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The Pissouri Basin fan-delta complex, southwestern Cyprus

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Abstract

The Pliocene–Pleistocene sedimentary fill of a small (70 km^2) sub-basin in southwestern Cyprus is interpreted as representing a fan-delta complex with braid channels, which shows a broadly progradational sequence influenced by both sea-level fluctuation and tectonic activity. Basin differentiation began in Middle–Late Miocene with the tectonic break up of uniform carbonate deposition along southern Cyprus. During the latest Miocene (Messinian) salinity crisis, the Pissouri Basin was a shallow silled depression in which thick gypsum deposits accumulated. Renewed basin-margin faulting led to the local development of slope fan deltas, followed by extensive deeper-marine micrites and marlstones. Upwards, these are intercalated with terrigenous siltstone/sandstone turbidites that represent the bottomsets and foresets of a large fan delta. Continued uplift and erosion of Troodos resulted in the southward progradation of stacked micro-Gilbert-type deltas with interbedded Terra Rossa palaeosols that form the fan-delta topset unit. A distinctive bioclastic calcarenite/sandstone body appears to represent a local channelised unit within the fan delta complex.

1. Introduction

Fan deltas and other coarse-grained deltas have received considerable attention in recent years (e.g. Nemec and Steel, 1988; Colella and Prior, 1990), although much debate remains as to the different types that exist and the terminologies that should be used to describe them (McPherson et al., 1988; Nemec, 1990, 1993). In reality, both modern and ancient systems that contain elements of the coarse-grained delta family, typically display very complex depositional architecture and have been influenced in their development by a range of interacting controls (Massari and Colella, 1988; Postma, 1990).

In this paper we present the results of detailed geological mapping and sedimentological study of the Miocene to Recent Pissouri Basin in southwestern Cyprus (Fig. 1), which has been filled, in part, by a Plio-Pleistocene fan-delta complex with braided channels. The nature and distribution of sediment facies is documented, and the evolution of the basin and fan delta discussed in relation to Neogene history of the eastern Mediterranean and neotectonic uplift of Cyprus.

1.1. Geological setting

Cyprus can be subdivided into three tectonostratigraphic terrains (Fig. 1; Robertson, 1990) which are as follows:

(i) The Troodos terrain—a Mesozoic ocean-crust/mantle complex including the Troodos

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ophiolite, the southern Troodos transform fault zone, the anti-Troodos ophiolite to the south (also known as the Limassol Forest block) and the Akamas ophiolite in northwestern Cyprus.

(ii) The Mamonia terrain—a structurally complex, late Palaeozoic to Late Cretaceous assemblage of sedimentary, igneous and minor metamorphic rocks in southwestern Cyprus.

(iii) The Kyrenia terrain—a structurally complex, late Palaeozoic to Recent, dominantly sedimentary assemblage in northern Cyprus.

The Troodos and Mamonia terrains were juxtaposed in Late Cretaceous times (Campanian–Maastrichtian) with final amalgamation occurring in the Middle Eocene (45 Ma; Robertson, 1990). Amalgamation with the Kyrenia terrain occurred in the Late Eocene–Early Oligocene but with the bounding faults remaining active into the Pleistocene. Although the Troodos and Mamonia terrains acted as an amalgamated unit from Middle Eocene times the reaction of the unit to regional stresses was influenced by subsequent reactivation of former lineaments.

From Paleocene to Late Oligocene times, the Troodos–Mamonia terrain underwent a relative period of tectonic quiescence represented by undisturbed pelagic carbonate deposition of the Lefkara chalk formation. Sluggish and episodic

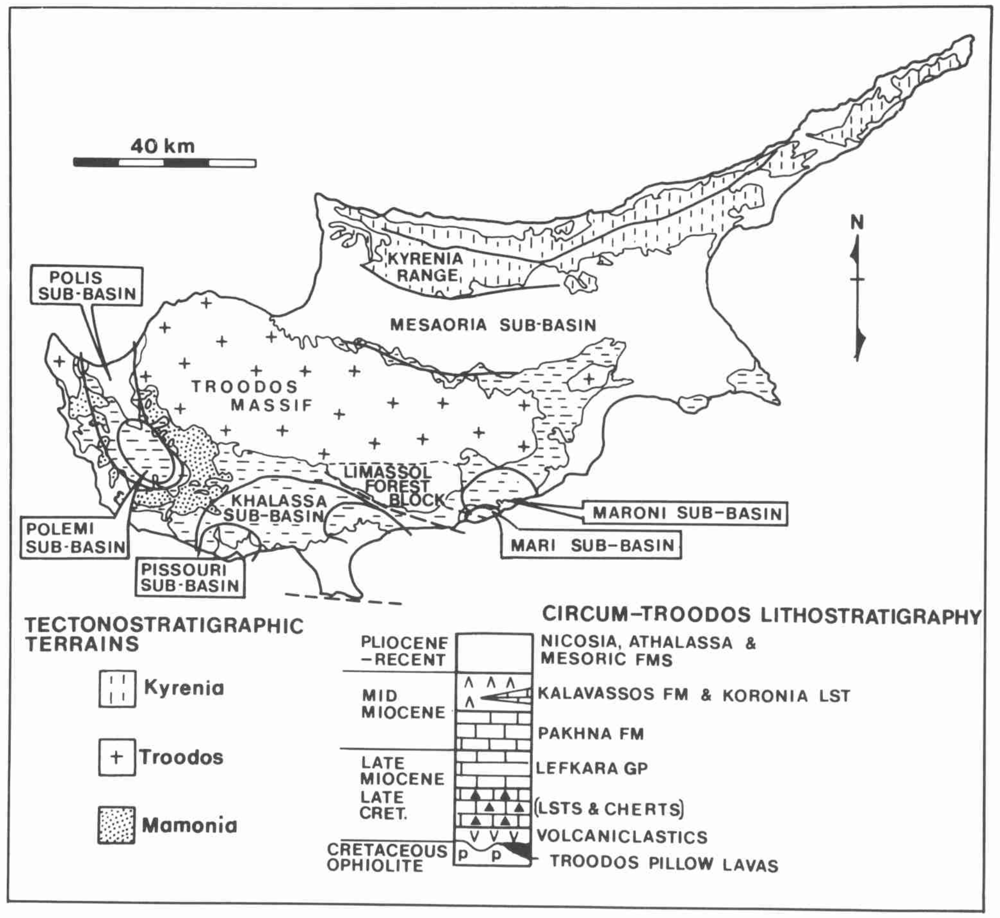

Fig. 1. Major structural elements and geological units of Cyprus, together with the main Neogene sedimentary basins (after Robertson et al., 1991).

subduction, due to the post-Late Eocene suturing of Mesozoic ocean basins and Africa–Eurasia convergence (Livermore and Smith, 1984) with the resulting northward underthrusting beneath Cyprus, initiated the Cyprus arc during Early Miocene times and associated reactivation of former microplate boundaries (Robertson, 1990). As underthrusting proceeded, the amalgamated Troodos–Mamonia terrain underwent progressive relative uplift.

During Early Miocene times, southwestern Cyprus was tectonically active with the break up of a sizable single oceanic basin into tectonically well-defined sub-basins, of which the Pissouri Basin is one. This large basin break up and associated palaeogeographic rearrangement have been deduced from the progressive differentiation of the Upper Lefkara and Pakhna formations (Robertson et al., 1991). In the Pissouri area the initiation of this change is marked by the formation of the Terra limestones—platform limestones with algal, coral and bioclastic debris dated as Burdigalian–Langhian (Mantis, 1970).

In the Late Miocene, a short-lived but dramatic event, known as the Messinian salinity crisis (Hsü et al., 1978), led to the partial to complete drying out of most of the Mediterranean and consequent widespread development of evaporite deposits. This event is variably marked in the different sub-basins of southern Cyprus, including the Pissouri Basin.

Ongoing gradual uplift of the Troodos ophiolite from the Pliocene to Recent led to considerable erosion and shedding of terrigenous material both to the north and south of Cyprus. In the southwest, much of this material was funnelled into the Pissouri Basin.

