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XERIAS RIVER EVOLUTION IN RELATION TO THE GEOLOGICAL BACKGROUND OF THE CORINTH BASIN AND ITS FLOODING IN 12/1/1997

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ABSTRACT

Flooding of the Xerias river due to narrow and shallow gorges near the town of Corinth owed mostly to the model of evolution of the river and less to human activity.

Xerias river evolution according the model of Seger and Alexander (1993) for rivers evolution of the Corinth graben, showed an antecedent drainage during Pleistocene, which changed to a reverse drainage from 80.000 yr. until the historical time, and now changed to a capture drainage. These river type changes owed to the geological background of the Corinth basin including tectonic pattern and stratigraphic composition of the drainage network.

Xerias river will increase in the next years the width and depth of its gorges in the area of the "wind gap" situated near the town of Corinth and it will produce more problems to the town.

KEY WORDS: Corinth; basin; gorges; river; drainage; antecedent; reverse; capture.

1. INTRODUCTION

The Corinth graben, 100km long and 40km wide, is a subsided area and separates continental Greece from Peloponnesus (Fig. 1A).

According to Poulimenos et al.(1989), Doutsos and Piper (1990), Poulimenos (1993), WNW trending listric faults are the master faults which influenced the basin evolution. The dominant tectonic style is characterized by the formation of asymmetric grabens which are bounded by listric faults. Due to the master faults that dips northwards, several tilted blocks dipping southwards were formed where a wedge-shaped terrigenous clastic sequence was accumulated during this tilting. Many times each master fault accompanied by 1-3 minor faults that dip southwards called "backward faults" showing smaller displacement and which tend to reduce the structural relief. Numerous WNW-trending master faults terminate abruptly at NNE-trending cross-faults (transfer faults).

The synchronous activity of master, minor and cross-faults influenced the basin configuration and the depositional environments. Small sub-basins were formed at the southern margins of the Corinth graben due to the minor backword faults (e.g. Egio and Evrostina sub-basins according to Poulimenos et al., 1993; Zelilidis & Kontopoulos, 1996) and lateral confinent in the depositional environment evolution (e.g. Egio sub-basins according to Poulimenos et al., 1989; Poulimenos, 1993).

Recent tectonic movements are indicated by vertical displacements of several marine terraces (Keraudren & Sorel, 1987) as well as by the high seismicity of the area (Papazachos, 1975).

According to Doutsos and Piper (1990) tectonic activity seems to be stronger westwards and weaker eastwards. Quaternary sediments exposed in the uplifted southern part of the Corinth graben consist, in a northward direction, of alluvial fan and lacustrine conglomerates near the graben margins, fan-delta (Gilbert- or Trapezoidal-type) conglomerates and marls,in the middle part of the graben; and lacustrine

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marls overlain by thin marine or fluvial terraces near the present coastline

Four drainage types were recognized in twenty four drainage basins, according Seger and Alexander (1993), in the Corinth graben influenced on the different movement between fault blocks coupled with regional uplift: (1) antecedent drainage, when a river has maintained its original direction of flow across later tectonic topography, (2) reverse drainage, when the flow direction along part of a river is reversed, caused by tectonic deformation of the river bed. Reverse drainage consists of two opposing drainage components: a misfit and a reverse element; the area between these two elements, resulting from tectonic deformation, termed "wind gap" and is a dry valley, (3) capture drainage, when reverse drainage elements return to their original flow direction, and (4) juvenile drainage basin, which consists of small incising and headward-eroding streams.

