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A CALABRIAN PRODELTA SEQUENCE OF A FAN DELTA SYSTEM ON KARPATHOS ISLAND

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ABSTRACT

The sedimentpetrographical and biofacial features of a Mid Calabrian sedimentary sequence (nannoplankton zone MNN19d due to large individuals of *Gephyrocapsa*) near Lefkos at the western coast of Karpathos Island are analysed with regard to their sedimentary environment in the neotectonically active external hellenic arc. This environment is regarded to be the prodelta of a fan delta system. Five types of gravity flow deposits (grainflows and turbidity currents of variable density) can be distinguished consisting principally of coarse-grained detritus from Preneogene rocks of Karpathos. Commonly, these gravity flow sediments are embedded as channel-like structures in a plankton- and smectite-dominated hemipelagic background sediment. Therefore, the 60 m thick section at the steep coast of Lefkos represents a special near-costal but deeper marine sedimentary environment already known from other localities in Greece, e.g. the southern margin of the Corinth graben.

KEY WORDS: fan delta system; prodelta sequence; gravity flows; Calabrian

1. INTRODUCTION

The Neogene and Quaternary history of the external hellenic arc is characterized by a regionally

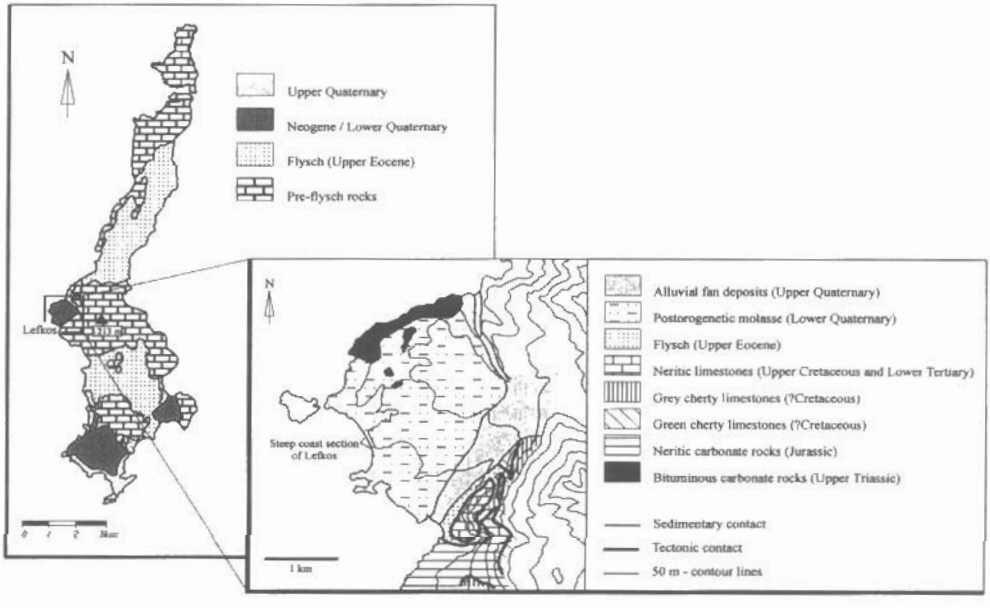

Figure 1: Geological sketch map of Karpathos Island and geological map of the surrounding area of the steep coast section of Lefkos.

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variable intensity of vertical tectonic movements with amplitudes up to several kilometres (cf. compilation of SCHRΦDER 1986). This tectonic activity results in a high variability of lateral and vertical development of facies which for example has been demonstrated for Crete by MEULENKAMP (1979). Glacial-eustatic sea level oscillations in Pliocene and Quaternary times lead to further complications (e.g. megacycles of the section of the Canal of Corinth: NEUSER et al. 1982 - Eastern Crete: PETERS et al. 1985). Consequently, only small scale analysis of stratigraphy and facies can produce an overall picture of the recent geological history of the hellenic arc. Based upon biostratigraphical, lithofacial and geomorphological data this study presents a genetic model for a well-exposed Pleistocene sequence at the western coast of Karpathos Island (Figure 1).

