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# SEQUENCE STRATIGRAPHY IN THE N. MARGIN OF THE GULF OF CORINTH: IMPLICATIONS TO UPPER QUATERNARY BASIN EVOLUTION

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## ABSTRACT

Continuous seismic profiling data (Air-Gun) have shown that four (at least) major oblique prograding sequences can be traced below the central part of the north margin (outer shelf -upper slope) of the Gulf of Corinth. These sequences have been developed successively during low sea-level stands (isotopic stages 2-3, 6 and 8) suggesting continuous and gradual subsidence of the marginal slopes down to -300 m. present depth during the upper Quaternary (late 250 Ka). The subsidence rates during this period was calculated to 0.9 - 1.3 m $Ka^{-1}$ from the relative altitude of successive topset to foreset transitions. The differential displacement between the north and the south margin of the Corinth graben is estimated to about 2.8 m $Ka^{-1}$. The prodelta sedimentation rates on the slopes are 0.3-0.4 m $Ka^{-1}$. The present data implies a few km northward shift of the Corinth basin during the late 250 Ka.

## 1. INTRODUCTION

The area is located in the northern margin of the recently formed Corinth graben (Plio-Pleistocene) and it is very active in terms of seismicity and neotectonics with high rates of vertical displacement (Brooks & Ferentinos 1984, Tselentis & Makropoulos 1986, Mouyaris 1987, Higgs, 1988, Papazachos & Papazachos 1989, Poulimenos 1991, Doutsos & Poulimenos 1992).

The tectonic graben of the Gulf of Corinth is one of the most active postalpine - neotectonic extensional features of Greece. With a general WNW-ESE trend it cuts across the regional NNW-SSE trending of the alpine orogenic structure of the Mainland of Greece, dividing Peloponnese to the South from Central Greece to the North.

The resulted Corinth Gulf has been filled up by gravitational deposits (turbidity flows, debris flows, mudflows etc.) (Brooks & Ferentinos 1984; Dart et al., 1994), while fun delta prograding deposits during Pleistocene sea-level changes, coupled by extensive slumping are the predominant sedimentary processes in the steep flanks of the gulf (Ferentinos et al 1988).

Since the oldest known sediments of the Proto-Gulf of Corinth, occurring in Northern Peloponnese, are of Pliocene age, the tectonic activity of the basin must have started during Middle - Upper Miocene. Angelier (1979) estimated a 100% total crystal extension of the area since Middle Miocene, the greatest part of which takes place in a N-S direction according to recent focal mechanism studies (Papazachos, 1976, McKenzie, 1978). At the same time very large vertical movements along the marginal fault zones of the tectonic basin created a vertical displacement of over 3000 m between the deepest parts of the basin, located in the eastern part of the Gulf (900 m water depth) and the peaks of the surrounding mountains of Northern Peloponnese mainly, where Pliocene sediments occur at an altitude of about 2000 m., and of Central Greece.

The sedimentological processes, that are mostly related to seismically induced mass gravity

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movements, has been extensively examined by Perissoratis et al., 1984, Ferentinos et al., 1988, Piper et al., 1990, Papatheodorou, 1990 and Lykousis, 1990.

Although there have been numerous published works related to tectonics, seismicity and sedimentary processes only Perissoratis et al., 1993 has made an attempt to compare the Late Pleistocene chronostratigraphic record with sea level changes studying basinwide acoustic reflectors and associated erosional surfaces.

The purpose of this work is to provide a further insight in the Upper Quaternary evolution of the Gulf of Corinth through the study of the seismic stratigraphic sequences from the northern margin of the basin. This part of the Gulf and especially the central region (Eratini to Antikira), favours this kind of study since the sediment sequences are relatively undisturbed due to their deposition north of the active northern marginal fault of the Gulf and partly within marginal basins (Eratini, Itea, Antikira) with right sediment influx.