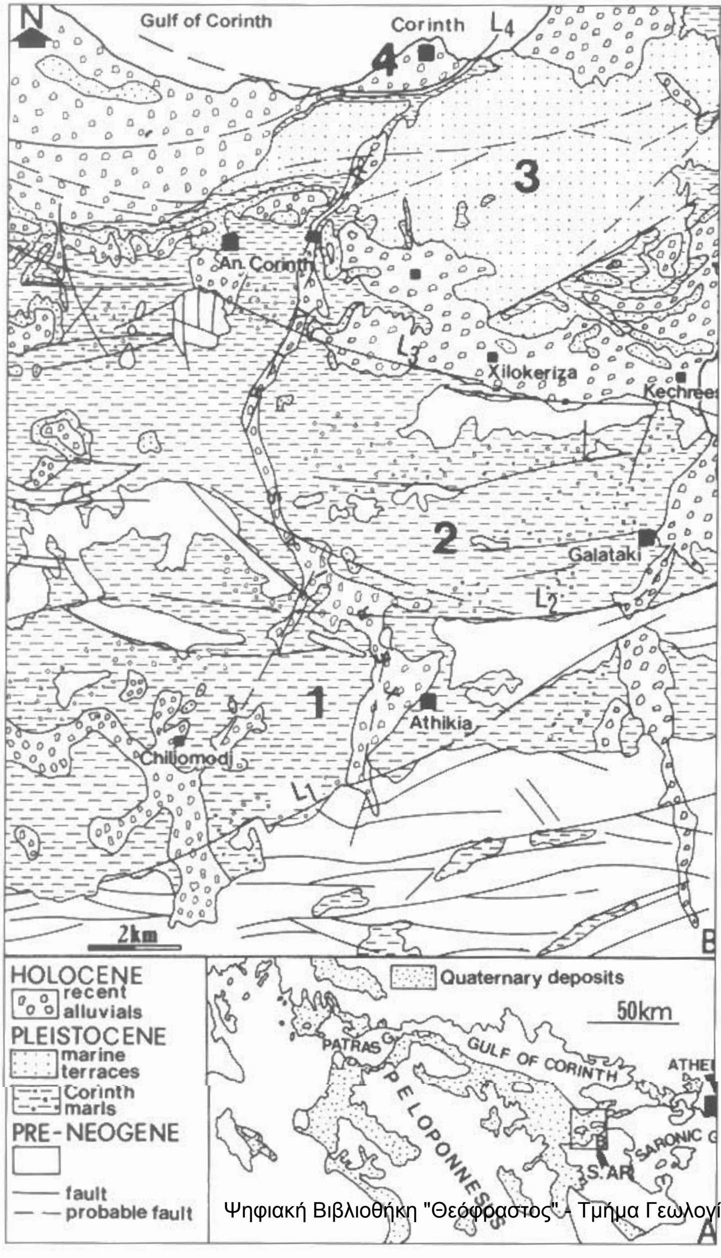

Fig. 1: (A) General map of the Gulf of Corinth - Patras rift, showing the ditribution of the Quaternary deposits. (B) Geological map of the Corinth basin showing the Quaternary sediment facies distribution and the principal extensional faults, modificated from Bornovas et al. (1971). Numbers 1 to 4 correspond to Athikia, Galataki, Ancient Corinth and New Corinth sub-basins respectively.

The Corinth basin situated at the eastern end of the Corinth graben undergoing the same tectonic and depositional processes as the whole Corinth graben (Fig. 1B). Drainage of this basin controlled from the Xerias river drainage network.

This paper focus on the Xerias river drainage evolution, the depositional environments that this river cross-cut through the time, the drainage type and changes through the time, and the problems that produced after its flooding in 12/1/1997.

2. GEOLOGICAL SETTING

Keraudren and Sorel (1987) found that the sedimentation in the Corinth basin, based on nannoplankton and oxygen-isotop, started in the middle Pleistocene (450.000 yr.) and not during late Pliocene as some other researchers determined. These two researchers, based on correlation of the terraces with oxygen isotope suggested that during part of the middle and all the late Pleistocene onwards the Gulf of Corinth had known alternations of fresh or brackish and marine water, related to eustatic sea level changes. Marine terraces represent marine highstands. The rhythm of these high sea levels is around 20-30ka, since at least 330.000 years ago.

Lowstands and highstands, during the Quaternary, recorded in the sedimentary sequence of the Corinth basin with lacustrine marls (Corinth marls) and marine terraces respectively (Piper et al., 1990). Marine transgression after the stage 2 lowstand restored marine conditions to the Gulf of Corinth at about 12-13ka. Marine highstand deposits during late Pleistocene consist of beach to offshore conglomerates and sandstones with wave-modified sedimentary structures and herringbone cross-stratification (Collier & Thompson, 1991). The distribution of marine facies controlled by the structural morphology of the basin.

3. TECTONIC BACKGROUND

Corinth basin bounded southwards by a master normal listric fault with WNW direction (Fig. 1B). Many others "counter faults" and "backward faults" were recognized within the Corinth basin. Due to these faults four sub-basins were formed from the southern margins to the recent coast (Athikia, Galataki, Ancient Corinth and New Corinth sub-basins respectively). In the Athikia, Galataki and ancient Corinth sub-basins the Pre-Neogene basement exposed in a WNW directed zones due to the counter and backward faults. Moreover NNE cross-faults (transfer faults) influenced the sub-basins expansion and the sedimentary thickness.

The active faults now are situated in the new Corinth town due to which its hangingwall subsided and a small delta plain was formed adjacent to the fault scarp, where the new town of Corinth was built up (New Corinth sub-basin). The footwall of this fault uplifted and tilted southwards (Ancient Corinth sub-basin). This tilting influenced the ancient Corinth sub-basin.