Particularly in the southern part of Karpathos Island there are widespread outcrops of postorogenetic molasse sediments which formed in tectonic basins (BARRIER & ANGELIER 1982) (cf. Figure 1). The alpidic rocks of Karpathos Island -Triassic to Lower Tertiary neritic carbonate rocks from the Tripolitza zone, cherty limestones from the Tripolitza-Pindos transition zone and the Pindos zone, ophiolitic rocks and Upper Eocene flysch sediments (DAVIDSON-MONETT 1974) - show structural features of a tectonic melange as been demonstrated by 15 geological mappings led by D. K. Richter from Ruhr-University of Bochum. Therefore, Karpathos Island has to be interpreted - analogous to Crete (e.g. FELDHOFF et al. 1993) - as an emerged part of an accretionary complex in the external region of the Hellenic Mountains.

2. FIELD OBSERVATIONS

The molasse sequence at the steep coast near Lefkos (Figures 1, 2) is formed by 60 metres of a gently SW-dipping principal series composed of marly and fine sandy sediments on the one hand and coarse-grained often channel-like intercalations with rich lithoclastic and poor bioclastic contents on the other hand. This principal series is unconformably overlain by 3 metres of cross-stratified conglomeratic sediments which finish up the steep coast section.

The principal series which is the main topic of this study can be divided into five sub-units (cf. Figure 2):

Unit I	/ A:	Sand-Marl-Unit
Unit II	/ B:	Gravel-Marl-Unit
Unit III	/ C:	Marly Unit
Unit	D:	Arenitic-ruditic Unit
Unit IV	/ E:	Arenitic Unit with bioturbation

All these units contain coarse-grained layers, channel-like intercalations particularly occur in Unit I / A, Unit II / B and Unit D. Channel fills reach a maximum thickness of 13,5 metres and show a lateral extension up to several tens of metres. Imbrication of flat boulder-size particles indicates a SW-direction of transport.

The relatively poor macrofauna of the principal series consists for the most part of pectinides (e.g. *Pecten jacobaeus*), bryozoes, scaphopodes and brachiopodes. Generally, the slight increase in macrofauna contents towards the top of the section just as the widespread occurrence of trace fossils in Unit D (ophiomorpha burrows and rarely teichichnus burrows) are supposed to reflect better conditions for benthic organisms in the upper part of the sequence.

3. STRATIGRAPHICAL POSITION

Since the early sixties the postorogenetic molasse sediments of Karpathos Island have been object of biostratigraphical investigations (e.g. *CHRISTODOULOU 1960, ANAPLIOTIS 1964, KERAUDREN 1970,* BARRIER et al. 1979, FRYDAS 1988).

Despite the occurrence of *Hyalinea balthica* CHRISTODOULOU (1960) supposed the principal series of Lefkos to be of Lower Pliocene age. KERAUDREN (1970) revised this assessment and found out an Lower Pleistocene age (Calabrian), especially due to a macrofauna with *Chlamys septemradiata* and *Cardita aculeata*. A nannoplankton analysis by BARRIER et al. (1979) yielded nannoplankton zone NN19

