GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L19314, doi:10.1029/2008GL034854, 2008

Comment on "A comparison of 10^3–10^5 year uplift rates on the South Alkyonides Fault, central Greece: Holocene climate stability and the formation of coastal notches" by J. F. Cooper, G. P. Roberts, and C. J. Underwood

Jenni Turner,[1] Mike Leeder,[1] Julian Andrews,[1] and Peter Rowe[1]

Received 9 July 2008; revised 23 August 2008; accepted 26 August 2008; published 15 October 2008.

Citation: Turner, J., M. Leeder, J. Andrews, and P. Rowe (2008), Comment on ''A comparison of 10^3–10^5 year uplift rates on the South Alkyonides Fault, central Greece: Holocene climate stability and the formation of coastal notches'' by J. F. Cooper, G. P. Roberts, and C. J. Underwood, *Geophys. Res. Lett.*, *35*, L19314, doi:10.1029/2008GL034854.

[1] An understanding of fault kinematics in areas of active tectonic deformation requires detailed knowledge of local and regional ground-surface displacement vectors. Where faulting displaces coastlines, dated raised marine notches can provide reference markers to measure the magnitude, rate and timing of fault displacement [*Pirazzoli*, 2005]. This is particularly important in areas of multi-generational faulting and where uplift may include both local and regional scale components, features which characterise the actively extending Gulf of Corinth rift (Figure 1). *Cooper et al.* [2007] interpret the distribution and elevation of raised Holocene and marine isotope stage (MIS) 5 ($\sim$125 ka) fossil shorelines from the Perachora peninsula in the Gulf of Corinth as due to spatially variable uplift along the fault footwall of a western segment to the Pisia fault which ruptured in 1981 [*Jackson et al.*, 1982]. This comment draws attention to previously published studies of raised shorelines in the area and presents new field observations that help test the structural uplift models of *Cooper et al.* [2007] and *Morewood and Roberts* [1999].

[2] *Cooper et al.* [2007] describe uplift rates increasing eastwards with distance from the fault tip at Makrugoaz Ridge to Agriliou Bay (Figure 1). They model spatially variable footwall uplift rates of the coastal section, increasing from 0.29 mm/yr to 0.5 mm/yr along the fault from the tip, values derived from *Leeder et al.* [2003, Figure 3]. However, as given by *Leeder et al.* [2003], the uplift rates are clearly stated as 0.5 mm/yr during the Holocene and an average of 0.2–.35 mm/yr since MIS 5 and interpreted as evidence of *spatially uniform* and *temporally variable* uplift of these shorelines, but are mis-quoted as *spatially variable* uplift rates.

[3] The model predictions of *Cooper et al.* [2007] were tested against the elevation of raised marine shorelines along the footwall coastal section. Their test is dependent on precisely mapped shoreline elevations and accurate reconstruction of the uplift history of Holocene and MIS 5 shorelines and is supported by chronologies that are extrapolated from other locations on the Perachora peninsula. For brevity, we comment here on the west tip at Makgrugoaz Ridge and more rapid uplifting east end at Agriliou Bay, modelled as laterally increasing uplift from 1.0 m to 3.0 m of Holocene uplift and 30 m to 80 m uplift of the MIS 5 shoreline At the west fault tip marine notches, which characteristically define sea level in this Mediterranean setting [*Pirazzoli et al.*, 1994], are preserved above 1.0 m elevation. These are recorded by *Vita-Finzi and King* [1985] where shells from the sublittoral-dwelling *Notirus irus* from 1.7 m elevation are ^{14}C dated to 6.89 ± 0.09 ka and proposed to represent a fossil shoreline of 3.0 m elevation. The evidence for Holocene shorelines above 1.0 m is supported by *Stiros* [1995]. At Agriliou Bay a well defined notch at 1.6 m is ^{14}C dated to 6.8 cal ka BP (sample OxA-14022; 5978 ± 30 ^{14}C year in *Leeder et al.* [2007]). We have found no evidence to support previous claims of a notch above this elevation at Agriliou Bay [*Leeder et al.*, 2007] (auxiliary photo of *Cooper et al.*'s [2007], the upper notch's deepest recess, at the man's shoulder, is 1.5 m above modern high water).

