GEOMORPHOLOGICAL SURVEY OF EASTERN KORINTHIA (GeoSEK)

Report on Activities for the 1998 Permit Year

Executive Summary

The project seeks to understand landscape change in the eastern Korinthia, particularly as it relates to the period of human occupancy of the region — about the past 40,000 years. This project will study the nature and pace of landscape change during the latest Pleistocene and Holocene, particularly as influenced by such factors as tectonism, sea level change, climate change, changes in land cover, and human land use.

In June-July 1998 we conducted the first phase of our geomorphological study of the eastern Korinthia (Fig. 1). Field work and sample collection were conducted primarily in the area bounded by the Korinth Canal, Oneion, Ancient Korinth and Isthmia. Limited reconnaissance was conducted in the other parts of the study area . Geomorphological mapping, soil-profile descriptions and stratigraphic descriptions were conducted north of Oneion. Soil erosion experiment stations were set up at several sites in the study area.

Figure 1. GeoSEK study area is described by eight hydrologic basins to the S and SE of the Isthmus.

We presented results of our study of the submergence of Kechries Bay at the International IGCP Field Trip in September. The work is soon to be published in *Geology*.

Geomorphological Studies

Our goal for this study is the construction of large-scale catenas (soil-sediment-slope-landscape profiles). Study of these catenas involves geomorphological mapping and classification; sediment and soil stratigraphy; geochronological control; and development of modern and long-term rates of soil erosion. Geomorphological mapping is based on analysis of satellite and aerial imagery that is extensively field checked. We began mapping of surficial deposits and landforms of the region at a scale of 1:5,000 on Greek National topographic maps (Fig. 2). Field mapping involved walking three N-S-oriented transects. Along these transects we described the physical landscape, typifying and categorizing the geomorphic surfaces, describing surficial deposits where exposed in natural outcrops (e.g., streambanks and coastal bluffs), and collected surface soil samples. We described soil profiles from available exposures in wells, garbage pits, and new house construction.

Active Tectonics

Coeval long-term uplift and subsidence are thought to have created the Isthmus, the narrow land bridge connecting the Peloponnesos with mainland Greece. The rise and fall of the Isthmus is background to the rises and falls of ancient city states and other elements of human history that occurred here. These seemingly contradictory trends in deformation of this spit of land between the Korinthiakos and Saronikos Gulfs are necessary to explain the changes in land level as expressed most recently by uplifted (Lecheion) and subsided (Kenchreai) harbors (Roman and earlier age in these water bodies, respectively.

The Korinthiakos Gulf lies at the western end of the Hellenic Volcanic Arc, with its active normal fault-bounded basins located behind the Hellenic trench. This also is one the most exemplary regions of extensional tectonics (Sebrier, 1977; MacKenzie, 1978; Higgs et al., 1988; Taymaz et al., 1991; Collier et al., 1992; Dart et al., 1994; Armijo et al., 1996; Roberts, 1996 a, b; Dia et al., 1997). The area was most recently impacted by the large-magnitude 1981 Korinth earthquakes, which affected land level changes in the northern Peloponnesos and Korinthiakos Gulf region (Jackson et al., 1982).

In the eastern Korinthia, we recognize a Holocene complex of active normal faulting south of the Isthmus may well mark the transitional area between three structural (fault) domains. The first domain is that of the W- and WNW-trending normal faults bounding the Korinthiakos Gulf. The second domain is that of the NWN-trending normal faults of the northeastern Peleponnesos. The third domain includes the western terminus of the Hellenic Volcanic Arc and its NW- and NE-trending structures. The analysis of seismicity and focal mechanisms of the Aegean region (Papazachos and Kiratzi, 1996) shows the study area to be one of extremes in extension rate, from 7 mm yr^{-1} in the north to less than 1 mm yr^{-1} in the south. How this extension is accommodated by faults, particularly as the primary orientation of Quaternary faults vary considerably over the region, is a secondary focus of this study. Study results should shed light on middle and late Quaternary interactions of these fault domains. Active and potentially active faults were preliminarily mapped based primarily on Landsat imagery, topographic inspection and reconnaissance field work (Fig. 3).