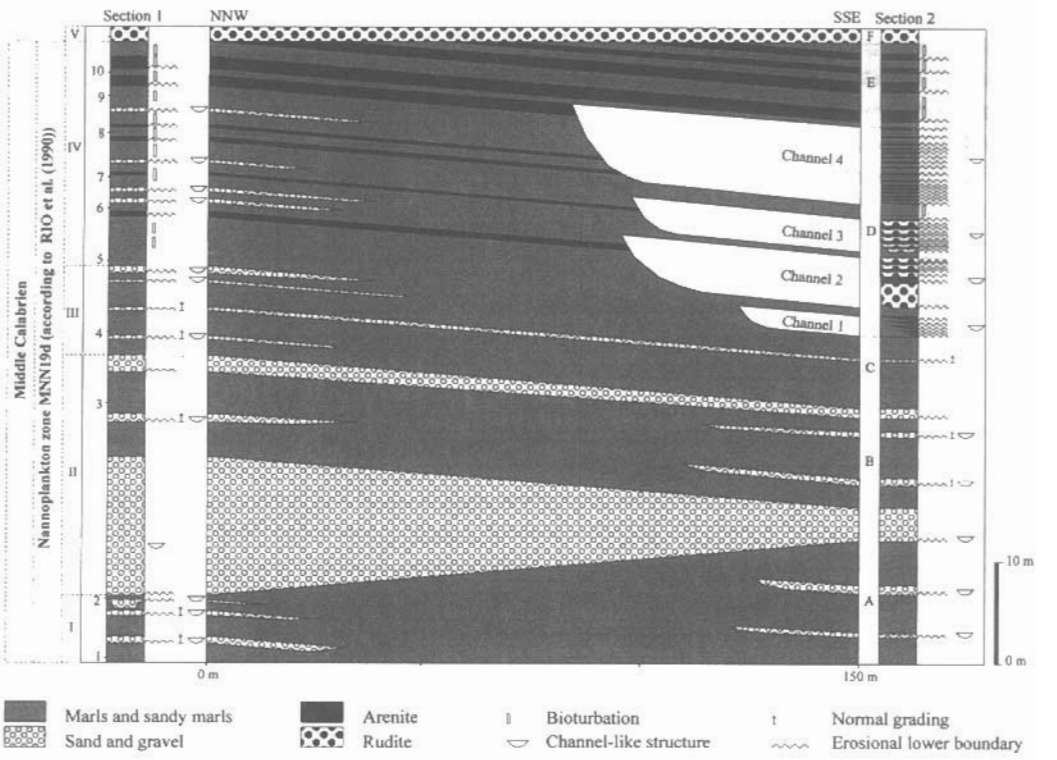

Figure 2: Schematic correlation of two single sections to a geological overall picture of the steep coast of Lefkos. I/A: Sand-Marl-Unit, II/B: Gravel - Marl - Unit, III/C: Marly Unit, D: Arenitic - ruditic Unit, IV/E: Arenitic Unit with bioturbation, V/F: Unconformably overlying conglomeratic horizon. 1-10: Samples with large individuals of *Gephyrocapsa*.

(Lower Pleistocene; MARTINI 1971) for the "marly-sandy-gravelly sequence" of Lefkos "with gravel-size detrital intercalations". An even higher precision of dating we reached by our own nannoplankton analysis of 10 samples. Referring to more recent biostratigraphical examinations in the mediterranean region by RIO et al. (1990) we correlate the principal series of Lefkos with nannoplankton subzone MNN19d (Middle Calabrian; MNN=Mediterranean Neogene Nannoplankton) due to large individuals of *Gephyrocapsa sp.* which reach or even exceed the stratigraphically significant diameter of 5,5µm. Consequently, the absolute age of the sediments comprises a period of time between 1,34 my (first occurrence of *Gephyrocapsa* > 5,5µm) and 1,1 to 1,13 my (last occurrence of *Gephyrocapsa* > 5,5µm).

The unconformably overlying and cross-stratified conglomeratic horizon at the top of the steep coast section (about 65 metres above present sea level) was considered to be of Tyrrhenian age by KERAUDREN (1970) without giving any index fossil like *Strombus bubonius*. We suppose this horizon to be older because XRD-analysis of red algae skeletons indicate a relatively small portion of $MgCO_3$ in the calcite lattice of about 1,7 to 3,1% (recent values: 13 to 16%). Referring to RICHTER (1984) this points to a Low to Mid Pleistocene age for meteoric-vadose influenced sediments of mediterranean regions with low precipitation. Consequently, we interpret the conglomeratic horizon as a relict of a post-Calabrian and pre-Tyrrhenian interglacial marine terrace.