[4] Establishing the age of mapped notches from which uplift is calculated is the key to determining uplift rates for validation of any uplift model. *Cooper et al.* [2007] infer ages for their sequence of four mapped notches (Table 1) by reference to ^{14}C dated *Lithophaga* shells by *Pirazzoli et al.* [1994], although *Cooper et al.* [2007] misquote the shells as *Notirus irus* species. The ages used for *Cooper et al.*'s [2007] model are from a flight of three notches at Heraion and one of three dated palaeoshores from Mylokopi (Figure 1) outside the study area of *Cooper et al.* [2007]. The Mylokopi age of 310 ± 190 B.P. adopted for the modelled youngest notch is a mixture of shell fragments and is discarded as an unreliable age by *Pirazzoli et al.* [1994, Table 1]. There are preserved *Lithophaga* shells suitable for dating along the coastal section discussed by *Cooper et al.* [2007] that can potentially provide a direct chronology and a more robust test of the model to supplement the two ages of *Vita-Finzi and King* [1985] and *Leeder et al.* [2007]; these require careful study.

[5] Over longer timescales uplift rates can be calculated where dated corals from marine sediments are associated with littoral zone beach conglomerates and notches of paleo-shorelines up section [*Vita-Finzi*, 1993; *Leeder et*

---

[1] School of Environmental Sciences, University of East Anglia, Norwich, U. K.

0094-8276/08/2008GL034854$05.00

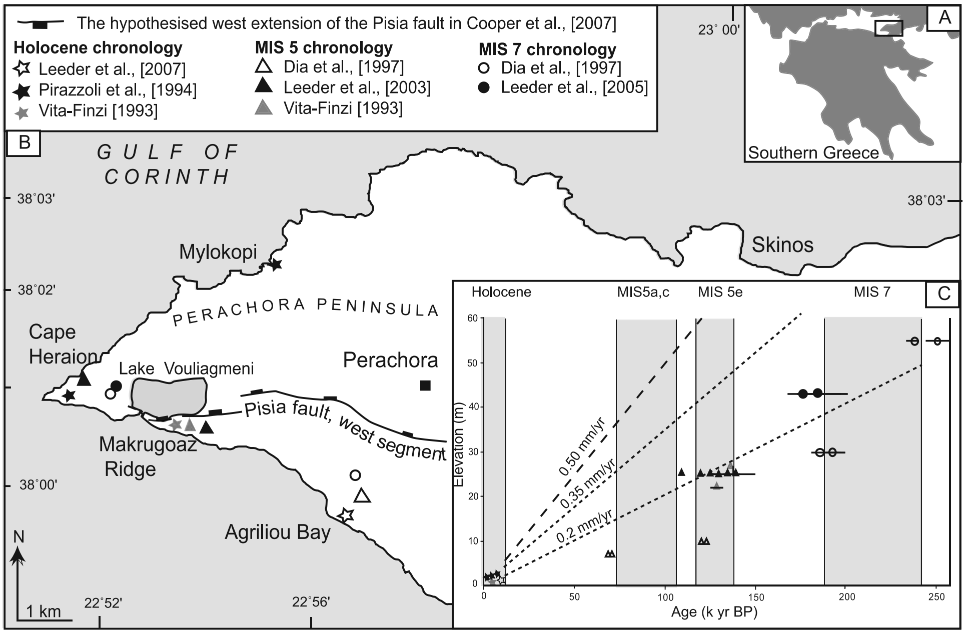

Figure 1. (a) Perachora peninsula in the eastern Gulf of Corinth, southern Greece. (b) Uplift of the shoreline from Makrugoaz Ridge to Agriliou Bay, inferred by *Cooper et al.* [2007] as footwall uplift by a hypothesised active western extension of the Pisia fault, but by *Leeder et al.* [2003, 2005] as regional uplift. (c) Uplift of dated shorelines is near-uniform on the footwall and hangingwall of the hypothesised fault; elevation points are shoreline inner edges, except those of *Dia et al.* [1997], which are coral sample elevations, symbol locations as in Figure 1b, see key for reference source.