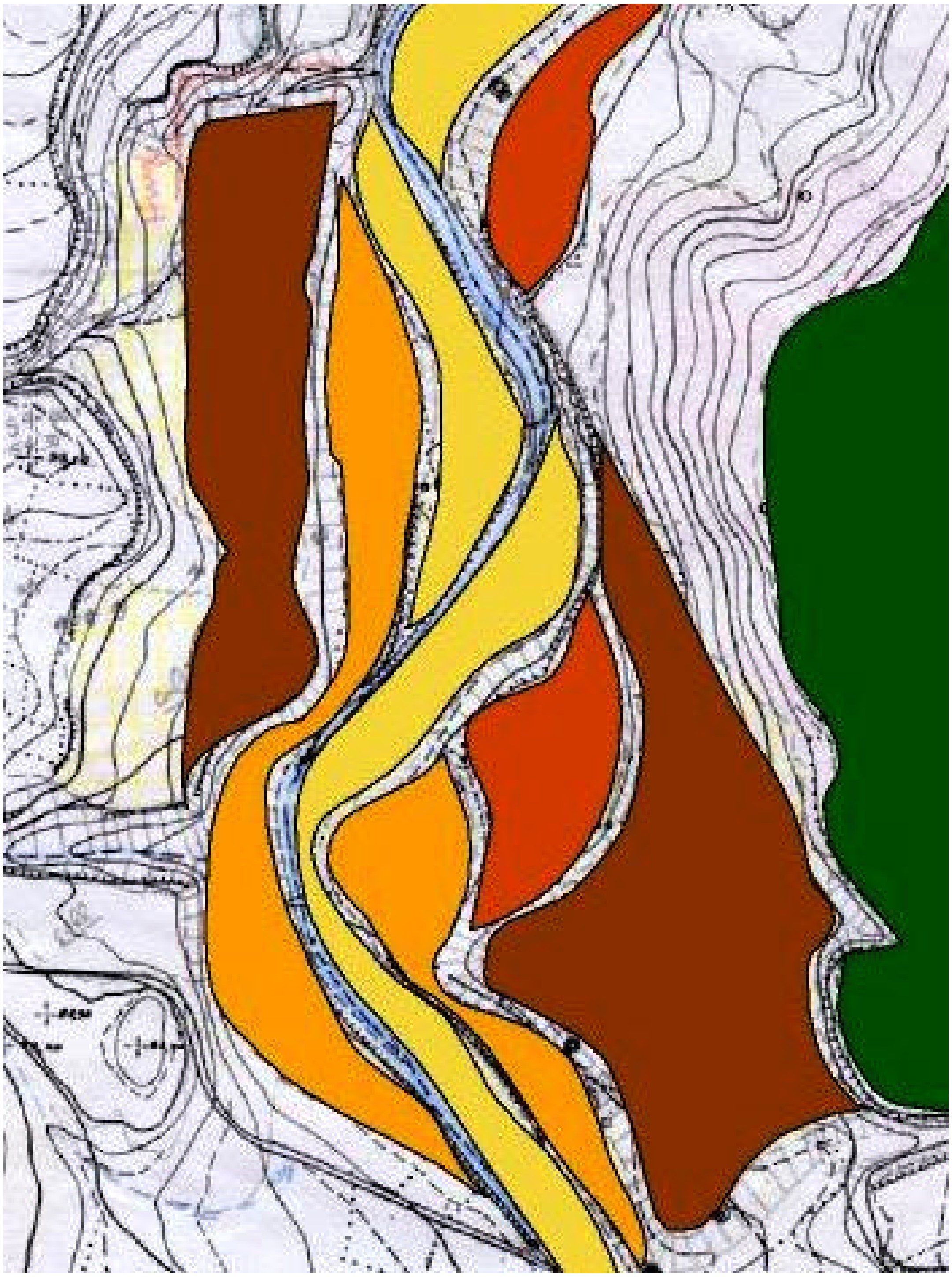

Figure 2. Preliminary geomorphic map of the Potamos Salamos (aka Xeropotamos), east of Kenchreai Gate of Ancient Korinth. The youngest alluvial terrace is along the river, the oldest surface is on the east map edge (green), and intermediate age terraces are between.