1.2. Basin extent

The effective extent of the Pissouri Basin has varied since its establishment as a tectonically

Table 1
Lithostratigraphic units in the Pissouri Basin and adjacent regions

Formation	Lithostratigraphic unit (member)	Subunits
Fanglomerate	Calcrete and soil cover	
	Valley fill and slope drift	
	Carbonate cemented conglomerate	
Athalassa	Pissouri Sandstones	Med-Coarse Sands
		Fine-Medium Sands
		Polymict Conglomerate
Nicosia	Bioclastic Calcarenites	
	Pissouri Marlstones	Silty marls + silts
		Marls + silts/sands
		Marls + micrites
	Calcirudites and Calcarenites	
Kalavassos	Polymict conglomerate + gypsum	
	Alabastrine gypsum	
	Selenitic gypsum	
	Gypsiferous conglomerates	
Pakhna	Reefal and Bioclastic Limestones	
	Paper Marlstone and Micrite	
	Well-bedded Micrites	
	Marlstone and Micrites	Marls and thin micrites
		Micrites, thin marls + calcarenites
Lefkara	Fissile-bedded Micrites	Fissile micrites
		Lentincular micrites
		Banded micrites
	Micrites and Cherts	
	Micrites and Silicified micrites	
Kanaviou	Melange	

driven depocentre in Burdigalian–mid-Miocene times (one of a series of well-defined structural depressions, Fig. 1). The basin boundaries are marked by the transition from undifferentiated Lefkara sediments to highly differentiated sedimentation of the Pakhna Formation, and encompass an area 23 km east–west and 12 km north–south centred around Pissouri village. However, the main focus of this study is the Pliocene–Pleistocene basin-fill succession, which includes the Pissouri fan-delta complex and has a maximum extent marked by the Lower Pliocene marine marls of 70 km^2.

2. Lithostratigraphic units and facies

Detailed mapping of the Pissouri Basin and adjacent region over the past few years has led to the recognition of six main lithostratigraphic units within the Plio-Pleistocene succession (Nicosia and Athalassa formations), two units within the Messinian evaporites (Kalavassos Formation), and seven units within the Eocene–Miocene limestone succession (Lefkara and Pakhna formations) (Table 1; Fig. 2). These units overlie and are juxtaposed against the Mamonia melange (Kanaviou Formation) west of the basin at Petra Tou Romiou. In several cases, distinct subunits can be identified and, in all cases, units and subunits are very variable in thickness and occurrence across the region, reflecting both an original variability in depositional architecture as well as post-depositional faulting and erosion. A composite stratigraphic column is presented in Fig. 2, in which the relative ages and positions of units are shown. The regional distribution of these units is shown in Fig. 3.

2.1. The Mamonia melange

The Mamonia melange is well exposed along the coast at Petra Tou Romiou and is found in the valleys up to 1 km inland. A chaotic jumble of very large and small clasts is set in a matrix of fissile, compacted and highly weathered brownish and greenish shale. Clasts include Triassic, hard, cemented reef talus blocks and fragments of

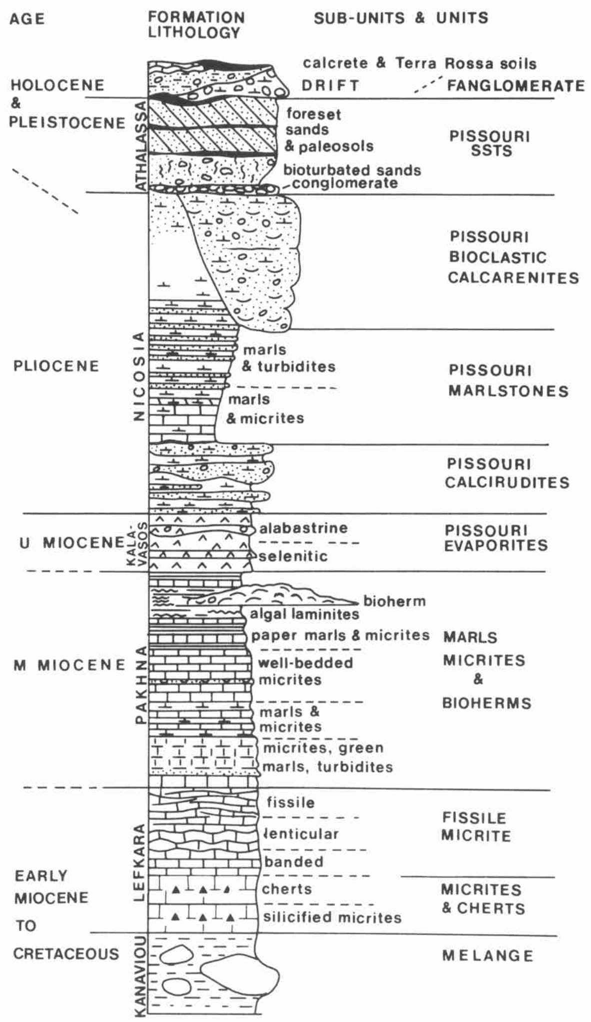

Fig. 2. Lithostratigraphic units recognised in the Pissouri Basin and their inferred relationship to the general stratigraphy of Cyprus.

oceanic pillow basalts up to some 50 m in diameter, together with a wide assortment of both exotic and local limestones, sandstones, cherts and mudstone of all sizes.

Although this melange is known to be related to the Late Cretaceous obduction and emplacement of the Troodos ophiolite, it has clearly proved to be a weak and ductile rock during subsequent tectonic activity on Cyprus. Clasts of the uppermost Pissouri Basin units (e.g. Pissouri Sandstones) can now be found incorporated into

the melange near Petra Tou Romiou, and suggest that movement along this zone of weakness in the west may have influenced tectonic evolution of the Pissouri Basin.

2.2. Lefkara limestones and cherts

Pure white micritic limestones interbedded with siliceous micrites and cherts (Figs. 4A and 4B) occur immediately above the melange west of Pissouri Basin and can be seen to underlie the mid-Miocene to Recent basin fill succession along the base of the high cliffs to the south and on the slopes to the north. These early Tertiary sediments of the Lefkara Formation form part of the mainly pelagic cover deposited over the deep oceanic pillow basalts now exposed on the flanks of Troodos.

In the upper unit of the Lefkara Formation in this area, the siliceous sediments are no longer present, the micrites remain pure and white and display a coarse fissile to lenticular style of bedding. Zoophycos trace fossils can be found throughout, but other bioturbational traces are more difficult to observe in the very homogeneous rock. There is little evidence for topographic differentiation in the area at this time, the sediments reflecting uniform deep-water pelagic sedimentation.

2.3. Pakhna limestones and marls

The main change from the Lefkara to Pakhna formations in the Pissouri Basin is the influx of more terrigenous material as observed in the generally browner hue of the limestones and incoming of thin to thick marlstone beds (Fig. 4C).

Pakhna sediments are well exposed in the area, particularly around the north and in the southwest, and display a range of different carbonate facies. These include well-bedded micrites, sparry micrites and sandy micrites (10–20% detrital