4. DEPOSITIONAL ENVIRONMENTS

Three depositional environments were recognized and studied within Corinth basin from late Pleistocene to present : Corinth fluvio-lacustrine marls and marine terraces deposited during late Pleistocene and Xerias river Holocene deposits.

4a. Corinth marls

Corinth marls near the bounding faults consist of coarse-grained massive, matrix-supported conglomerates, up to 200m thick (e.g. Ancient Corinth sub-basin). Mean clast size is 2-4cm, whereas max. clast size is 20-30cm. Clasts derived from limestones and igneous rocks (50-50%), are well rounded and spherical. Matrix is 40-50% and consists of fine granules. Conglomerates are high dipping in a SSW direction.

These massive sediments lacking of sedimentary structures, suggest debris flows in a progradational alluvial fan environment (Nichols 1987).

Unconformably over them and in some places (e.g. Ancient Corinth) alluvial fans pass upwards to an up to 50m thick sequence of thick interbedded sandstone (0.5 - 5m thick) and well sorted, clast-supported conglomerates (3-8m thick), which are dipping subhorizontally in a NE direction. These deposits accumulated in an asymmetrical trough with its thickness increasing towards the bounding fault. Sandstone beds are fining upwards with sandy mudstone at the uppermost part (5-30cm thick). Conglomerates (Fig. 2A), with erosional the lower contact, relief up to 30cm, consist of well rounded, sub-spherical clasts. Each conglomerate body composed by channelised fining upwards cycles up to 15-20cm thick. In some places conglomerates are openwork. Mean clast size is 4cm and max. is about 7cm. Clasts are 95% limestones and 5% chert.

The above sandstone and conglomerate deposits probably represent braided river deposits.

Both, alluvial fans and braided river deposits pass laterally to the lacustrine calcareous siltstones.

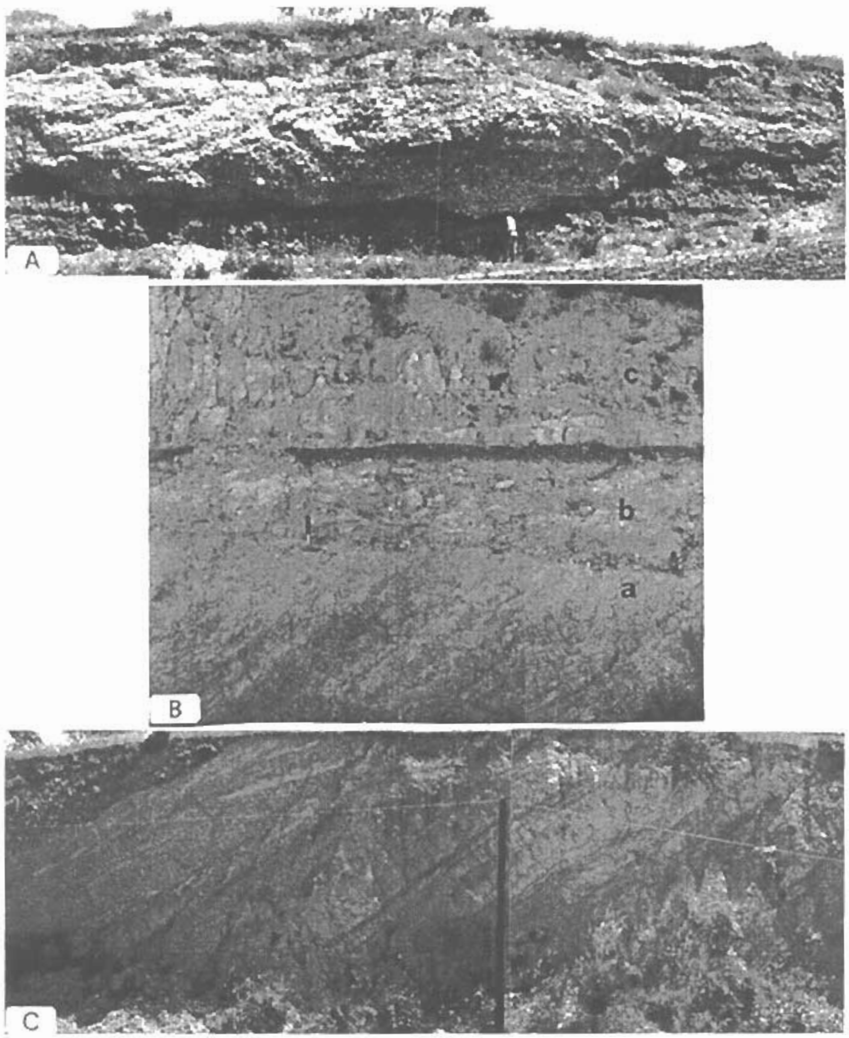

Fig. 2: Photographs from the Corinth marls. A: Channelised clast-supported conglomerates near the town of ancient Corinth. B: (a) the lower high dipping group of the lacustrine facies. (b) the upper subhorizontally dipping group of the lacustrine facies, that unconformably overlying the lower group, wedged out eastwards (c) marine terraces. C: thick interbedded mudstone-sandstone and conglomerate beds.