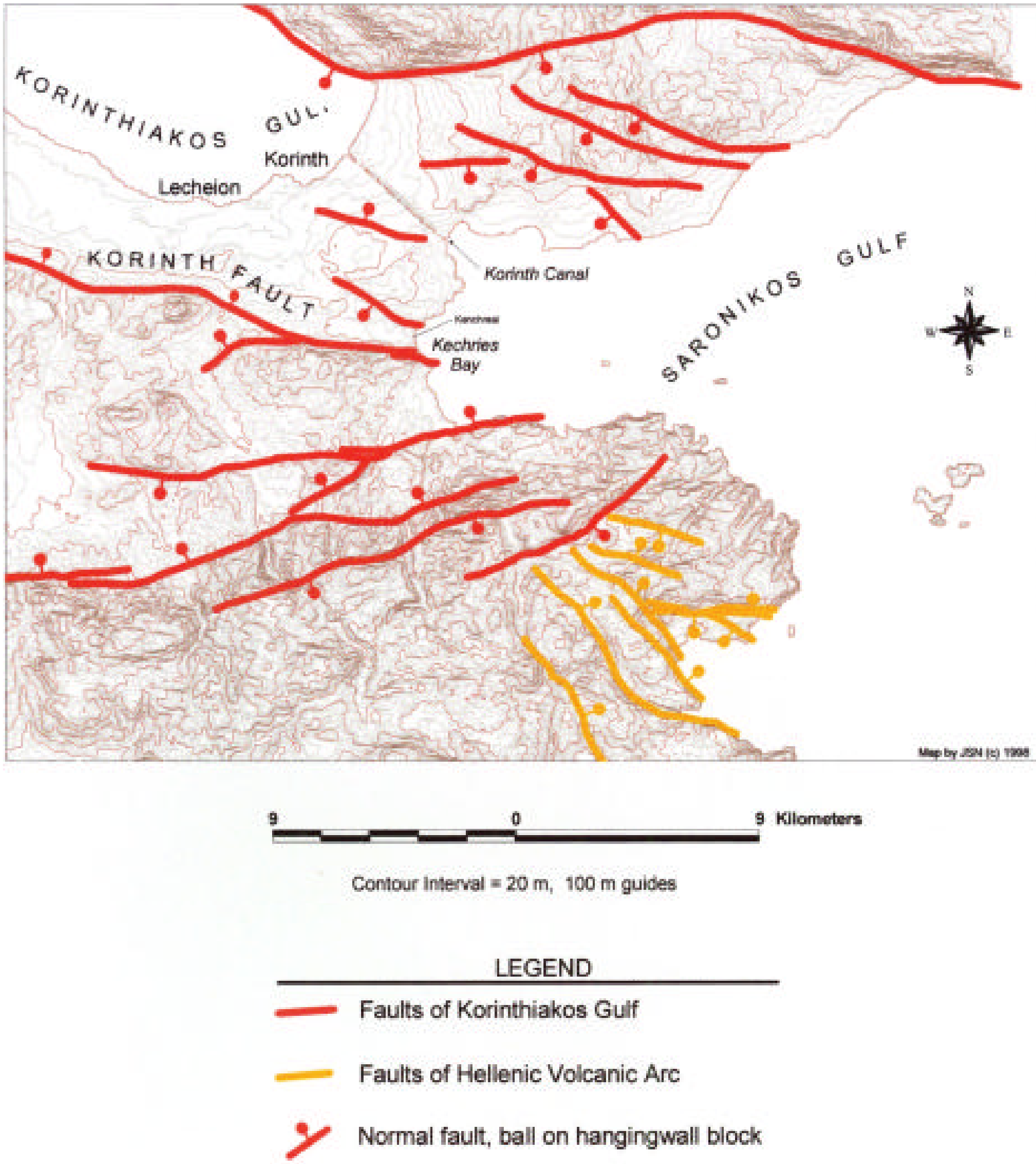

Figure 3. Preliminary active tectonic map of the Isthmus and region.