4. SPECIAL SEDIMENTPETROGRAPHICAL FEATURES

Generally, the principal series of Lefkos is formed by two main types of sediments (cf. Figure 2):

1. Marls with a variable [illegible]

2. Uncemented or weakly cemented coarse-grained intercalations with an erosional lower boundary.

Marls with a variable portion of sand form the base sediment of the Calabrian sequence of Lefkos. According to macroscopic, microscopic and clay mineralogical aspects, the composition of sediment is characterized by hemipelagic background sedimentation, autochthonous benthic organisms and allochthonous components.

The hemipelagic influence is indicated by abundant nannoplankton (*Gephyrocapsa oceanica*, *Gephyrocapsa sp.*, *Calcidiscus leptoporus*, *Helicosphaera carteri*, *Neosphaera coccolithomorpha*, *Pontosphaera sp.*, *Syracosphaera pulchra*) and pelagic foraminifers (*Globigerina sp.*, *Globigerinoides sp.*, *Orbulina universa*, *Orbulina bilobata*). But, regarding the relative abundance of pelagic foraminifera in total foraminifera assemblages there can be discovered considerable variations between 14 and 88% in the course of the section. Quantitative XRD-analysis of fine-grained hemipelagic detritus (<2µm) yielded a dominance of smectite (49 to 65% of the clay mineral association). Besides that, there occur illite (24 to 41%), chlorite (5 to 10%) and kaolinite (5 to 9%).

The autochthonous benthic microfaunal assemblage mainly consists of foraminifers (e.g. textulariids with variable frequencies in the range of 0,2 to 20%, rotaliids). In addition to that the episodic occurrence of trace fossils (ophiomorpha) in the upper part of the section reflects autochthonous benthic life.

Allochthonous components are lithoclastic sandy detritus and redeposited biogenic grains from shallow-marine near-coastal environments (miliod foraminifers, *Elphidium sp.*). The relative abundance of miliod foraminifers within the total foraminifera assemblage ranges from sample to sample between 0 and 3%.

Generally, the composition of the sandy marls reflects a quite complex interaction of different factors:

1. More or less constant background sedimentation
2. Lithoclastic and bioclastic input from near-coastal shallow marine environments (distal parts of gravity flows with low density)
3. Variable development of benthic life (e.g. episodic occurrence of trace fossils) which is obviously controlled by sedimentation rate

The water depth is suggested to be about 50 to 100 metres, due to the lack of ripple marks and hummocky cross-stratification (sedimentation beneath storm wave base) on the one hand and the widespread plankton association of *Globigerina sp.*, *Globigerinoides sp.* and *Orbulina universa* on the other hand which is according to BI (1977) typical for this bathymetric range.

The coarse-grained intercalations with erosional lower boundary and frequently channel-like geometry have to be interpreted as gravity flow sediments. In the SSE part of the steep coast section Unit D (Arenitic-ruditic Unit) comprises four striking channels for which structural criteria point to a NE-SW-extension. The internal sedimentary construction comprises laterally lensing-out arenitic-ruditic layers with erosional lower boundary and marly interbeds.

Generally, 85 to 100% of the components of coarse-grained intercalations is formed by lithoclasts (70% dolomite, 25% limestone, 5% chert, accessory dolomitic limestone and sandstone) which exclusively can be assigned to Preneogene rocks of Karpathos. The low or moderate roundness of clasts, the considerable maximum grain size up to some decimetres and the poor compositional maturity indicate a steep and nearby source area.

The portion of biogenic particles within coarse-grained intercalations ranges between 0 and 15%. Commonly, these biogenic particles are redeposited fragments of shallow marine organisms (benthic foraminifers, e.g. *Elphidium sp.*, *Quinqueloculina sp. Amphistegina sp.*; red algae; barnacles; pelecypodes, e.g. *Ostrea sp.*).