This lacustrine facies can be subdivided in two groups. The lower stratigraphic group (Fig. 2Ba), high dipping westwards (from WSW to WNW), covers the whole Corinth basin but its lithologies depend on the sub-basins configuration. In Athikia and Galataki sub-basins this facies is thinner and coarser than in Ancient- and New- Corinth sub-basins where this facies is thicker and finer. Generally it is composed by coarsening upwards cycles with mudstone and silty sandstone beds. The mudstone beds are characterized by massive and bioturbated structures. Burrows, horizontal and ripple lamination, fossils and cross-lamination are rare. Leaf fossils, shaley and split coal lenses, and thin gypsum beds in some places are common. The gastropod Neritica was recognized. The silty sandstone beds coarsen upwards.

The upper group subhorizontally dipping NW, developed unconformably over the lower high dipping group (Fig. 2Bb), restricted in a small area around the town of Ancient Corinth, consists of strongly cemented thin to medium interbedded mudstone and sandstone beds with the same structures as the sediments of the lower group. These deposits probably formed a lacustrine terrace.

Structures and textures of the fine-grained sediments (lower and upper group) indicate a lacustrine environment.

Moreover, in a NNE direction (transfer zone) (e.g. Solomos area) within the lacustrine deposits an up to 300m thick sequence consisting of thick interbedded mudstone-sandstone and conglomerate beds (3-20m thick) was formed (Fig. 2C), with high dipping northwards. Clast size of conglomerates decreases upwards either in each cycle or in the whole sequence from bottom to top and from bounding fault towards the basin. These deposits represent a distributary channel that evolved due to transfer faults within the lake.

4b. Marine terraces

Marine sequence lies unconformably on predominantly fluvio - lacustrine deposits termed Corinth marls (Fig. 2Bc). Marine deposits dated from 300.000 to 80.000 years (isotopic stages 9.3 - 5.3, according to Keraudren and Sorel (1987)) or about 200.000 (isotopic stage 7, according to Collier and Thompson (1991)) subdivided from Collier and Thopson (1991) into four different lithologies: (a) planar-bedded, cross-bedded and massive sandstone/ conglomerate facies association related to a beach to offshore transition forming a transgressive unit above the underlying unconformity, (b) variably laminated and bioturbated siltstone/ sandstone facies association related to a marine environment below fair-weather wave base of low energy and high faunal activity, (c) oolitic sandstone facies association. Ooid production characterizes a warm shallow, high energy, tidal influence of a shoal environment. Ripple and dune bedform are present within this association suggesting that significant currents were active in this environment. Also, herringbone cross-stratification structures within the oolitic sands imply that a tidal mechanism may have been involved in current generation, and (d) transverse dunes. Details of bedding within the dunes reflect periodic sediment input and transport processes.

4c. Holocene Xerias river deposits

Recent alluvial deposits have their greatest thickness, <25m, near the Examilia area, and consist of thin to thick interbedded mudstone, sandstone and conglomerate beds (Fig. 3A). Lithology depends on the depositional environments. Overbank deposits consist of thin to thick interbedded mudstone and sandstone beds with rare conglomerate lenses. Within bank and channel conglomerates are more abundant and thicker (Fig. 3B). Although palaeocurrents analysis indicate a northward direction of flows, in the Examilia area palaeocurrents show an eastward flow (Fig. 3C).

5. PALEOGEOGRAPHIC EVOLUTION

5a. Paleogeographic evolution of the Corinth basin

The two probably synchronous unconformities between alluvial fan / braided river deposits, and lacustrine / lacustrine deposits, with high angle unconformity, within Corinth marls, indicate a sudden change of the tectonic activity influencing the depositional pattern of the Corinth basin (Fig. 4A,B). The whole basin uplifted and eroded and only a small area remained as a lacustrine environment in the Ancient

Corinth sub-basin. This theory is in argument with the Collier and Thompson (1991) model for the paleogeographic evolution of the Corinth basin where subsidence and sedimentation, periodically interrupted by intrabasinal tectonic uplift and erosion. Glasio-eustatic have strongly influenced coastal morphologies and depositional patterns.