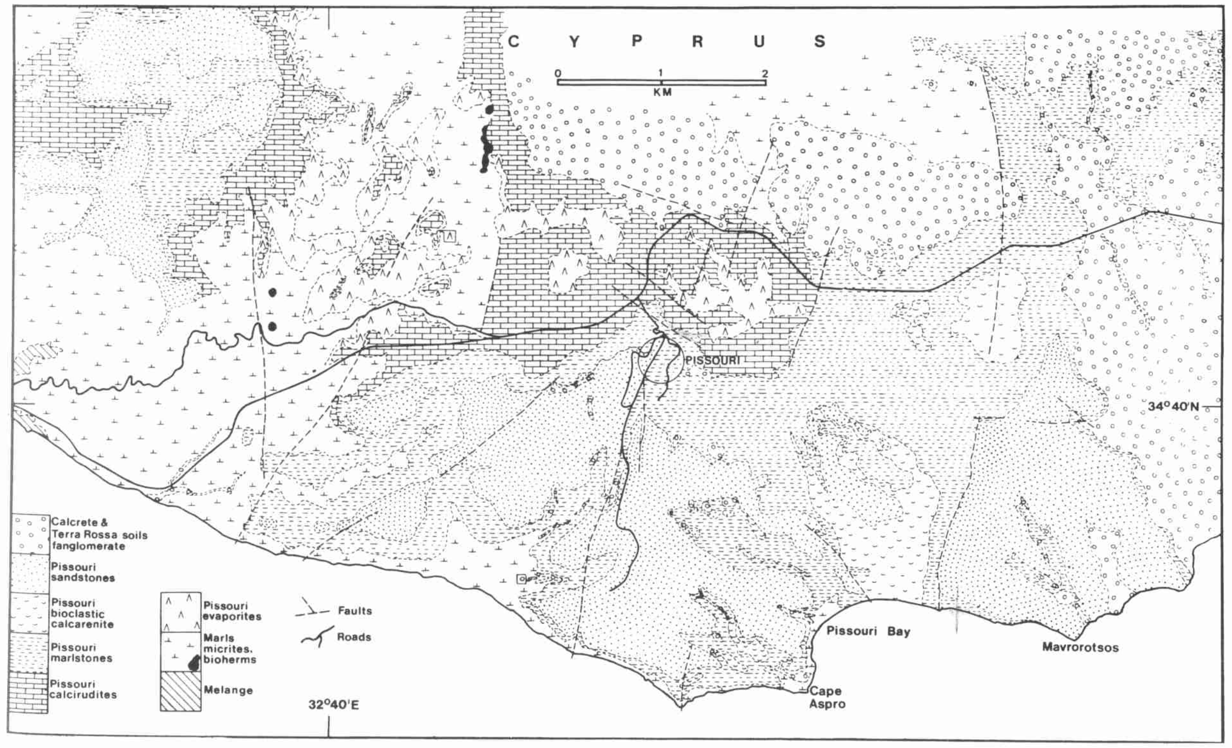

Fig. 3. Summary geological map of the Pissouri Basin and adjacent area, based on 1:5000 mapping over the past three years.

quartz in some beds), variably interbedded with whitish, pale greenish and brownish marls. The brown sandy marls are generally thicker in the upper units and have a distinct fissile or paper lamination. Upwards these are locally intercalated with hard algal laminites (Fig. 4D) or biomi-

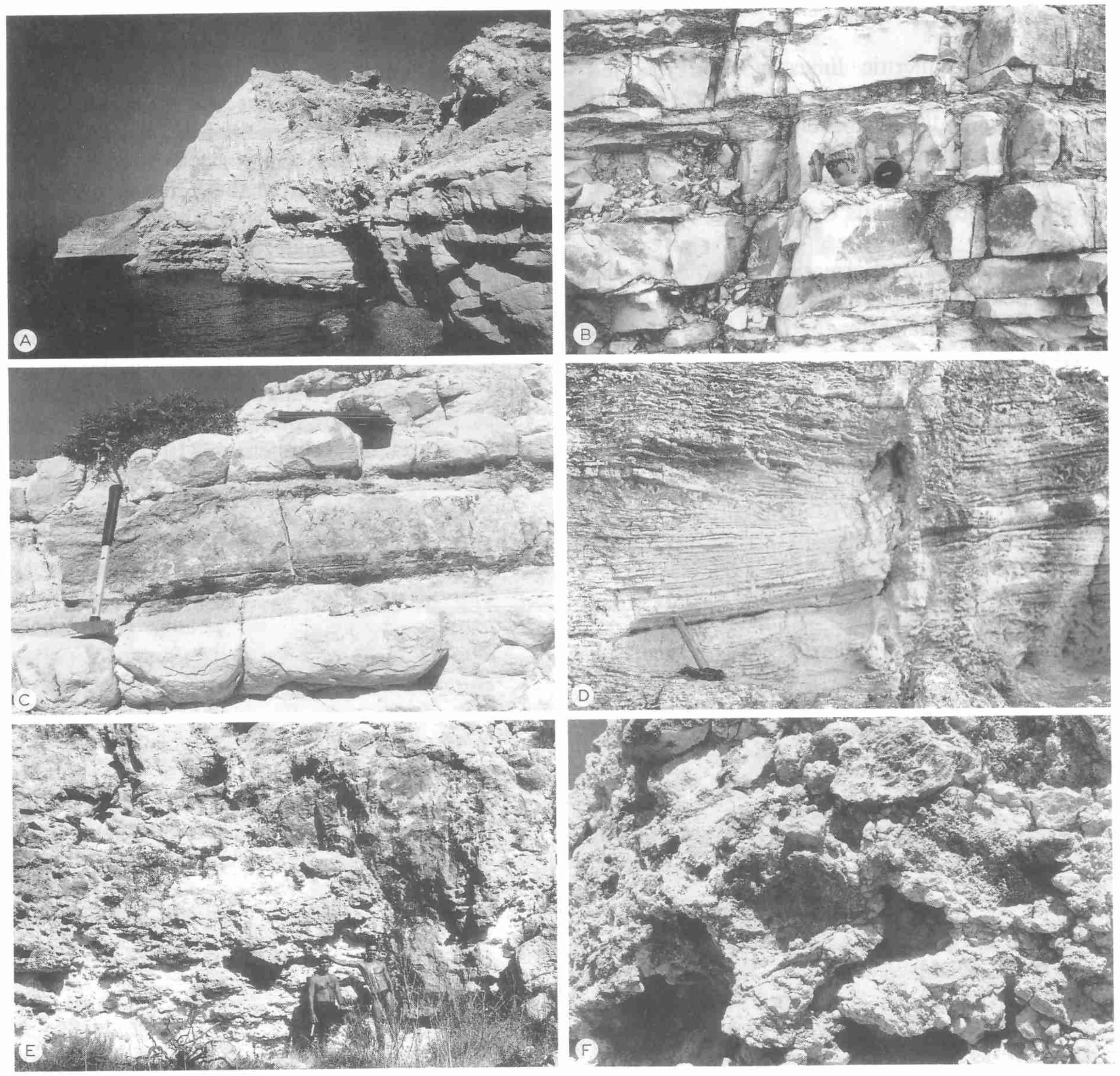

Fig. 4. Photographs of sedimentary facies that occur in the Miocene and older succession of the Pissouri Basin and the adjacent area. (A) Thick succession of well-bedded micrites of the Lefkara Formation overlain by Pakhna formation from western margin of Pissouri Basin. (B) Lefkara Formation showing detail of micrites and silicified micrites with general absence of marly interbeds. Lens cap diameter 7.5 cm. (C) Pakhna Formation showing detail of rare calcarenitic turbidite interbedded with micrites and sandy micrites. Hammer length approx. 40 cm. (D) Detail of algal laminites coeval with bioherm mound (above). Hammer length approx. 25 cm. (E) Bioherm mound and fringing talus (part) near top of Pakhna Formation from northwest of the Pissouri Basin. Figures for scale. (F) Detail of bioherm talus (above). Width of photo 1.5 m.

