 36 Ma) in the eastern sections, and from later Oligocene to Early Miocene time (28–18 Ma) in the western outcrops (Fig. 6). Faint lamination with burrowing and the possible winnowing of turbidite tops are found as early as Middle Eocene in the Lymbia Motorway section suggesting that the influence of bottom currents on sedimentation began rather earlier in this area. So too the Middle Eocene turbidites of the Lefkara section commonly show thin but relatively coarse-grained B-divisions overlain by a reduced/absent C-division and bioturbated calcilutites with reduced radiolarians (Fig. 5d). The early influence of bottom currents in reworking turbidite tops therefore seems likely in this area.

Several features of the Upper Marls lead to the inference that the whole unit may have been affected by bottom currents. There is a diachronous start to the unit coincident with the earlier onset of contourites in the east, and generally very low sedimentation rates throughout. The absence of radiolarians in Upper Marl sediments may be due either to the winnowing out of this very light skeletal debris by bottom currents or to slight chemical changes in the bottom waters leading to their ready dissolution. Heavier benthic foraminifers as well as other allochems, by contrast, are concentrated in thin irregular laminae as winnowed residues in the eastern sections. The enhanced clay component leading to the formation of marls rather than chalks might have originated by bottom-current entrainment of dilute turbidity current suspensions that are known to have deposited turbidites in the Mesaoria Plain to the north (Kythrea Flysch, Robertson and Woodcock, 1986). The variable thickness recorded for the Upper Marl unit, both in this study and by previous workers, further supports the influence of bottom currents in shaping contourite drift sedimentation of the Upper Marls during the Oligocene and Early Miocene.

6. Regional evolution and depositional controls

The development of the mixed pelagite–turbidite–contourite sedimentary system of the Lefkara Formation, as described in the foregoing, can best be understood in terms of regional tectonic and palaeogeographic effects on the one hand, acting in consort with global sea-level and palaeoceanographic controls on the other.

In general, the Lefkara Formation represents sedimentation in a closing small ocean basin. The unit subsequently preserved by ophiolite emplacement is known as the Troodos terrane. The facies observed are typical of those found in the more distal parts of a carbonate slope-apron system to basin plain setting (e.g. Mullins and Cook, 1986; Stow, 1986; Eberli, 1991). As a result of early localised uplift in the west of Cyprus the basin formed an asymmetric geometry which led to the distal character of turbidite facies deposited on what was effectively a counter-slope (cf. Eberli, 1987).

Estimates of palaeowater depth based on sediment facies, microfossil assemblages and preservation suggest depths in the range of 2000–3000 m (Kähler, 1994). The nearest land, and hence any potential source area for downslope resedimentation, lay to the north and is now represented by the Taurus Mountains of southern Turkey and the Kyrenian Range of northern Cyprus (Robertson, 1975; Baroz, 1980). The tectonic evolution of these source areas has been reconstructed by Robertson and Woodcock (1986) and is briefly referred to in the following, paying particular attention to the effect on deposition within the Lefkara Formation.

6.1. *Maastrichtian–Early Eocene: pelagites*

The earliest phase of Lefkara deposition, represented by the lower part of the Lower Marls, was dominated by pelagic sedimentation (Fig. 8A). Marls, marly chalks and radiolarian-rich calcilutites are the dominant facies, either directly above pillow lavas or locally overlying ridge-derived volcaniclastics and metalliferous chemogenic deposits. Accumulation rates were slow and, particularly in the oldest preserved sections, occurred close to the palaeo-CCD. Pelagic sedimentation continued throughout the rest of the Lefkara Formation, generally well above CCD, so that pelagites are interbedded with the turbidites and contourites discussed below.

The Kyrenia Range to the north was undergoing a period of subsidence, so that any material resedimented as turbidites and debrites from the Taurids was mostly trapped before reaching the Troodos terrane. The first evidence of minor turbidites in the Lefkara Formation is from the Paleocene–Eocene boundary zone.

6.2. *Early–Middle Eocene: turbidites*

A gradual increase in turbidite influx from the north marks the Lefkara Formation during deposition of much of the Lower Marl and Chalk and Chert units (Fig. 8A). By the top of the Early Eocene, most of the areas studied were receiving turbidites with an acme of input and hence rates of sedimentation at this time. This coincides with ophiolite obduction to the north, tectonic uplift of the Kyrenia terrane and the beginning of partial overthrust onto the Troodos terrane to the south. The background sedimentation remained deep-water pelagic in nature.