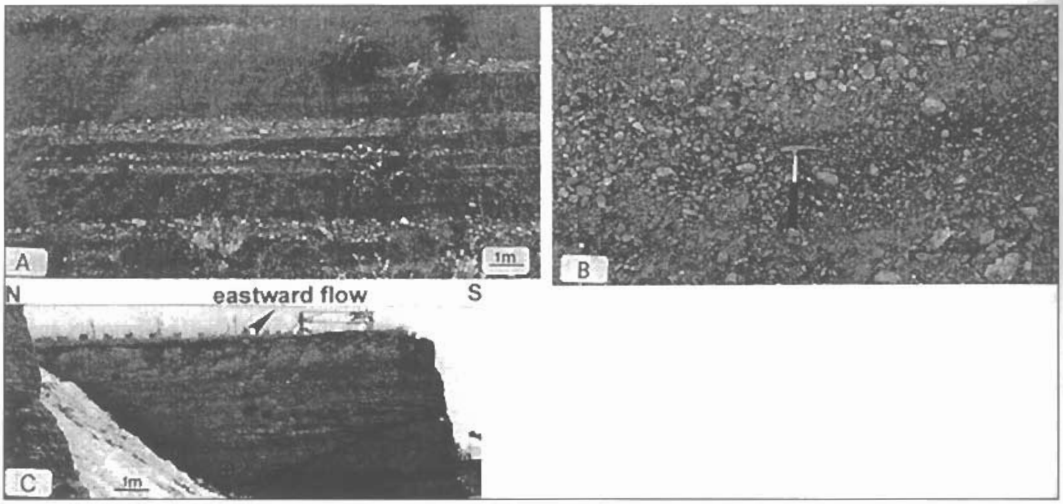

Fig. 3: Recent alluvial deposits of the Xerias river in the Examilia area. A: Thin to thick interbedded mudstone, sandstone and conglomerate beds. B: thick channelised clast-supported conglomerates. C: A large sandstone-conglomerate channel which show an eastward paleoflow direction.

Erosional marine terraces have been cut at levels of relative stillstand. Marine deposits related to highstands. Coarse-grained deposits situated on the hangingwall of major basement bounding normal faults. Due to continuing uplift of the footwall in the major faults succesive transgresive and regressive cycles have cut marine terraces at lower altitudes generating "staircase" morphologies.

5b. Paleogeographic evolution of the Xerias river

The Plio-Quaternary evolution of the Xerias river influenced on the tectonic activity and the pre-existing deposits which cross-cutted.

Xerias river pass through the three southern sub-basins (Athikia, Galataki, Ancient Corinth) and discharge in the forth new Corinth sub-basin.

Xerias river during Pleistocene formed an antecedent drainage where the river had maintained its original direction of flow across pre-existing tectonic topography (Fig.4C). The river incised through uplifted footwall of the two internal sub-basins (Galataki and Ancient Corinth). The river flowed through shallow gorges in its lower reaches and had mature forms in the upper reaches in the Pre-Neogene basement. The shallow gorges in the lower reaches owed to the soft pre-existing Pleistocene lacustrine sediments that cross-cut.

During Holocene time Xerias river changed again in a capture drainage (Fig. 4E) because the reverse element returned to its original flow direction. Headward erosion by misfit stream through wind gap extended into the area of the reverse drainage and captured the stream.

The evolution of the capture drainage in the area of the wind gap showed that gorges been evolved in this area are increased on width and deep during the last 100 yr. eroding the pre-existing late Pleistocene deposits. After the sedimentation of the late Pleistocene marine terraces on the footwall of the fault L4 [dated <80.000 yrs, after Keraudren and Sorel (1987) based on oxyzen - isotope curve given by Imbrie et al., (1984)], this footwall was uplifted and tilted southwards as far as the fault L3. Due to this evolution the pre-existing antecedent drainage changed to a reverse drainage consisting by two opposing drainage elements: a reverse drainage component and a misfit drainage component (Fig. 4D). The reverse drainage component referred to the footwall of fault L4 which is the platform between L3 and L4 faults and which represent the "wind gap" (after Seger and Alexander, 1993).