Due to structural features the coarse-grained intercalations can be subdivided into five types of gravity flow sediments (cf. Table 1) deposited from grainflows and turbidity currents with variable density (according to CHOUGH et al. 1990, SURLYK 1984, FÜCHTBAUER 1988). On the whole, the steep coast section of Lefkos contains about 120 gravity flow deposits from which as much as 40% are concentrated in Channel 1, 2, 3 and 4 (Unit D in the SSE part of the section) forming dm-thick type III-

and type IV- intercalations. Also the "Arenitic-ruditic Unit with bioturbation" (Unit IV / E) is clearly dominated by type III-deposits. In the lower units of the section (Units I, II, III and A, B, C) there is a much smaller number of coarse-grained intercalations which can be assigned to type I and II as well as type III. Type I- and type II- deposits generally form intercalations with the highest thicknesses and the biggest maximum grain diameters.

Table 1: Sedimentological features and transport mechanisms of the coarse - grained gravity flow sediments

	Type I	Type II	Type III	Type IV	Type V
Type of sediment	boulder / gravel	gravel / sand (boulder)	gravel / sand	sand (gravel)	sand
Stratification	random	normal grading	random	normal grading	mm-lamination
Sorting	poor	moderate	moderate, rarely good	moderate, rarely good	good
Structural features	often channel-like; imbrication	often channel-like	channel-like or sheet-like	channel-like	channel-like
Maximum grain size	some decimetres	some centimetres	few centimetres	few centimetres	< 1 mm
Thickness	up to 13,5 m	some decimetres	some decimetres	some decimetres	some centimetres
Mechanism of transport	density modified-grainflow	high-density turbidity current	high-density turbidity current	low to high density turbidity current	low-density turbidity current

5. GENETIC MODEL

The genesis of hemipelagic sandy marls on one hand (background sedimentation in about 50 to 100 metres water depth) and channellized or sheet-like gravity flow deposits on the other hand requires a special sedimentary environment, especially in view of a nearby and steep region of denudation. These sedimentological and geomorphologic features seem to indicate sedimentation in a fan delta environment (e.g. NEMEC & STEEL 1988, COLELLA 1988, CHOUGH et al. 1991). In Greece, fan delta deposits are particularly known in the area of the southern margin of the Corinth graben (e.g. ZELELIDIS & KONTOPOULOS 1996, POULIMENOS 1993, ORI 1989, FERENTINOS et al. 1988, BROOKS & FERENTINOS 1984)

The subaerial part of a fan delta (Figure 3) is formed by an alluvial fan which progrades from an adjacent highland into a standing body of water, i.e. in this case a marine basin. The submarine part of a fan delta is characterized by a narrow coastal and shelf zone, a rapid increase of slope gradient towards the basin and a following decrease of gradient towards the basin plain.

The proximal part of a fan delta is formed by a coarse-grained Gilbert-type delta containing brackish and shallow marine faunistic elements. Caused by tectonic movements or gravitational instability of steeply inclined Gilbert-type foresets material of the shelf, the shelf edge and the slope is episodically transported into distal hemipelagic delta environments by gravity flows.

All sedimentological properties indicate a prodelta position within a fan delta environment for the molasse sequence of Lefkos. Due to structural features of some coarse-grained intercalations (imbrication, direction of channels) the more proximal fan delta subenvironments (Gilbert-type delta, alluvial fan) and the hinterland presumably are located NE of the analysed steep coast section. Consequently, the high portion of smectite in the clay fraction of hemipelagic marls can be put down to widespread outcrops of *flysch sediments in the reconstructed source area (cf. Figure 1).*

Actually, the Mid-Calabrian sequence of Lefkos represents only a part of a regressive postorogenetic fan delta sytem on Karpathos Island. Eustatic sea level oscillations as well as tectonic elevation of Karpathos Island (which is, referring to BARRIER & ANGELIER 1982, considered to be about 1,8cm/100y for the last 13my and 2,2 to 2.8cm/100y for the last 260ky) led to dramatic changes of the coastal line of Lefkos, so that [illegible] an erosional remnant of

regional geologic history during Quaternary times. Finally, it is the detailed analysis of a great number of such small jigsaw pieces that will result in an overall picture of Neogene and Quaternary development of the external Hellenic Arc.