## 2. MATERIALS AND METHODS

The field work involved closely spaced overlapping grids (Fig. 1) of (various directions) parallel lithoacoustic profiles of the seabed (every 300-500m). A combination of different sound sources (3.5KHz acoustic profiler, Air-Gun 1, 5, 10 and 40in$^3$) was used in order to achieve very high vertical resolution and higher penetration of the subbottom strata. A total of 1000km sub-bottom profiles was performed covering the area of Central Gulf of Corinth between Eratini bay to the West and Antikyra bay to the East.

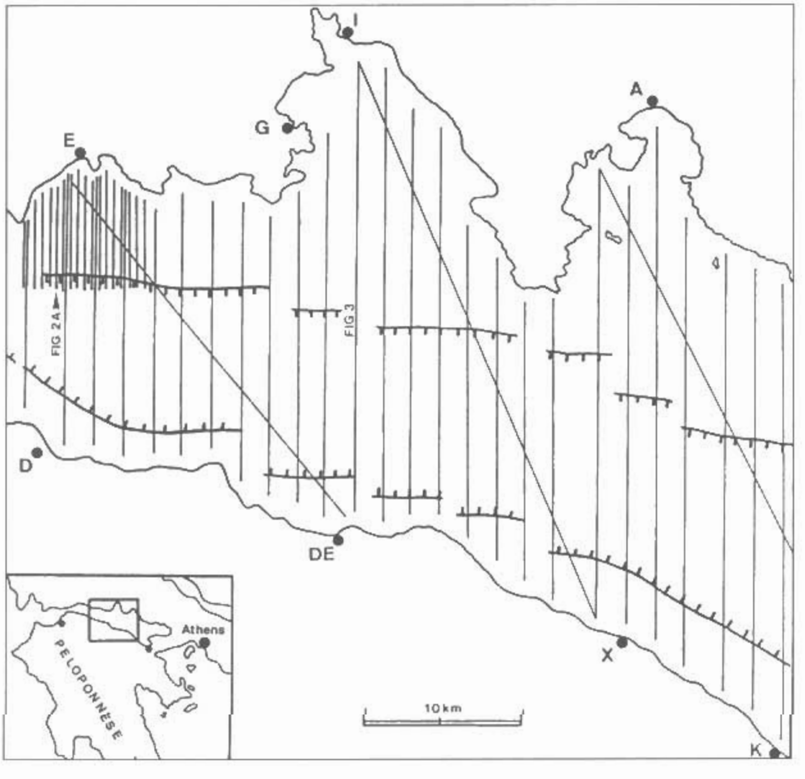


**Fig. 1:** Location map of the area in study. N-S solid lines indicate Air Gun seismic profiles obtained during the present survey. The main marginal faults of the Gulf (after Papanikolaou et al 1997) are shown as well on the map. A: Antikira, D: Diakopto, DE: Derveni, E: Eratini, G: Galaxidi, I: Itea, K: Kiato, X: Xylokastro.

The field work was carried out by the R/V AIGAIO during June 1996. Position fixing and navigation was obtained with a satellite G.P.S. (TRIMBLE 4000 SURVAYOR) with a mean accuracy of ±80m. The investigation was financially supported by the Earthquake Planning and Protection Organisation of Greece.

The seismic profiles were analysed and studied according to the method of Mitchum et al., 1977 that correlates sub-bottom seismic reflectors and sequences with sediment facies and stratigraphic units.

## 3. RESULTS

### *Sequence stratigraphy*

The Air Gun seismic profiles across the north margin of Corinth Gulf show series of characteristic oblique progradational sequences that are located below the sea bed of the shelf and the upper slope (Fig. 2 & 3). These at least four sequences (Fig. 2A & B) display very steeply dipping foresets that are erosionally truncated in their upper boundary due to erosion from wave activity (shallow water environment) during their progradation.