The Korinth Fault is a west-striking normal fault exposed for about 15 km along the base of the escarpment formed by the Oneion Range and Acrokorinth (Fig. 3). Despite the assertion of Dia et al. (1997) that the Kechriae fault (Korinth fault) is inactive, my reconnaissance of nearly the entire length of the fault reveals strong evidence of Holocene offset (Noller et al., 1997). First, Kechries Bay formed in part by subsidence along this fault at its southern shore. Second, near Xilokeriza I identify an approximately 1.5-m-high offset of late Pleistocene-Holocene colluvium along the fault trace, adding to the documentation of active faults in the eastern Korinthia (Stiros, 1995). Third, compound fault scarps exceeding 5 m in throw offset middle Pleistocene alluvial fans and Holocene colluvium along the Korinth fault west of Xilokeriza.

The sunken harbor of Kenchreai and submerged wave-cut notches around Kechries Bay serve as indicators of timing, location and amount of deformation associated with earthquakes on the Korinth fault (Noller et al., 1998, submitted). Based on this evidence we estimate slip rate on the Korinth fault for the past two millenia to about 1.2 mm yr^{-1} and subsidence rate of Kechries Bay for the same period to be between 0.8 and 0.5 mm yr^{-1}. This fault accounts for a minimum of 10-20% of the historic local horizontal extension velocity of <5 mm yr^{-1} (Papazachos and Kiratzi, 1996). Other faults in the region must be taking up the remainder of slip. This needs to be further studied and quantified.

Marsh Stratigraphy

Incomplete sediment cores of Korfos marsh were collected. We expect the cores to reveal land level and environmental changes that have occurred over the past few centuries to millenia. Our samples await analysis.

Soil Erosion and Atmospheric Nutrient Flux

Modern rates of erosion will be quantified at our Soil Erosion Experiment Demonstration (SEED) stations that were installed at various sites in the study area. The emplacement of erosion pin networks (<200 m^2 areas), consisting of surveyed arrays of steel rods driven into soil, should provide direct measures of annual changes in relative soil surface elevation, and hence an estimate of material flux across the surface. Atmospheric nutrient (inorganic and organic eolian dust) flux to the basins will be quantified by our emplaced atmospheric precipitation and dust traps.

Laboratory Analyses

In early 1999 we will begin analyzing soil samples collected during the 1998 field season. Soil analyses will include particle size analysis, organic matter and carbon, conductivity, pH, total chemistry, and select elemental analyses. We will attempt to estimate mean residence ages of soils using the oxidizable carbon ratio method on surface and buried soil A horizons.

Bibliography

Armijo, R., Meyer, B, King, G. C. P., Rigo, A., and Papanastassiou, D. 1996. Quaternary evolution of the Corinth Rift and its implications for the late Cenozoic evolution of the Aegean. *Geophysical Journal International.* 126:1:11-53.

Collier, R. E. Ll., Leeder, M. R., Rowe, P. J., and Atkinson, T. C. 1992. U-series dating and tectonic uplift of upper Pleistocene marine sediments from the Corinth and Megara Basins, Greece. *Tectonics* 11:1159-1167.

Dart, C. J., Collier, R. E. Ll., Gawthorpe, R. L., Keller, J. V. A., and Nichols, G. 1994. Sequence stratigraphy of (?)Pliocene-Quaternary synrift, Gilbert-type fan deltas, northern Peloponnesos, Greece. *Marine and Petroleum Geology*. 11:5:545-560.

De Kaenel, E., Siesser, W.G., and Murat, A. 1999. Pleistocene calcareous nannofossil biostratigraphy and the western Mediterranean sapropels, sites 974 to 977 and 979, in R. Zahn, M.C. Comas, and A. Klaus, eds., *Proceedings of the Ocean Drilling Program, Scientific Results*. 161, in press.

Dia, A. N., Cohen, A. S., O'Nions, R. K., and Jackson, J.A. 1997. Rates of uplift investigated through Th-230 dating in the Gulf of Corinth (Greece). Chemical Geology 138:171-184.

Freyberg, B. von, 1973, Geologie des Isthmus von Korinth: *Erlanger Geologische Abhlangdungen*, 95.