Table 1. Ages From *Pirazzoli et al.* [1994] Inferred for Age of Notches on the Coastal Section Modelled by *Cooper et al.* [2007][a]

	Pirazzoli et al. [1994]				*Cooper et al.* [2007]
Location	Sample	Elevation (m)	Age ^{14}C (yr B.P. ± σ)	Calibrated Date (yr)	Makrugoaz Ridge to Agriliou Bay
Heraion	*Lithophaga*	3.1	5820 ± 60	4440–4320 B.C.	6330 ± 60 B.P.
	Lithophaga	2.2	4120 ± 60	2440–2260 B.C.	4300 ± 90 B.P.
	Chthamalus	1.4 ± 0.1	1990 ± 100	190–440 A.D.	1635 ± 125 B.P.
Mylokopi	*Lithophaga*	3.0	4705 ± 50	3170–3010 B.C.	not used
	Chthamalus	1.1 ± 0.3	620 ± 130	1450–1830 A.D.[b]	310 ± 190 B.P.
	V triqueter	0.8	1865 ± 55	400–540 A.D.	not used

[a] The dated shell species *Notoris irus* described by *Cooper et al.* [2007] is correctly shown as *Lithophaga* in Table 1.

[b] Denotes an age determined as unreliable by *Pirazzoli et al.* [1994]. See Figure 1 for sample locations.

al., 2003, 2005]. *Dia et al.* [1997] do not record inner edge elevations associated with dated coral elevations but we have mapped these in the field (Table 2). The MIS 5 and MIS 7 chronologies and shoreline elevations are coeval on the footwall and hangingwall suggesting the pre-Holocene uplift rate is spatially uniform at $\sim$0.25 mm/yr along and across the hypothesised fault section [*Leeder et al.*, 2003, 2005].

[6] Recent activity of the 'South Alkyonides' fault segment west of Perachora village that is central to the uplift model of *Cooper et al.* [2007, Figure 1] is not supported by field evidence. Following the 1981 rupture event, *Jackson et al.* [1982, Figure 1] mapped the Perachora peninsula in detail. They found evidence for rupture of the Pisia fault east of Perachora village but, contrary to descriptions by *Cooper et al.* [2007], no evidence was found for rupture west of Perachora village, neither on the proposed fault line nor as coastal uplift or subsidence. To accommodate the hypothesised 80 m of uplift since MIS 5 at the eastern end of the fault near Agriliou Bay (Figure 1) a hangingwall subsidence of at least 160 m is required, and thus a total throw of 240 m if a footwall:hangingwall partition of 1:2 is applied (see review by *McNeill et al.* [2005]). Throws of this magnitude and a defined fault line typical of an active fault have not been demonstrated or observed in the field.

Table 2. Palaeoshore Inner Edge Elevation and U/Th Ages From In Situ *Cladocora caespitosa* Coral Samples Collected From the Coastal Section Described by *Cooper et al.* [2007]

		Elevation (m)			
MIS	Location	Sample	Inner Edge[a]	Age (ka)	Publication
1	Agriliou Bay	1.6	1.6	6.8	*Leeder et al.* [2007]
5a/c	Agriliou Bay	7	12 ± 1	70.2 ± 0.7	*Dia et al.* [1997]
5e	Agriliou Bay	10	25 ± 6	123.1 ± 0.7	*Dia et al.* [1997]
5e	Agriliou Bay	10	25 ± 6	120.5 ± 0.9	*Dia et al.* [1997]
5e	Makrugoaz	23	25–30	134	*Vita-Finzi* [1993]
5e	Makrugoaz	23	25–30	108.5 ± 0.7	*Leeder et al.* [2003]
5e	Makrugoaz	23	25 ± 30	132.1 ± 8.2	*Leeder et al.* [2003]
5e	Makrugoaz	23	25 ± 30	118.4 ± 0.8	*Leeder et al.* [2003]
5e	Makrugoaz	23	25 ± 30	128.7 ± 0.7	*Leeder et al.* [2003]
5e	Makrugoaz	23	25 ± 30	133.4 ± 0.9	*Leeder et al.* [2003]
5e	Makrugoaz	23	25 ± 30	124.7 ± 1.0	*Leeder et al.* [2003]
5e	Makrugoaz	23	25 ± 30	125.9 ± 0.7	*Leeder et al.* [2003]
7	Agriliou Bay	55	63 ± 2	250.1 ± 6.3	*Dia et al.* [1997]
7	Agriliou Bay	55	63 ± 2	236.2 ± 3.0	*Dia et al.* [1997]

[a] Maximum uncertainties of palaeoshore inner edge elevation. The inner edge elevations associated with coral samples dated by *Dia et al.* [1997] are inferred by us based on recent mapping. See Figure 1 for sample locations.