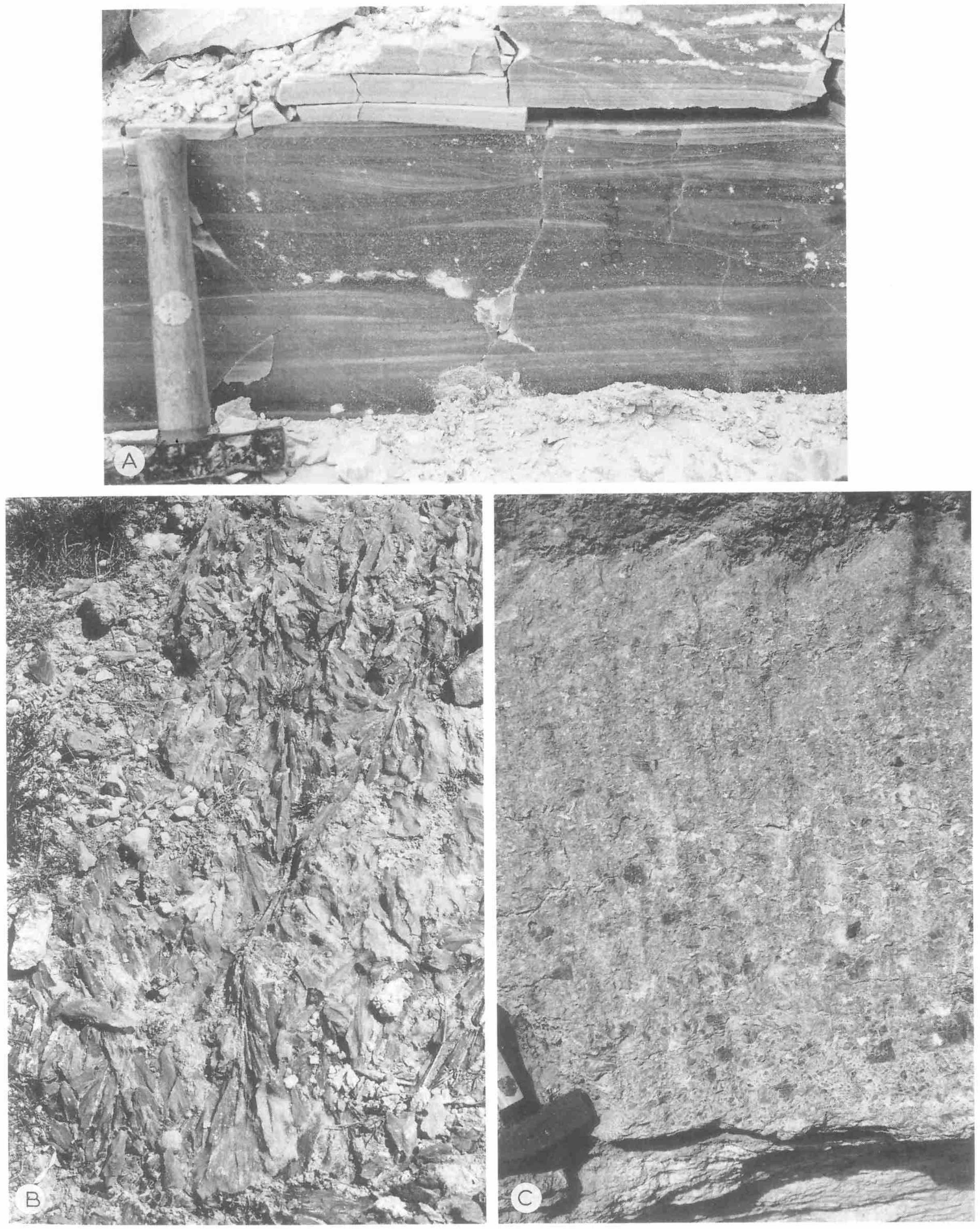

Fig. 5. Photographs of Messinian evaporite facies of the Pissouri Basin. (A) Gypsum breccia turbidite. Hammer head width approx. 12 cm. (B) Alabastrine gypsum. (C) Selenitic gypsum. Photo width approx. 20 cm. Hammer length approx. 25 cm.

crites, bioclastic calcarenites and calcirudites representing reef talus and resedimented deposits. Isolated carbonate mounds or reef knolls (Figs. 4E and 4F) are also present at the top of the Pakhna Formation and testify to an overall upward shallowing trend through the Miocene, with local emergence particularly around the rim of the newly formed Pissouri Basin.

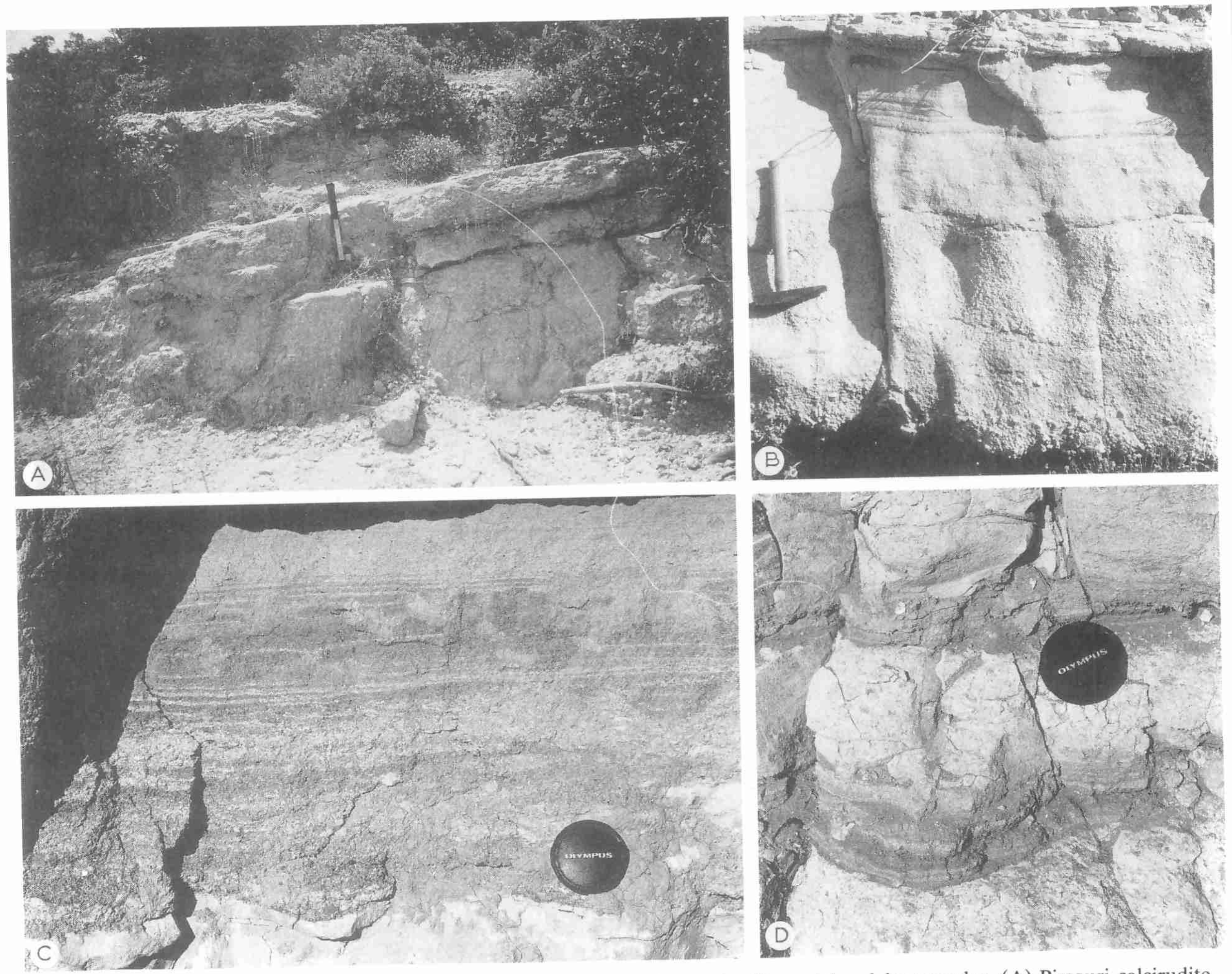

Fig. 6. Photographs of the Plio-Pleistocene sediment facies that make up the Pissouri fan delta complex. (A) Pissouri calcirudite unit (roadside northeast of village) showing calcirudite debrite (structureless lower bed) overlain by calciturbidite (crudely stratified upper bed). Hammer length approx. 40 cm. (B) Pissouri calcirudite unit (roadside northwest of village) showing detail of calcarenite turbidite. Hammer length approx. 25 cm. (C) Pissouri marlstone unit (small quarry face southeast of village) showing thick-bedded Troodos sandstone turbidite (T_{abcd}) erosive into bioturbated marlstone. Lens cap diameter 7.5 cm. (D) Pissouri marlstone unit (roadside southeast of Pissouri village) showing thin-bedded Troodos sandstone turbidites (T_{cde}, T_{de}) within bioturbated marlstone. Lens cap diameter 7.5 cm. (E) Bioclastic calcarenite unit (south side of Pikrokremmos) showing crude stratification in coarse-grained bioclastic sediment within channelised portion of the Pissouri fan delta foreset system. Hammer length approx. 40 cm. (F) Bioclastic calcarenite unit (Pissouri bay cliffs) showing detail of marine washed bivalve nest. Hammer length approx. 25 cm. (G) Pissouri sandstone unit (near Pissouri village) showing part of 4 m thick foresetted sands of Gilbert-type microdelta directly overlying 1.5 m thick dark red Terra Rossa palaeosol horizon. Figure for scale. (H) Pissouri sandstone unit (Mavrotoso bay cliffs) showing detail of foreset lamination partially destroyed by bioturbation. Photograph width approx. 15 cm.