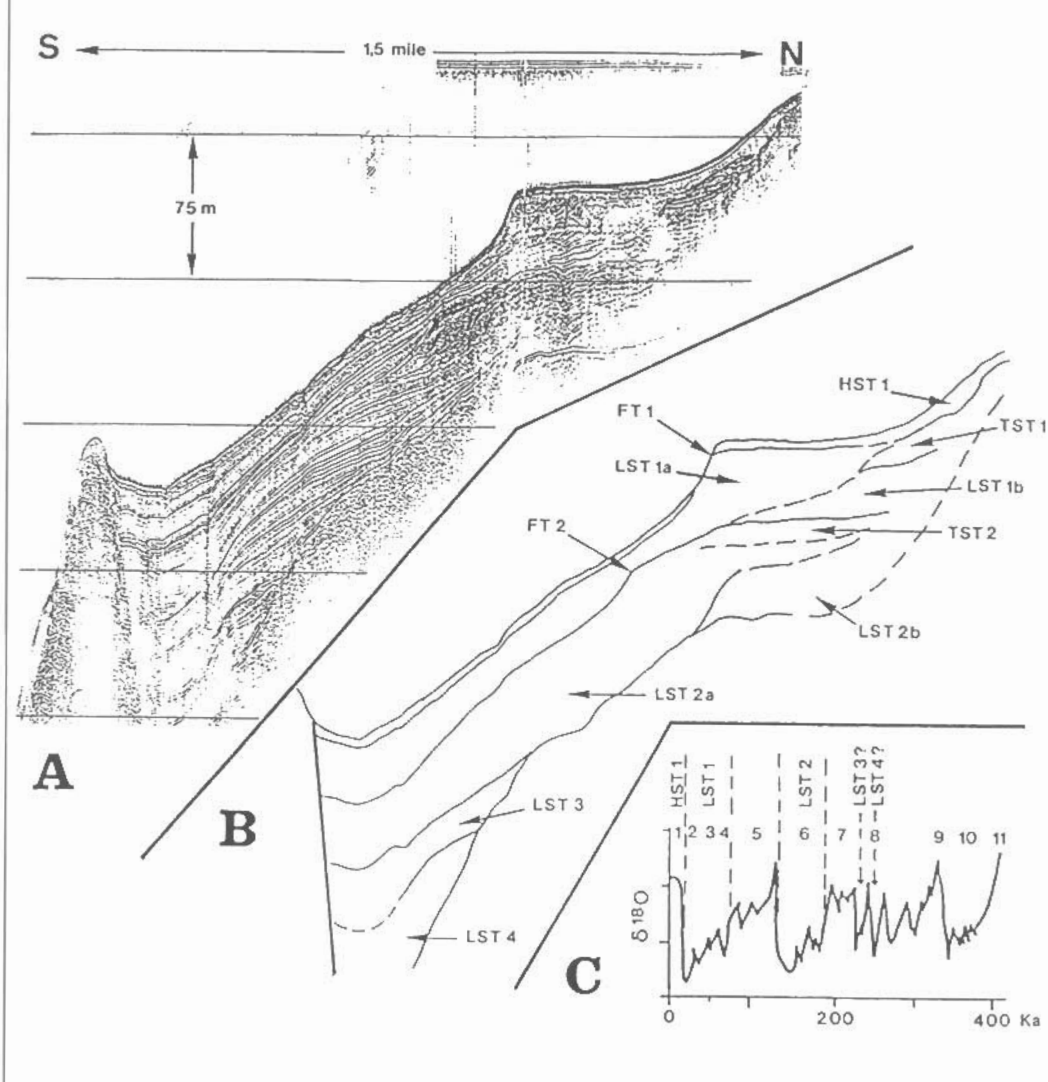


**Fig. 2A:** Air Gun 1 in3 seismic profile illustrating prodelta progradational sequences below the sea bed of the shelf and the upper slope offshore Eratini (for location see Fig. 1).

**Fig. 2B:** Line drawing of Fig. 2A. See text for explanations.

**Fig. 2C:** Upper Quaternary $\delta^{18}O$ isotopic curves after Chapell & Shackleton (1986) and time relation of the deposition of the prodelta sequences shown in Fig. 2B and described in text.