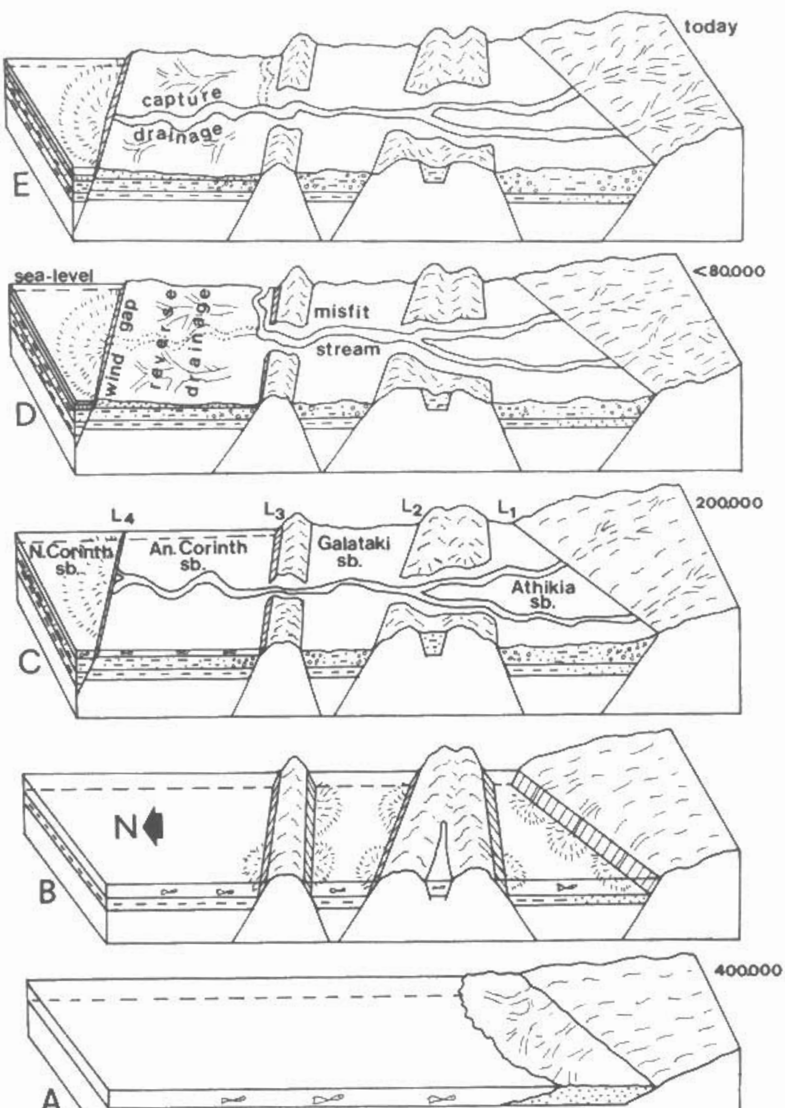

Fig. 4: Block diagrams showing the paleogeographic evolution of the Corinth basin and the evolution of the Xerias drainage pattern in five stages.

The misfit drainage had its original flow as far as the hangingwall of L3 fault where its flow changed from NNE to ESE direction, parallel to L3 fault, towards Kechrees coast. This flow change suggest an asymmetrical subsidence of the platform between L3 and L4 faults.

The development of the reverse drainage type indicates also a great reduce in water and sediment discharge in the original flow of the river by the reduction in catchment size.

6. XERIAS RIVER FLOODING IN 12/1/1997

Xerias river is composed of two branches (Chiliomodi and Athikia) about 10km long each (Fig. 5A). These two branches coalesce in one main channel, about 10km long, in the central part of the basin and through this discharge their material to the sea. The area from the joining of the two branches as far as the coast there are flooding events. From the joining point as far as the area of the reverse element (see above) and although the channel width in few places is up to 130m. But human activities reduce channel width to 10-15m and so the river flooded. Human activities referred to vegetables within the channel, bridges e.t.c.(Fig. 5B,C).

Only near the town of Corinth (reverse element) the initial width of the Xerias river was between 12-18m and its depth between 1.5-3m. Human activities in this area reduced more the channel size, mostly in its depth (Fig. 5D,E).

So, the results of the Xerias river flooding in the area before the reverse element were to destroyed vegetables and bridges and to return to its initial channel configuration (Fig. 5C). In the area of the reverse element -wind gap- Xerias river flooding owed mostly to its initial geometry evolution and less to human activities. Its initial geometry was not quite enough to accept the large amounts of material that river transported. Human activities which reduce the channel geometry (reverse element) decrease the channel capacity and increase the problems.