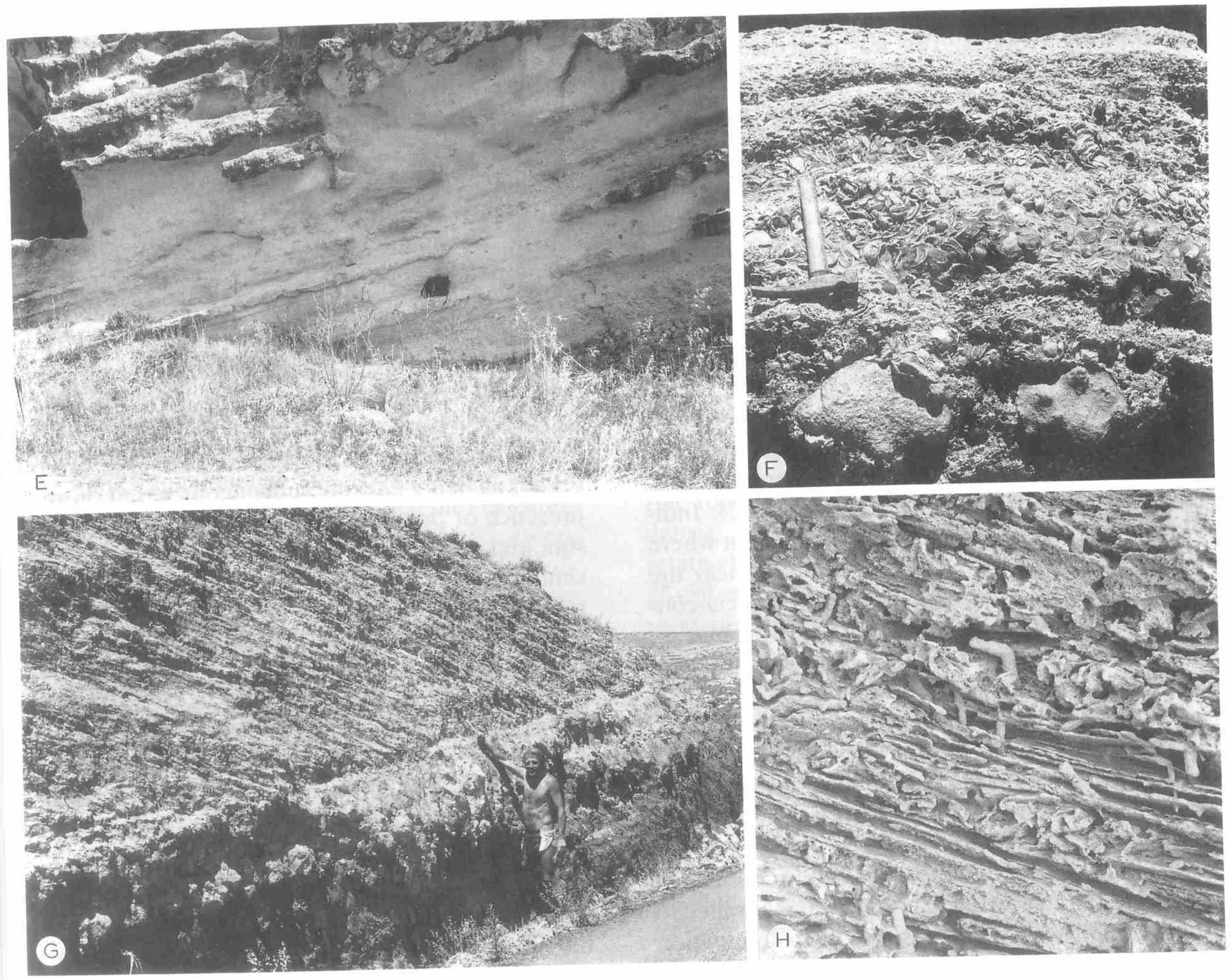

Fig. 6 (continued).

Bioturbation is evident through much of the formation with both epistratal grazing traces and a rich in-stratal burrowing fauna present in the limestones and marlstones. Thin to medium beds of bioclastic sandy calcarenites are found in the lower and middle units. In the former, they are clearly turbiditic in origin, displaying sharp erosive bases, normal grading and partial Bouma sequences, whereas in the latter unit they are generally structureless to weakly laminated and may represent storm-resedimented concentrations of fragmented shell debris. Evidence from ripple structures in the calciturbidites would suggest southward-flowing palaeocurrents.

The deposits of the Pakhna Formation in the Pissouri Basin area are similar to sequences described from other basins in southern Cyprus, e.g., the Maroni and Khalassa basins (Eaton, 1987). Much of the succession probably represents hemipelagic slope sedimentation within and around a shallowing basin on the south flank of an uplifting Troodos. This was punctuated by the rare influx of turbidity currents, storm-reworked shell debris and mass wasting from reef talus slopes. Full emergence was only very localised in the Late Miocene.

2.4. Messinian evaporites

At their maximum extent in the central and northern part of the Pissouri Basin, the Messinian age gypsum deposits of the Kalavassos Formation are some 40 m in thickness.

In general, the lower part of the section is dominated by coarse crystalline selenitic gypsum, with bladed twinned and untwinned crystals typically from 10–100 mm in length (Fig. 5C). Individual beds are not readily apparent except where intercalated with alabastrine gypsum or, near the base of the unit, with gypsiferous breccia-conglomerates. These latter are locally present as thin to thick beds with clasts and blocks of gypsum set in a chalky gypsiferous matrix. Some beds are normally graded (or reverse-normally graded) and clast-supported (Fig. 5A), whereas others are structureless and matrix-supported, indicating probable turbidity current and debris-flow depositional mechanisms, respectively.

The upper unit of evaporites comprises mainly fine-grained alabastrine gypsum, with parallel to sub-parallel lamination and rare cross-lamination (Fig. 5B). Selenitic gypsum may be interbedded in parts, especially in the transition zone between units and towards the top. Commonly, in the upper 3–6 m of this unit there are one or two beds of polymict breccia-conglomerate containing angular to sub-angular clasts (10–199 mm in diameter) of calcarenites, micrites, diatomites and selenitic gypsum set in a calcarenitic-calcilutitic matrix. Thin slump horizons may be associated with this interval and occur more widely in the alabastrine unit.

Coeval with the Messinian evaporites, there are localised occurrences of calcareous diatomaceous and algal laminates indicating very restricted shallow-marine/lagoonal conditions especially on the northern margin of the Pissouri Basin. Although not exposed, evaporites are believed to underlie the south-central part of the basin, where the small-scale folding and faulting of the overlying units is similar to that observed above the gypsum in other parts of the basin. However, they do not occur to the west where Pakhna limestones are directly overlain by Pissouri marls (see below).

The dominant control on the occurrence of evaporites in southern Cyprus was the repeated drying out of the Mediterranean during the Messinian salinity crisis (Hsü et al., 1978). The distribution of facies in the Pissouri area, however, was controlled by the inherited pre-Messinian basin topography and its subsequent evolution. The gypsum in the Pissouri Basin is interpreted as being entirely subaqueous based on the presence of parallel fine-grained alabastrine gypsum and coarse selenitic gypsum facies which are similar to facies identified in other Mediterranean areas (Schreiber et al., 1976; Vai and Ricci Lucchi, 1977). Both the morphology and topography of the Pissouri Basin were highly varied and basin margins locally steep. Algal filaments within certain evaporitic horizons (Rouchy and Monty, 1979; Elion, 1983) indicate very localised deposition within the photic zone, whereas the presence of slump units and gypsiferous turbidites and debrites show instability and resedimentation down steep basin margins. The polymict breccia-conglomerate towards the top of the unit is also interpreted as a resedimented deposit, most likely a subaqueous debris flow, and indicates renewed instability of the basin margins that continued during deposition of the overlying unit. Similar deposits of this age have been recognised in other basins in southern Cyprus (Orzag-Sperber et al., 1989).

2.5. The Pissouri calcirudite unit

The Pissouri calcirudite unit, named for its distinctive carbonate conglomerates (Figs. 6A and 6B) directly overlies the Messinian evaporites and ranges up to 25 m thick at its maximum development. Thickness variation across the basin is rather irregular. The lower few metres, which mark a localised transition from the evaporites below, comprise marls and silty marls yielding an abundant lagoonal type microfossil assemblage (Elion, 1983; Orszag-Sperber and Rouchy, 1983). Upwards, these are interbedded with thin calcisiltites and calcarenites progressively giving way to thick-bedded calcarenites and calcirudites with only thin intervening marls.