The oblique prograding sequences represent prodelta progradation during low-sea (water) level stand (Lowstand system Tracts - LST) since the high level sequences (Highstand System Tracts - HST) have been previously winnowed by the erosional processes during the rapid subsequent regression.

The dipping foresets are transformed downslope to bedding strata with strong parallel and continuous reflectors alternating with reflection free stripes. This configuration of the reflectors implies mostly turbiditic sedimentation although in this case represent distal prodeltaic sediments on steep slope that are usually interbedded finer (muddier) of coarser (silty-sandy) horizons. These sediment horizons appeared in sediment cores from similar in character steep pro-delta deposits off shore Mornos river (Lykousis, 1990). The oblique progradation sequences are topcapped by a few strong semi parallel or hyperbolic reflectors indicating coarse grained sediments (gravely) deposited during the rapid subsequent transgression (Transgressive Systems Tract - TST)

The two (or three) limited in extension and volume prograding sequences that appeared buried 60-80 m below the seabed at middle-lower slope should represent very short time older LST's.

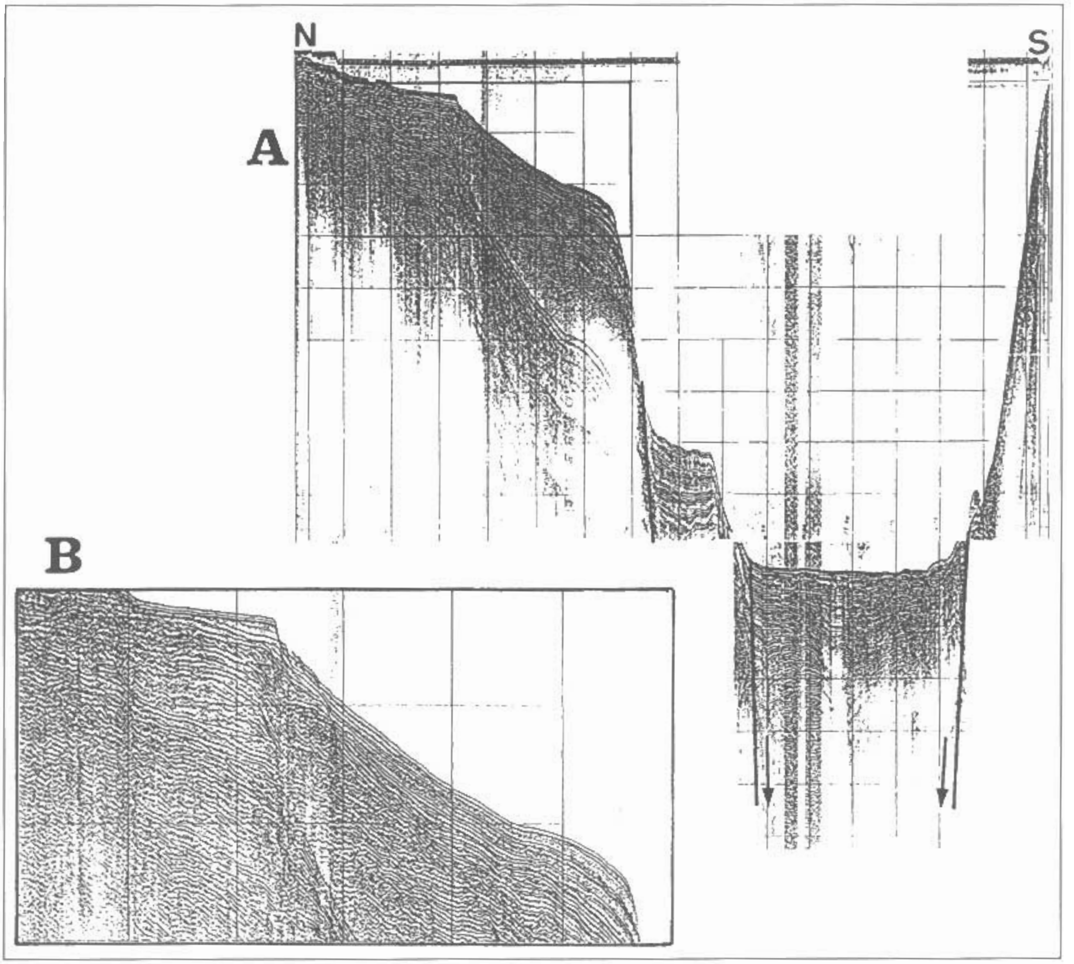


**Fig. 3A:** Air Gun 10 in3 seismic profile across the Gulf of Corinth (see Fig. 1 for location) showing the southern steep slope of the Gulf, the deep sedimentary basin bounded by the southern and the northern marginal faults and the prodelta progradational sequences below the sea bed of the northern shelf and upper slope. Scale: each cell is 75 m. high and 0.5 mile (926 m.) wide.

**Fig. 3B:** Detail of Fig. 3A ... upper slope in the Gulf of Itea.

The two major oblique progradation systems (LST1, LST2) display a "twin" configuration in the sense that incorporates an older prograding sequence developed under a slightly lower sea (water) level. This configuration reflects prodelta progradation within the same major low sea level stand (major glacial stage) with minor sea level fluctuations. All the oblique prograding sequences display an onlap reflector termination to the Alpine basement rock (B.R.), while the shallower (and younger) LST1 and the TST1 are covered with a transparent (muddy) horizon that represent the Holocene distal prodelta sediments. This "wedge"-like transparent horizon is transformed towards to shallow water foreset and topset prodelta sediments (depths 5-10 m). These prodelta sequences display the typical complex sigmoid oblique prograding configuration and represent the latest Highstand system Tracts (HST1).