Higgs, B. 1988. Syn-sedimentary structural controls on basin deformation in the Gulf of Corinth, Greece. *Basin Research*. 1:155-165.

Jackson, J.A., Gagnepain, J., Houseman, G., King, G.C.P., Papadimitriou, Soufleris, C., and Virieux, J. 1982. Seismicity, normal faulting, and the geomorphological development of the Gulf of Corinth (Greece): The Corinth earthquakes of February and March 1981. *Earth and Planetary Science Letters*, 57:377-397.

Koukis, G., 1990, Peleponnesos: History, geology and engineering geology aspects, in P. Marinos and G. Koukis, eds., *Engineering geology of ancient works, monuments and historical sites*: Rotterdam, Balkema, 2213-2234.

Mariolakos, S., and Stiros, S. C. 1987. Quaternary deformation of the Isthmus and Gulf of Corinth (Greece). *Geology* 15:225-228.

Noller, J.S. 1993. Late Cenozoic stratigraphy and soil geomorphology of the Peruvian Desert, 3°18°S: Long-term evidence of hyperaridity and El Nino. PhD Dissertation, Boulder, University of Colorado.

Noller, J.S., Wells, L.E., Reinhardt, E., Rothaus, R.M., 1997, Subsidence of the Harbor at Kenchreai, Saronic Gulf, Greece, During the Earthquakes of AD 400 and AD 1928. *EOS (American Geophysical Union Transactions)*. 78:636.

Noller, J.S., Wells, L.E., Reinhardt, E., and Rothaus, R., 1998, Episodic subsidence at Kenchreai, Greece: Recent considerations and concerns, Proceedings of the IGCP 367 Annual Meeting — Rapid Coastal Changes in the Late Quaternary.

Noller, J.S., Wells, L.E., Reinhardt, E., and Rothaus, R. Subsidence of the ancient harbor of Kenchreai, Greece. *Geology,* submitted.

Papazachos, C.B., and Kiratzi, A.A., 1996, A detailed study of the crustal deformation in the Aegean and surrounding area: *Tectonophysics* 253:129-153.

Pirazzoli, P.A., Laborel, J., and Stiros, S.C. 1996. Earthquake clustering in the eastern Mediterranean during historical times. *Journal of Geophysical Research*. 101B:6083-6097.

Roberts, G. P. 1996a. Variation in fault-slip directions along active and segmented normal fault systems: *Journal of Structural Geology* 18:6:835-845.

Roberts, G. P. 1996b. Noncharacteristic normal faulting surface ruptures from the Gulf of Corinth, Greece. *Journal of Geophysical Research.* 101B:11:25,255-25,267.

Rothaus, R.M., 1996 Earthquakes and temples in late antique Corinth, in S. Stiros and R.E Jones, eds., *Archaeoseismology*: Fitch Laboratory Occasional Paper 7, The British School at Athens, 105-112.

Stiros, S. C. 1995. The 1953 seismic surface fault: Implications for the modeling of the Sousaki (Corinth Area, Greece) geothermal field. *Journal of Geodynamics*, 20:167-180.

Taymaz, T., Jackson, J., and McKenzie, D. 1991. Active tectonics of the north and central Agean Sea. *Geophysical Journal International*, 106:433-490.

Vita-Finzi, C. and King, G.C.P., 1985, The seismicity, geomorphology and structural evolution of the Corinth area of Greece: *Philosophical Transactions of the Royal Society of London*, 314:379-407.

Zreda, M.G., and Noller, J. S. 1998a. Cosmogenic ^{36}Cl dating of the Hebgen Lake, Montana, fault scarp, in J.M. Sowers, J.S. Noller, and W.R. Lettis, eds., *Dating and Earthquakes: Review of Quaternary Geochronology and its Application to Paleoseismology:* U.S. Nuclear Regulatory Commission, NUREG/CR 5562: 4-39-4-48.

Zreda, M.G., and Noller, J. S. 1998b. Ages of prehistoric earthquakes revealed by cosmogenic chlorine-36 in a bedrock fault scarp at Hebgen Lake. *Science* (Nov. 6, 1998).