The calcisiltite and calcarenite beds show features characteristic of turbidites, including sharp or erosive bases, normal grading and partial Bouma sequences. The calcirudites are typically matrix-supported with a variety of subangular to rounded limestone clasts (centimetric to decimetric size) set in a calcilutitic to calcarenitic matrix. The bases are sharp and commonly highly irregular, indicating loading and scouring, whilst the tops are either sharp or gradational into calcarenites or stratified calcirudite. Possible water-escape structures have been identified in some beds. Subaqueous debris-flow and debris-flow/turbidity-current depositional processes are inferred.

This unit is interpreted as reflecting rapid fault-controlled subsidence of the Pissouri Basin which was at that time confined to the area of evaporite deposition. Erosion along the basin margin led to downslope resedimentation of intraformational carbonate conglomerates as calcidebrites and associated sand-grade material as calciturbidites. The palaeosol horizon recognised by Orszag-Sperber et al. (1989) supposedly within this unit is in fact a more recent Pleistocene palaeosol beneath the topmost fanglomerate and drift units that unconformably overlie the Pissouri calcirudites along the main Paphos to Limassol road sections.

2.6. The Pissouri marlstone unit

Conformable with the Pissouri calcirudite unit and more widely distributed over the area are the Pissouri marlstones (Figs. 6C and 6D). These form a composite tripartite unit that ranges up to 120 m in thickness, and shows an evolution from more pure white micrites and marls at the base to brownish marls and terrigenous siltstones towards the top:

(i) The lower subunit is characterised by greyish-white structureless marlstone with regularly spaced (60–80 cm) intercalations of thin white micritic limestone (10–15 cm thick beds). Lateral thickness variations are marked, with a general E–W-oriented thinning from a maximum of 20 m.

(ii) The middle subunit is marked first by the incoming of very thin siltstone/fine sandstone beds, and then by a progressive up-section increase in bed thickness from 5–10 cm up to a maximum of 70–80 cm. These terrigenous beds typically show sharp planar to erosive bases, normal grading, partial Bouma sequences (T_{de}, T_{cde} and T_{bcde}) with bioturbation towards the top, and are clearly of turbiditic origin. They are composed of mainly terrigenous/volcaniclastic material together with minor bioclastic and lignitic debris. The overall thickness of the subunit is relatively constant throughout the basin at about 25–30 m, with an average sandstone/marlstone ratio of between 1:3 and 1:2, increasing up-section.

(iii) The upper subunit is characterised by medium- and thick-bedded (10–100 cm) siltstones and sandstones interbedded with marlstone in approximately equal proportions. The sandstones are similar in composition to those of the underlying subunit, but the internal structures range from distinctly turbiditic (sharp bases, normal grading, etc.) to more heavily bioturbated (vertical and subvertical traces) and laminated. Overall thickness ranges from 50 to 80 m.

The lower subunit (i) corresponds to the Lower Pliocene MPL1-2 zones represented by the white and blue "Trubi" marls of Sicily (Orzag-Sperber et al., 1989). The sediments indicate re-establishment of more stable, deep-water basinal conditions in which low-energy pelagic sedimentation was dominant. The middle subunit (ii) represents the influx of terrigenous turbidites derived from an uplifting Troodos source in the north, with the increase in thickness and proportion of turbidites reflecting increased uplift and/or tectonic adjustments at the basin margins. This trend continues into the upper subunit (iii), in which the less distinctly turbiditic sands towards the top indicate a general shallowing of the Pissouri Basin, most likely due to regional tectonic uplift. The unit as a whole is interpreted as the basinal through bottomset and foreset portion of a large fan delta prograding into the area from the north and west.

2.7. The Bioclastic calcarenite unit

This highly variable and laterally discontinuous unit appears to be partly coeval with and partly incised into the Pissouri marlstone. It ranges up to 110 m in thickness but is restricted in occurrence to tongue-like bodies that now form positive relief features across the basin from northwest to southeast. Coarse-grained pebbly bioclastic sandstones or calcarenites are the dominant facies throughout, showing poor to very poor sorting and a wide range of sedimentary structures (Figs. 6E and 6F). Bedding is generally thick to very thick (30–150 cm) but somewhat indistinct, with crude parallel, sub-parallel and cross-stratification in parts and structureless or graded beds in other parts. Shallow scour features are present with coarse basal pebble lag deposits. Unidirectional cross-lamination gives SSE-directed palaeocurrents, consistent with rare occurrences of large-scale cross-stratification (up to 2.0 m sets). Herring-bone bi-directional cross-lamination has been observed but is rare.

In the thicker parts of the unit, there is a marked upward change in clast composition from dominantly bioclastic, including a reef talus assemblage and thick-shelled bivalves, gastropods and scaphopods, to mainly terrigenous, including a Troodos-derived igneous assemblage. There is a corresponding change in sand composition as detailed in a subsequent section.

The lower part of this unit is interpreted as forming as a more locally channelised part of the fan-delta foreset system that prograded into the then shallow-marine Pissouri Basin. The Pissouri marlstones of the finer-grained foresets and adjacent slope sediments are, in places, deeply incised by the Bioclastic calcarenites. The mainly bioclastic debris was derived in part from uplifted Pakhna (Miocene) reefal limestones around the rim of the basin and in part from fringing shell-rich banks. More intense uplift of the Troodos hinterland led to the increased contribution of igneous detritus upwards through the unit. Marine influence, as evidenced by rounding of pebbles, bivalve nests and more distinct lamination, is greater towards the southeast.

2.8. The Pissouri sandstone unit

The Pissouri sandstones occur as a thick (up to 80 m), laterally persistent and distinctive upper unit that forms the higher ground over most of the Pissouri Basin (Figs. 6G and 6H). They generally overlie and are broadly conformable with the Pissouri marlstones and, more locally, overlie the Bioclastic calcarenites. The sandstones are intercalated with widespread, thick, well-developed, deep red-coloured palaeosols and with somewhat less widespread conglomerates.

The main sandstone and conglomerate facies include:

(a) fine- to medium-grained, laminated to bioturbated, well-bedded sandstones;

(b) fine-to medium-grained sandstones with irregular, discontinuous lenses of pebbly sandstone-conglomerate;

(c) coarse-grained and pebbly sandstones, generally thick bedded, with parallel-lamination or trough cross-stratification;

(d) medium- to coarse-grained, very thick-bedded sandstones, showing large-scale Gilbert-type delta foresets in units up to 5 m thick, commonly with intense bioturbation in the upper part of the bed;

(e) poorly sorted, irregularly lenticular, thin- to thick-bedded conglomerates, with well-rounded clasts.

Facies (a) to (d) tend to occur in sequence from base to top of the unit, indicating firstly a major influx of terrigenous sediment into the area via a well-supplied fan delta, and then rapid progradation of this system across the margin of the Pissouri Basin. Individual Gilbert Deltas can be seen to prograde in a generally S to SE direction for up to 4 km, showing characteristic finger-like geometries with broad lenticular cross sections. The conglomerate facies (e) occurs most commonly as a relatively widespread basal conglomerate generally < 1 m thick, perhaps indicative of local erosion and/or a depositional hiatus, and then more rarely as isolated lenticular horizons higher in the unit. There are up to three palaeosol horizons (0.5–2 m thick) intercalated with the sandstone bodies and a further palaeosol capping the uppermost sandstone. All are Terra Rossa type soils with moderate levels of Fe/Al oxides and local cornstone concretions, indicating periods of low to zero sedimentation under warm relatively humid conditions.

2.9. The Pissouri fanglomerate / drift unit (Fig. 6)

The most recent sediments capping the Pissouri fan-delta succession are very variable in thickness and extent. In parts there is a relatively thin (0.5–1.5 m), very poorly sorted, moderately well-cemented, polymict conglomerate facies, interpreted as an alluvial fan sheet deposit or fanglomerate. This occurs as a partial caprock to the seaward-sloping higher ground across the area and is generally underlain by the topmost Terra Rossa palaeosol noted above. Chaotic debris-filled solution hollows can be seen to cut down some 2.5 m from this unit into the underlying strata.

Along the floors and margins of the currently active, seasonally dry valleys that cross the area, unconsolidated drift deposits of very poorly sorted, calcareous sandy muds, pebbly muds and muddy conglomerates may be up to 30 m or more in thickness. Their occurrence as terraces at several different levels can be attributed to the most recent phase of tectonic uplift and valley incision. Slope drift is found down the flanks of some of the steeper hills in the region.