The already described sequences, ranging in thickness, can be traced more or less in the northern margin of the basin depending upon the stability of the sediments (extension of slumping) and the relative sediment supply due to the shift and distance from the palaedepocenters. Since the observed oblique prograding sequences are not interrupted by major uncomformities, it is inferred that the sedimentation during successive low sea (water) level stands should be regarded as continuous without any geological hiatus, excluding the erosion of the prograding sequences during high level stands that are not appeared in the seismic profiles. Consequently the relative chronostratigraphic age of the LST sequences can be deducted from the Quaternary glacio-eustatic curves assuming comparable low sea (water) level stands during their formation, since the Gulf should be occasionally transformed in lake due to Rion-Antirion sill (-75m depth).

The HST1 represents Holocene prodelta sediments that have been deposited under marine conditions during 6.5-0 Ka B.P. (Isotopic stage 1, Fig. 2C). The Holocene transgression sediments are represented by the TST1 and was deposited during 6-12 KaBP, since about 12 KaBP the Late glacial "lake" of Corint Gulf was flooded by the Holocene transgression (see Holocene sea level curves, Fairbanks, 1989). The shallower $LST1_a$ is expected to have been deposited during the extended Late glacial period 12-60KaBP (Isotopic stages 2-3), while the $LST1_b$ correspond to isotopic stage 4 (60-75 KaBP) that is a short fluctuation slightly lower sea level during the beginning of the Late glacial. The two following prominent sequences ($LST2_a$ and $LST2_b$) should be correlate to fluctuations within isotopic stage 6 (6.2, 6.4 or 6.6, ca. 130-190 KaBP) during glacial conditions, (see Up. Quaternary curves Chapell and Shackleton, 1986; Pisias et al., 1984). The last two small and deeply buried LST3-LST4 is estimated to be deposited during short time fluctuations during the termination of isotopic stage 8 (8.1-8.4) or during isotopic stage 7.4 (c.220-260 KaBP).

***Basin evolution, subsidence and sedimentation rates***

The topset - foreset transition of the shallowest LST1 (FT1, Fig. 2), located on the shelf edge in a water depth of 80 m, indicates the lowest stage of delta evolution during the late glacial maximum in isotopic stage 2.2. (Pisias et al., 1984; Chapell and Shakleton, 1986) and probably till about 12 KaBP when the sea level flooded the glacial lake of Corinth Gulf (isotopic stage 2.1-2.0). Besides, the location of LST1 in -80 m. depth documentates the assumption that the Gulf was a lake during late glacial (Perissoratis et al., 1993) and identifies the lake water to about 75-80m depth relatively to the present sea level.