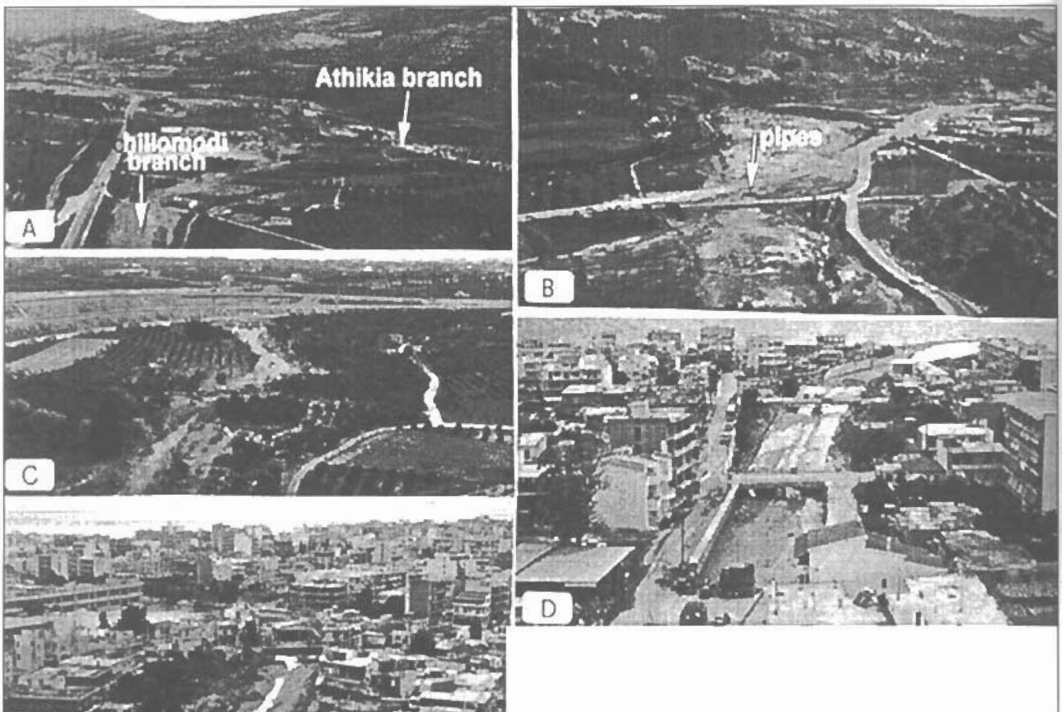

Fig. 5: Photographs from Xerias river after its flooding event. A: the coalence of the two brances of the Xerias river. For location see Fig.1. B: Due to human activity (four pipes in the coalence point through which Xerias river owed to transport its matterial to the sea) the river width decreased dramatically and so was flooded. C: narrowing of the river width due to bridges near the town of Corinth. D, E: the channel depth reduced due to bridges in the town of Corinth.

With the time Xerias river will produce larger gorges in the area of the reverse element [see other examples in the Corinth graben; Seger and Alexander (1993)] as a result of its evolution (subsidence of the hangingwall of the L4 fault and uplift of the footwall respectivelly), producing more problems to the Corinth town.

7. DISCUSSION AND CONCLUSION

Corinth basin evolution showed a northward migration of the tectonic activity recorded in the four sub-basins development. The three southern Athikia, Galataki and Ancient Corinth sub-basins are characterized by coarse-grained deposits adjacent to the major fault scarps, passing laterally to lacustrine marls. Sandstone marine terraces accumulated mostly in the Ancient Corinth sub-basin, unconformably overlay lacustrine deposits. The main tectonic activity with the higher displacement in each sub-basin situated on the major bounding, northwards dipping faults, forming asymmetrical grabens, with the thickness increasing southwards, towards the fault scarp, in each sub-basin. Moreover, due to the migration of the tectonic activity northwards, every time, the footwall of the active fault, uplifted and back-tilted southwards. Due to this back-tilting of the Ancient Corinth sub-basin, the Xerias river flow changed its pre-existing direction (NNE-wards) towards to Kechrees (ESE direction), when the tectonic activity migrated to the recent coastline.

The answer in the question why the flow of the river changed only this time span, when the Ancient Corinth basin back-tilted and no when the Galataki and Athikia sub-basins also back-tilted, probably is 1. the different lithologies between these two cases. Ancient Corinth sub-basin lithologies were the cohesive sandy marine terraces whereas for the Galataki and Athikia sub-basins were the soft uncohesive lacustrine marls, 2. the distance from the source - Pre-Neogene basement. The ancient Corinth sub-basin was far from the source and there was also a large platform before the Pre-Neogene basement which was practically horizontal with a high reduce in the river power; whereas the other two sub-basins were near the source and the river power was strong.

In the area where the river changed its flow (to reverse drainage) a large area (wind gap) was formed where thick recent alluvial deposits were accumulated. These soft, uncohesive (inarticulate) deposits were inclined to erosion and for this reason large quantities of sediments could be transported after the erosion during a flooding event, as this happened during the 12/1/1997 flooding of the Xerias river.