The whole area is covered by a patchy development of deep red Terra Rossa soil and a more widespread calcrete cemented layer that may penetrate deeply into the underlying rocks.

3. Petrographic trends

Preliminary petrographic studies of the coarse fraction of sediments in the Pissouri Basin succession reveal three main populations of sand grains and pebble clasts: (a) basic to ultrabasic igneous material derived from the Troodos ophiolite complex; (b) limestones, cherts and biogenic debris derived from the circum-Troodos sedimentary suite; and (c) biogenic material and sedimentary clasts of intraformational origin. Some more exotic clasts include quartz-rich sandstones and red siliceous mudstones from the Mamonia melange, and gypsiferous material from the intra-basinal Kalavassos Formation.

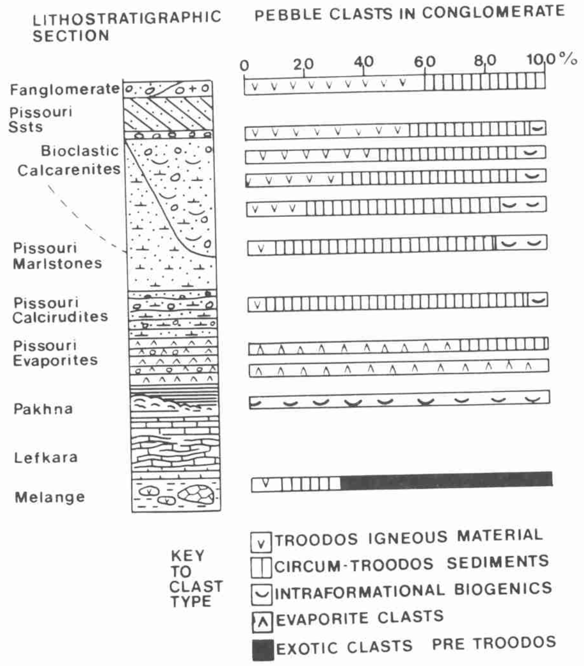

Fig. 7. Distribution of pebble clast types through the upper lithostratigraphic units of the Pissouri Basin succession, based on field counts of > 200 clasts for each interval indicated.

The distribution of pebble clasts is shown in Fig. 7, from the topmost Pakhna Formation to the Pissouri fanglomerate/drift unit. Basin differentiation was not fully established prior to late Pakhna times so that coarse-grained particles are rare in the earlier formations. The general trend is from a limestone-dominated intraformational population at the base to a progressively more igneous dominated polymict suite at the top. Gypsiferous conglomerates of the Kalavassos Formation break this otherwise uniform trend. The limestone/biogenic suite comprises mainly locally derived reef talus (corals, bryozoans, algal micrites and a variety of bivalves) in the upper Pakhna, and then more limestone (micrite) clasts in the higher units. Fragmented shell concentrations are common in the Bioclastic calcarenites, including *Chlamys, Glans, Modiolus, Mya, Pitar, Antalis, Dentallum* and *Turritella* genera. The igneous suite is generally dominated by basaltic clasts but shows an upward increase in dolerite and gabbro. Ultramafic clasts first appear in the Pissouri sandstone unit.

The petrography of sand grains, from both sandstones and conglomerate matrix material, shows very similar trends to those described above. In order to study a more uniform grain-size population and to yield a more sensitive indicator of petrographic variation through the Pissouri fan-delta interval, the carbonate material was dissolved in weak acid and the residue dried, sieved and mounted for point counting. The sandstones are purely lithic sandstones and the variation in different lithic components is shown in Fig. 8. Basalt is the most common constituent of all samples, ranging from nearly 40% in the Pissouri marlstone unit to some 70% in the Pissouri sandstones. The percentage of diabase and gabbro both increase up section, whereas chert and volcanic glass both show a decreasing trend. Ultramafic material (including olivine rich plutonics and serpentinised grains) is rare, and only occurs from the base of the Pissouri sandstone upwards.

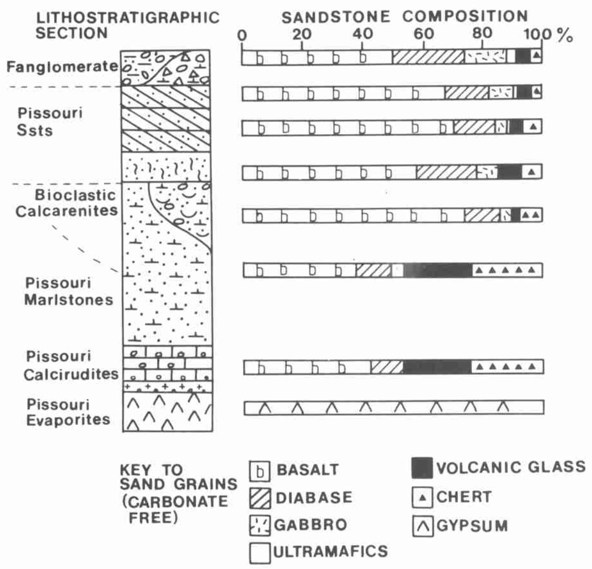

Fig. 8. Distribution of carbonate-free sand grain components through the upper lithostratigraphic units of the Pissouri Basin succession, based on point counts of > 300 grains for each interval indicated.

The stratigraphic trends observed from this petrographic study are the reverse of the ophiolitic stratigraphy that occurs in the principle source area of Troodos terrane. The fan-delta succession therefore reflects, in general, progressive erosion of the Troodos. Certain abrupt changes in composition, for example between the Pissouri marlstones and Bioclastic calcarenites, may indicate periods of rapid uplift in the Early Pliocene and Late Pliocene/Early Pleistocene. The paucity of ultramafic grains is due, in part, to their relative chemical instability.

4. Architectural evolution

The Pissouri Basin became a distinct depocentre on the southern flank of Cyprus during the latter part of the Miocene. This is evidenced by marked facies differentiation at the top of the Pakhna Formation, in which small mounded bioherms surrounded by reef-talus interfinger with shallow-water algal laminites and deeper-water fissile marls, micrites and bioclastic turbidites. The overlying Kalavassos Formation evaporites of Messinian age were further confined to the central part of this relatively small, probably fault-controlled basin as shown clearly from their mapped distribution (Fig. 3). Synsedimentary faulting is inferred from the presence of gypsum breccias, slump units and turbidites.

It was into this tectonically unstable basin that the Pissouri fan-delta complex was introduced. Depositional architecture of the different units identified was controlled by basin/slope topography, tectonic uplift and subsidence, Neogene sea-level changes and climatic variation through the Pleistocene period. The key elements of this complex are summarised below with reference to a series of time-slice cartoons illustrating basin evolution (Fig. 9) and a composite fan-delta cross section (Fig. 10):

(1) Localised development of small slope fan deltas apparently fringing the northern part of

the basin (Pissouri calcirudite unit), was principally controlled by fault subsidence. Only the bottomset/foreset deposits are now preserved, comprising resedimented calciturbidites and calcidebrites with thin interbedded hemipelagites. A series of smaller fan deltas is inferred from the marked variation in thickness of the unit across the area although its apparent continuity does