The topset - foreset transition of the relatively deeper and older LST2 (FT2) indicates the lowest stage of prodelta progradation during the termination of the glacial period in isotopic stage 6.0-6.1 (ca 128 KaBP). By comparing the vertical displacement of the two successive prodelta sequences, we can estimate the relative subsidence rates assuming similar water level lowstands with a degree of uncertainty due to Rion-Antirion sill location. Accordingly to the relative subsidence of the northern margin of Corinth Gulf from isotopic stage 6.1 (128 KaBP) to isotopic stage 2.0 (12 KaBP) is 0.6 $mKa^{-1}$ (70m subsidence / 128$Ka^{-1}$) and about 1.0 $mKa^{-1}$ from isotopic stage 8.0 (244 KaBP) to isotopic stage 2.0 (12 Ka BP) (225m subsidence / 232 KaBP). These values are appreciably higher than those estimated in the Central and Eastern Aegean margins ( Table I) and slightly lower than the calculated values in the N. Aegean margins. Nenertheless they are very comparable with the subsidence rates (0.9 - 1m $Ka^{-1}$) that were estimated in the Patraikos Gulf (Chronis et al., 1991).

| Table I. Comparative subsidence rates (m $Ka^{-1}$) during Late Quaternary | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Isotopic events** | **NW Aegean (Lykousis, 1991)** | **N. Aegean (Piper and Perissoratis, 1991)** | **Kusadasi Bay (Aksu et al., 1987)** | **Izmir Bay (Aksu et al., 1987)** | **C. Aegean (Lukousis et al., 1995)** | **NE Patraikos Gulf (Chronis et al., 1991)** | **This study** |
| 6.1 - 2.0 | 0.9 | 0.3 - | 0.48 | 0.45 | 0.33 | 0.9-1.0 | 0.6 |
| 8.0 - 2.0 | 1.3 | 1.5 | | | 0.32 | | 1.0 |

The rate of differential vertical movement between the subsiding north margin and the uplifting south margin of the Gulf of Corinth could be calculated based on the location of uplifted marine terraces deposited during isotopic stage 6.0-6.1 (128 KaBP) in the northern coasts of Peloponnese (south margin) and the corresponding submerged terraces in the northern margin of the Gulf (Fig. 4). The altitude of the uplifted terraces on shore in Xylokastro region is about 200m (Keraudren and Sorel, 1987) while the depth of the submerged sequence (FT2) is estimated to about 160 m depth (this study). Consequently, the differential vertical displacement is estimated to 2.8 m $Ka^{-1}$, which is comparable with that of Schroeder and Kelletat, 1976 (2m $Ka^{-1}$) but a value lower than the displacement calculated by Brooks and Ferentinos, 1984 (5m $Ka^{-1}$) between the south margin and the basin floor.

Almost the same differential displacement rate is calculated when compared the older uplifted terraces and submerged sequences (isotopic stages 7.5-8, about 240 KaBP) that are located at about 400m and -280 m respectively. During this period the Corinth graben should be located slightly southward the present position particularly towards their SE part (Corinthia region) where it was expected to be wider than today.

The mean sedimentation rates in the marginal slopes of at least the central part of the northern Corinthiakos Gulf are estimated to 0.3-0.4m Ka based on the thickness of the prodelta sediment deposits (oblique and distal sequences) and the deposition period. This value is reasonably lower than the corresponding sedimentation values within the basin 1m Ka (Brooks and Ferentinos 1984) and 0.8-2.5 m Ka (Varnavas et al., 1986).