Both the Troodos terrane and the Mamonia terrane in the west/southwest were also undergoing localised uplift at this time, leading to relative elevation of the western part of the study area and hence a more distal aspect to the turbidites in these sections. That the acme of input also coincided with a global sea-level highstand is probably less significant than the tectonic influence of the source area, although carbonate highstand systems tracts do favour increased resedimentation.

The marked decrease in turbidite influx through the rest of the Mid-Eocene and their complete absence from younger rocks is in direct opposition to the coarsening-upward resedimentation sequence observed in the Lapithos Formation in the Kyrenia Range. This is because overthrusting to the south had created an inter-terrane basin that served to trap turbidity currents derived from the north.

6.3. *Late Eocene–Early Miocene: contourites*

Slower rates of sedimentation returned for most of the Chalk and Upper Marl units of the Lefkara Formation reflecting the absence of turbidites and the dominance once more of pelagic deposition. However, bottom-current influence on these sediments became marked from the Early Oligocene in the east and Early Miocene in the west (Fig. 8B). In fact, the first indication of contourites and bottom-current reworked turbidites comes from the Middle Eocene of the Lymbia Motorway and Lefkara sections, whereas the Upper Marls of all areas can be interpreted as dominated by contourites.

A change in depositional environment after Early Oligocene time is related to the collapse and rapid submergence of the Kyrenia Range and to subsequent development of a large submarine fan system (the Kythrea Flysch). A large amount of fine-grained material would have been put into suspension by turbidity currents feeding this fan and thus made more clay available for deposition in the Lefkara Formation. At the same time, subduction to the south of Cyprus and uplift of the Troodos terrane would have led to increased slope gradients in the area and hence to probable intensification of bottom currents, which were therefore more competent in the redistribution and winnowing of turbiditic input (Robertson et al., 1991).

The gradual uplift as well as increasing sediment input from the northeast is reflected in the diachronous onset of the Upper Marl lithology. While erosion and marl deposition took place in the east-