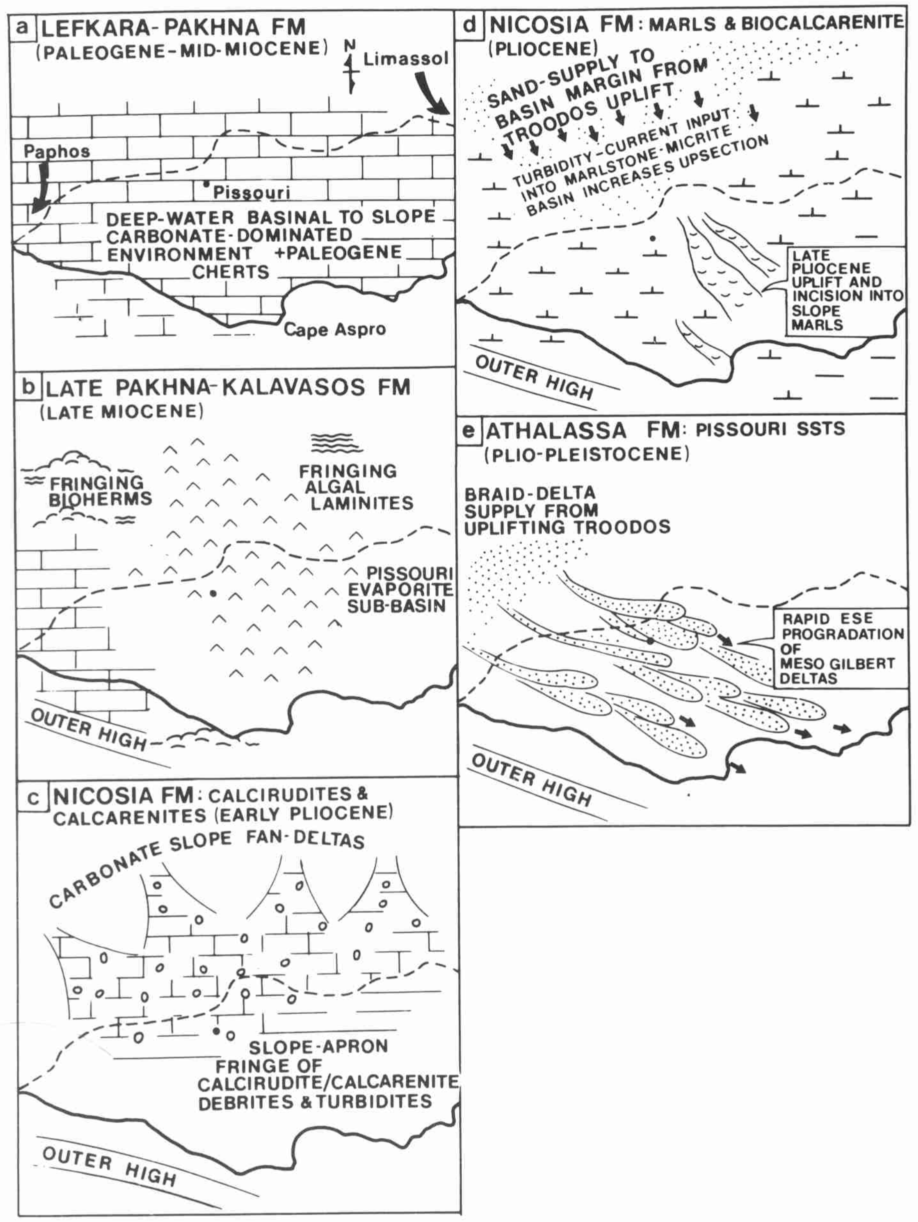

Fig. 9. A series of time-slice maps showing inferred depositional environments during evolution of the Pissouri fan delta complex. The present-day coastline, main Paphos to Limassol road (dashed) and position of Pissouri village (*P*) are given for location on each map. The ornament used is the same as that on Figs. 2 and 3.

imply extensive overlap of individual fan deltas along the margin. A more proximal facies (e.g. delta topset) might be expected in the most northern part of the area, but this has either been removed by subsequent uplift and erosion or is obscured by intense weathering and calcrete formation.

(2) Widespread and uniform blanket deposition of pelagic marls and micrites in a stable deep-water basin at its maximum development (lower Pissouri marlstone, subunit i), occurred during relative sea-level highstand. The basin appears to have developed rapidly at this stage, both in water depth and lateral extent, as the lowermost pelagic micrites and marlstones (subunit i) overstepped the earlier basin margins and were deposited in apparent conformity with the underlying Pakhna limestones.

(3) Influx of siltstone/sandstone turbidites into a rapidly shallowing basin (middle to upper Pissouri marlstone subunits ii and iii), reflected lowering sea-level coupled with the onset of gradual pulsed uplift of Troodos. These sediments may be interpreted as the bottomset and foreset deposits of a broad-headed fan delta. In the lower part the background hemipelagic slope deposits dominate, whereas upwards they are intercalated with progressively more terrigenous material supplied from the fan delta, that are confined to the central part of the area where the unit shows its thickest development. A broad single input point in the north is inferred, with progradation of the shallower-water facies towards the southeast. No unequivocal palaeocurrent data has yet been obtained from this unit.

(4) Interrupting the succession from underlying marlstones to the capping Pissouri sandstones, there are locally thick, channelised, bioclastic calcarenites that protrude as lenticular tongue-like bodies several kilometres across the basin from the north (Bioclastic calcarenite unit). They are, in part, deeply incised into the slope marlstones and turbidites, and appear to represent confined or channelised fan-delta foreset

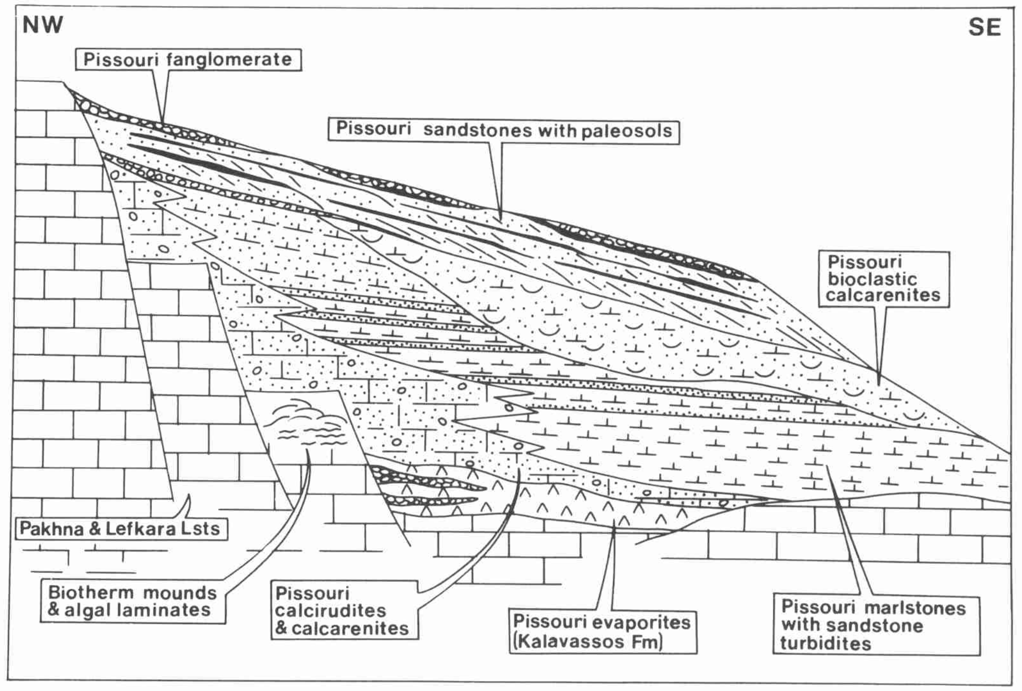

Fig. 10. A composite NW–SE cross section through the Pissouri fan delta complex. The vertical scale is much exaggerated and the stepped faulted margin largely inferred.

deposits resulting from localised basin margin faulting and uplift, and the reworking of bioclastic material. The upper part of the unit is again characterised by more terrigenous input from the main fan-delta system. The tongue-like geometry, observed channel margins and locally developed cross-stratification all indicate progradation to the southeast, where marine reworking of the sediments became more marked.

(5) The upper sandstones (Pissouri sandstone unit) are a thick and widespread unit showing an overall broad fan-like and partly elongate geometry with an apex west of the present village of Pissouri. Palaeocurrents were mainly directed towards the southeast. Individual, stacked, meso-Gilbert deltas can be seen to prograde up to 4 km across the area, with finger-like geometries and broad lenticular cross sections. These are particularly well exposed in the cliff section between Pissouri bay and Mavratoso bay. They are interpreted as a braided channel topset of the well-supplied fan delta that was feeding the bottomset and foreset facies of the Pissouri marlstone unit. This significant sediment influx was controlled principally by intense (pulsed) uplift of Troodos and its rapid erosion during the main pluvial periods of the Pleistocene. Deposition occurred entirely on the coastal plain above or near sea level and appears not to have been influenced significantly by high-frequency sea level fluctuation over the past 2 m.y. Interpluvial periods are thought to be represented by thick palaeosol development.

(6) The Pissouri sandstones pass upwards into patchily distributed sediments of more recent alluvial-fluvial origin, including alluvial fan sheets and present-day valley and slope unconsolidated drift deposits. These reflect continued uplift of Troodos and valley incision into the underlying sediments.

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