According to Seger and Alexander (1993) model for the 24 rivers of northern Peloponnesus, three types are suggested for the Xerias river evolution through the time. 1. An antecedent drainage from 400.000 to 80.000 yr., 2. A reverse drainage from 80.000 to historical yr., and 3. A capture drainage from historical years until now. The reverse element of the reverse drainage situated in the northern part of the Ancient Corinth sub-basin and a part of this remain as reverse drainage.

The answer to the questions: 1. why other reverse drainage such as Feneos drainage remain as reverse drainage?, 2. Why other capture drainage such as Vouraikos, Kerinitis and Selinous, rivers have large gorges at the areas of the wind gap? and 3. why the Xerias flow changed eastwards and not westwards? are that all questions related to tectonic pattern and the sediments that the rivers cross-cut. The answer to the question if there is any connection between the change of a reverse drainage to a capture with transfer faults is that probably the absence of transfer faults in the wind gap of the Feneos drainage bind the flow of the Olivios river to change in a capture drainage on the Dervenios river and also because the wind gap consists of Pre-Neogene limestones. Probably the reason for the large gorges in the Vouraikos, Kerinitis and Selinous rivers in the wind gap related with the coarse-grained fan-delta deposits that the rivers cross-cut, and the age of the development (earlier evolution than the Xerias river). The eastward flow of the Xerias river probably related to differential subsidence and uplift along a fault, indicating an westward increase of the subsidence and uplift of the hangingwall and footwall respectively (the same conclusion was indicated by Keraudren and Sorel (1987) studying the elevation of isochronous marine terraces).

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REFFERENCES

BORNOVAS,J., LALECHOS,N. & FILIPPAKIS,N. 1971. Geological Map Korinthos Sheet, 1:50.000. IGME, Athens.

COLLIER, R. & THOMPSON, J. 1991. Transverse and linear dunes in an Upper Pleistocene marine sequence, Corinth Basin, Greece. *Sedimentology* **38**,1021-1040.

DOUTSOS, T. & Piper, D.J.W. 1990. Listric faulting, sedimentation, and morphological evolution of the Quaternary eastern Corinth rift, Greece: First stages of continental rifting. *Geol.Soc.Am.Bull.* **102**, 812-829.

IMBRIE, J., HAYS,J.D., MARTINSON,D.G., McINTYRE,A., MIX,A., MORLEY, J.J., PISIAS,N.G., PRELL,W.L. & SHACKLETON,N.J. 1984. The orbital theory of Pleistocene climate: support from a revised chronology of the marine δ18O record. In: *Milankovitch and Climate, Part 1* (Ed. By A.L.Berger, J.Imbrie, J.Hays, G.Kukla & B.Saltzman), pp.269-305. D.Reidel, Dordrecht.

KERAUDREN, B. & Sorel,D. 1987. The terraces of Corinth (Greece) - A detailed record of eustatic sea-level variations during the last 500.000 years. *Marine Geology* **77**, 99-107.

NICHOLS, G.J. 1987. Syntectonic alluvial fan sedimentation, southern Pyrenees. *Geol.Mag.* **124**, 121-133.

PAPAZACHOS,B. 1975. Seismic activity along the Saronikos - Corinth - Patras gulfs. *Month.Bull.seism.Inst.nat.Observ.*, Athens: 1-16; Athens.

PIPER,D.J.W., STAMATOPOULOS,L., POULIMENOS,G., DOUTSOS,T. & KONTOPOULOS,N. 1990. Quaternary history of the Gulfs of Patras and Corinth, Greece. *Z. Geomorph. N.F.* **34**, 451-458.

POULIMENOS,G. 1993. Tectonics and sedimentation in the western Corinth graben. *N.Jb.geol.Paleont.Mh.* **H10**, 607-630.

POULIMENOS,G., ALBERTS,G. & DOUTSOS,T. 1989. Neotectonic evolution of the central section of the Corinth graben. *Z.dt.geol.Ges.* **140**, 173-182.

POULIMENOS,G., ZELILIDIS,A., KONTOPOULOS,N. & Doutsos,T. 1993. Geometry of trapezoidal fan deltas and their relationship to extensional faulting along the south-western active margins of the Corinth rift, Greece. *Basin Research* **5**, 179-192.

SEGER,M. & ALEXANDER,J. 1993. Distribution of Plio-Pleistocene and modern coarse-grained deltas south of the Gulf of Corinth, Greece. *Spec.Publs.Int.Ass. Sediment.* **20**, 37-48.

ZELILIDIS,A. & KONTOPOULOS,N. 1996. Significance of fan deltas without toe-sets within rift and piggy-back basins: examples from the Corinth graben and the Mesohellenic trough, Central Greece. *Sedimentology* **43**, 253-262.