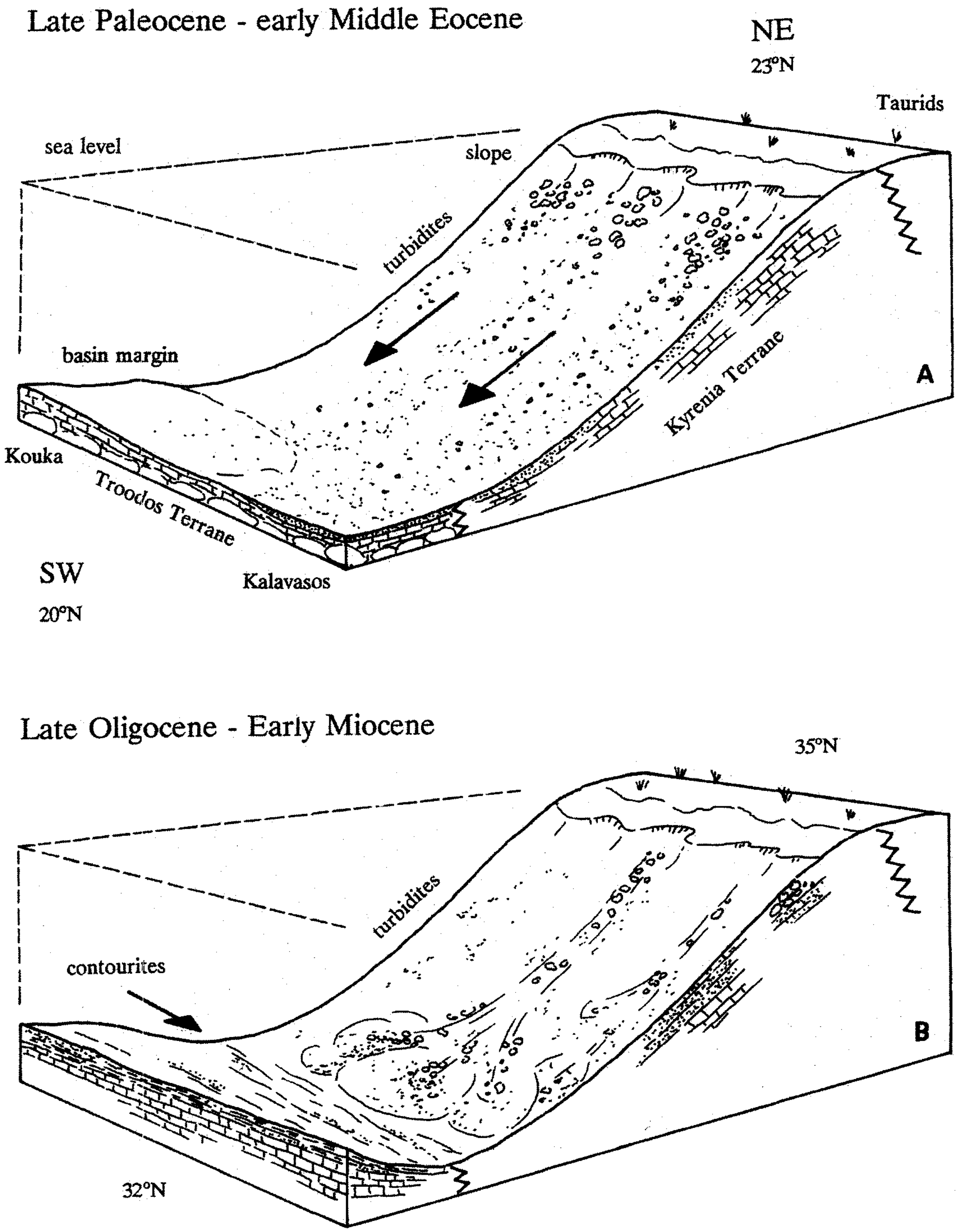


Fig. 8. Schematic depositional models for early Tertiary and mid-Tertiary time periods in the Cyprus–Taurid region of the Tethys Ocean. No precise scale is implied and the vertical zigzag lines on the side blocks indicate greater horizontal distances than those drawn. The inferred palaeolatitudes shown give an indication of the distance between the Taurid Range in the northeast and the uplifting Troodos terrane in the southeast around which the study sections are located.

ern sections (Kalavasos, Stavrovouni and Lymbia), weak bottom currents redeposited allochthonous bioclasts in the otherwise little affected western sections (Ayios Nicolaos and Kouka) during the Oligocene. The Lefkara section is an exception amongst the eastern localities, perhaps being protected from strong bottom currents due to its position in a topographic indentation in the uplifting ophiolitic basement. Upper Marl lithologies, therefore, only appeared in the Early Miocene at Lefkara as in the west.

Worldwide, the time between Late Eocene and Oligocene is characterised by a lowstand of sea-level and to the start of major glaciation and ice build-up in the Southern Hemisphere (Haq et al., 1987). Widespread hiatuses in ocean sediments are caused by subsequently enhanced bottom-current erosion, with maxima in the Late Eocene, Oligocene and Early Miocene (Vail et al., 1980; Miller et al., 1987). The hiatuses recognised in this study are dated to the same time interval and therefore seem to indicate a sedimentological response in the Lefkara Formation to a global change in climate. Consequently, Palaeogene-age hiatuses in Cyprus do not reflect exclusively the effects of local uplift, as proposed by Robertson et al. (1991) for the overlying Early Miocene Pakhna Formation.

If the whole Upper Marl Member is in fact related to bottom-current processes and the bottom currents, on the other hand, are the result of enhanced cold deep-water production in the Antarctic, then the decrease in carbonate in this unit may partly result from sea-floor dissolution (e.g. Sarnthein and Faugères, 1993) in addition to the sedimentary causes discussed previously.

There is no direct sedimentary evidence in Cyprus from which to infer the direction of bottom-current flow in the western Tethys Ocean during the Oligocene and Early Miocene. The Tethys was still open to the North Atlantic for westward-directed surface currents so that a deep counterflow to the east may have existed. Alternatively, an arm of Antarctic bottom water might have penetrated westwards part way into the western Tethys along the North African margin and then returned via a cyclonic gyre to flow in an easterly direction across the study area and along the southern margin of Eurasia.

Further studies of fossil contourites in Oligo–Miocene successions from different parts of the Tethyan region would provide valuable insight into the nature and evolution of palaeobottom circulation as the Tethys Ocean closed.

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