[7] **Acknowledgments.** We thank Stathis Stiros, Lisa McNeill and Umberto Fracassi for detailed and constructive comments that much improved the manuscript. We also acknowledge IGME (Athens, Greece) for permission to carry out fieldwork. Radiocarbon date OxA-14022 quoted in the text was done at the Oxford University Radiocarbon Accelerator Unit. The calibrated age was computed with Oxcal (v.35) using atmospheric data from INTCAL98 [*Stuiver et al.*, 1998]. The calibrated age is the mean of the age ranges that contain 95.4% of the area under the probability curve. A reservoir correction for marine shell carbonate was not applied.

References

Cooper, F. J., G. P. Roberts, and C. J. Underwood (2007), A comparison of 10^3-10^5 year uplift rates on the South Alkyonides Fault, central Greece: Holocene climate stability and the formation of coastal notches, *Geophys. Res. Lett.*, *34*, L14310, doi:10.1029/2007GL030673.

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

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

Leeder, M. R., L. C. McNeill, R. E. L. Collier, C. Portman, P. J. Rowe, J. E. Andrews, and R. L. Gawthorpe (2003), Corinth rift margin uplift: New evidence from Late Quaternary marine shorelines, *Geophys. Res. Lett.*, *30*(12), 1611, doi:10.1029/2003GL017382.

Leeder, M. R., C. Portman, J. E. Andrews, R. Collier, E. Finch, R. L. Gawthorpe, L. C. McNeill, M. Perez-Arlucea, and P. Rowe (2005), Normal faulting and crustal deformation, Alkyonides Gulf and Perachora peninsula, eastern Gulf of Corinth rift, Greece, *J. Geol. Soc.*, *162*, 549–561.

Leeder, M., J. Andrews, R. Collier, R. Gawthorpe, L. McNeil, C. Portman, and P. Rowe (2007), *The Gulf of Corinth*, *Classical Geol. Eur.*, vol. 11, 164 pp., Terra, Harpenden, U. K.

McNeill, L. C., R. E. L. Collier, P. DeMartini, D. Pantosti, and G. D'Addezio (2005), Recent history of the Eastern Eliki Fault, Gulf of Corinth: Geomorphology, paleoseismology and impact on paleoenvironments, *Geophys. J. Int.*, *161*, 154–166.

Morewood, N. C., and G. P. Roberts (1999), Lateral propagation of the surface trace of the South Alkyonides normal fault segment, central Greece: Its impact on models of fault growth and displacement-length relationships, *J. Struct. Geol.*, *21*, 635–652.

Pirazzoli, P. A. (2005), Marine erosion features and bioconstructions as indicators of tectonic movements, with special attention to the eastern Mediterranean area, in *Sea Level Changes in Eastern Mediterranean During Holocene*, *Z. Geomorphol.*, vol. 137, edited by E. Fouache and K. Pavlopoulos, pp. 71–77, Gebrüder Borntraeger, Berlin.

Pirazzoli, P. A., S. C. Stiros, M. Arnold, J. Laborel, F. Laborel-Deguen, and S. Papageorgiou (1994), Episodic uplift deduced from Holocene shorelines in the Perachora peninsula, Corinth area, Greece, *Tectonophysics*, *229*, 201–209.

Stiros, S. C. (1995), Paleogeographic reconstruction of the Heraion-Vouliagmeni Lake coast since Early Helladic times, *Annu. Br. Sch. Athens*, *90*, 17–21.

Stuiver, M., P. J. Reimer, E. Bard, J. W. Beck, G. S. Burr, K. A. Hughen, B. Kromer, G. McCormac, J. Van Der Plicht, and M. Spurk (1998), INTCAL98 radiocarbon age calibration, 24,000–0 cal BP, *Radiocarbon*, *40*, 1041–1083.

Vita-Finzi, C. (1993), Tectonics and convergent margins: Evaluating late Quaternary uplift in Greece and Cyprus, *Geol. Soc. London Spec. Publ.*, *76*, 417–424.

Vita-Finzi, C., and G. C. P. King (1985), The seismicity, geomorphology and structural evolution of the Corinth area of Greece, *Philos. Trans. R. Soc. London, Ser. A*, *314*, 379–407.

J. Andrews, M. Leeder, P. Rowe, and J. Turner, School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, U. K. (jenni.turner@uea.ac.uk)