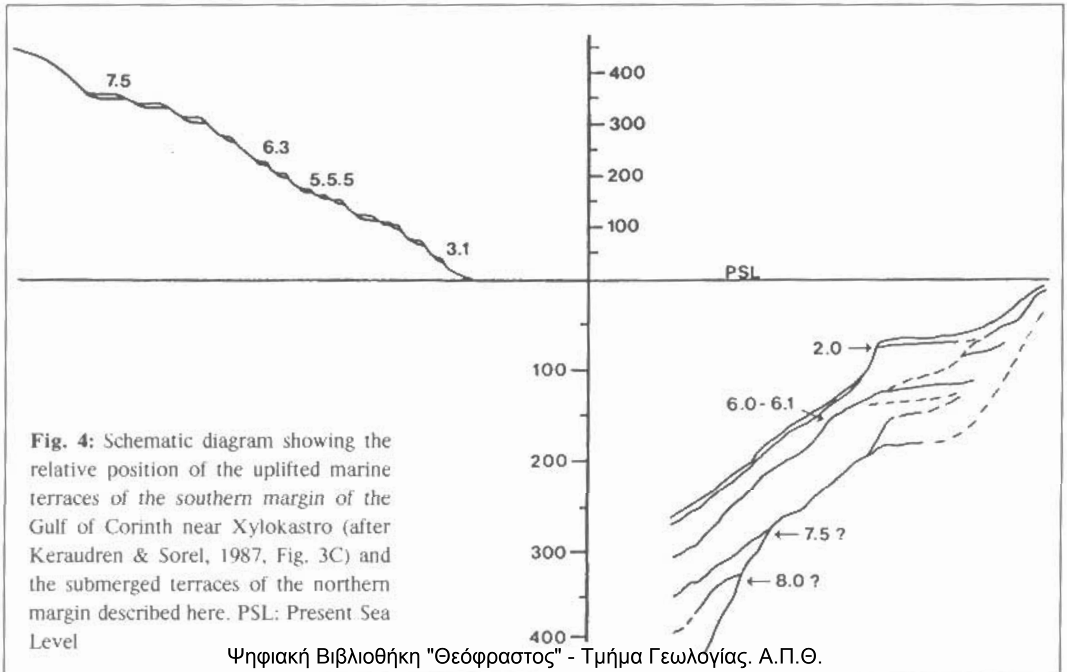


**Fig. 4:** Schematic diagram showing the relative position of the uplifted marine terraces of the southern margin of the Gulf of Corinth near Xylokastro (after Keraudren & Sorel, 1987, Fig. 3C) and the submerged terraces of the northern margin described here. PSL: Present Sea Level

## 4. CONCLUSIONS

During the Upper Quaternary four major oblique prograding (prodelta) sequences were constructed on the central part of the north margin of Corinth graben. These sequences reflects delta progradation at major sea-level low stands during oxygen isotopic stages, 2-3, 6 and 8. The older detected sediment sequences (isotopic stages 7.5-8.2) implies continuous prodelta sedimentation of the northern margin during the last 250 Ka down slope to about -300m (present depth) and since they lay uncomformably on the Alpine basement, the marginal slopes down to this depth (-300 m) have been submerged during the late 250 Ka.

During a long period (isotopic stages 2-3) the Gulf of Corinth was a "lake" with a water level 75 ± 5 m below present sea level. This is deduced by the extensive late glacial (LST1) prodelta sequences that have been constructed the present "outer shelf - shelf break" of the north Corinthiakos Gulf. Successive topset to foreset transitions implies continuous subsidence which has been estimated to 0.9-1.3 m $Ka^{-1}$. The mean sedimentation rates on the marginal slopes was calculated to 0.3-0.4 m $Ka^{-1}$ from the thickness of the prodelta sediment sequences. Estimations based on the vertical difference between submerged and uplifted prodelta terraces deposited during the same period (isotopic stage 6 to 8) suggest differential displacement between the north and south margins of the Gulf up to 2.8 m $Ka^{-1}$. According to these assumptions the actual Corinth basin should have been gradually shifted northwards a few kilometres during the last 250 Ka.

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