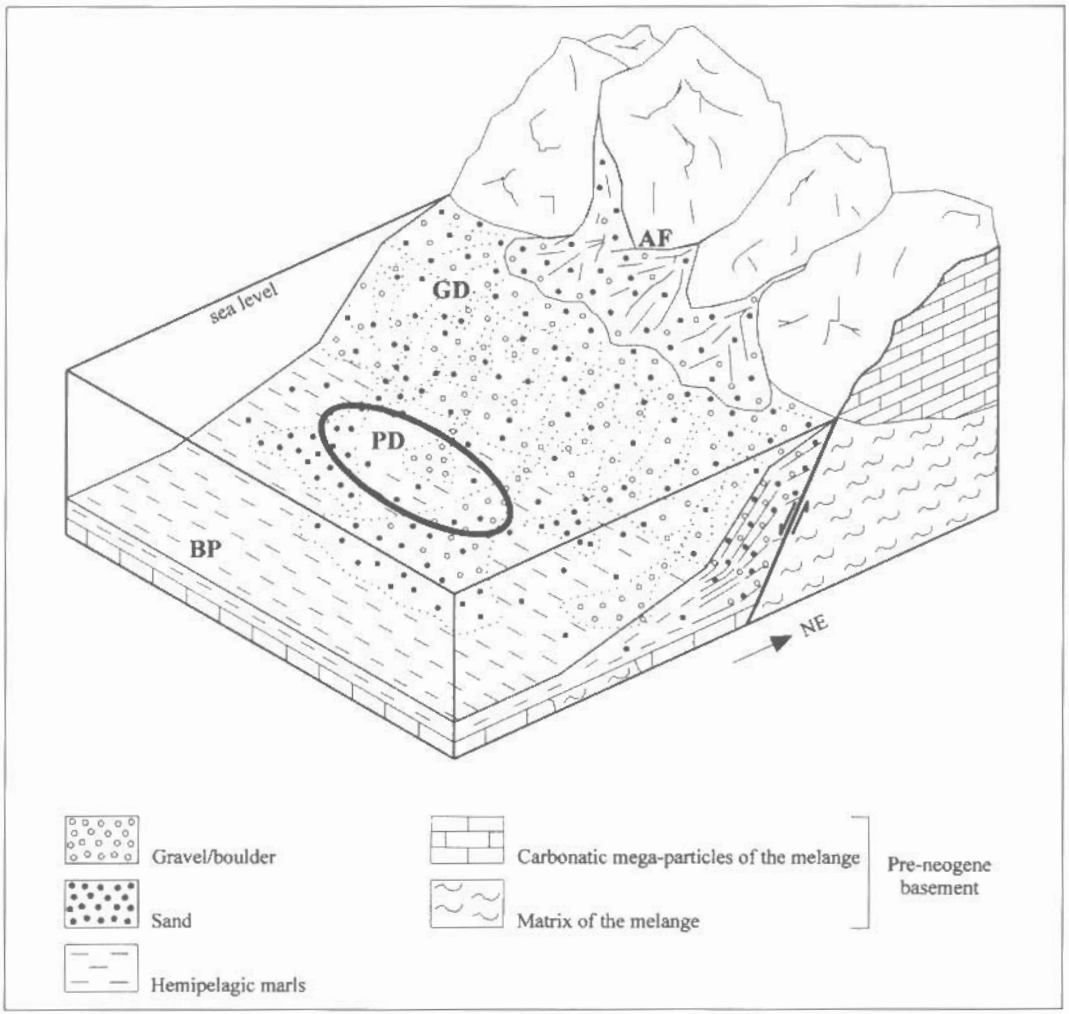

Figure 3: 3 D picture of a fan delta system and its subenvironments. The outlined area marks the position of the Mid Calabrian sequence of Lefkos. (AF=alluvial fan; GD= Gilbert-delta; PD= prodelta; BP=basin plain)

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