Archaeological Evidence for Eustatic Sea Level Change and Earth Movements in South West Turkey

Article · December 1976

DOI: 10.1016/B978-0-12-221950-4.50027-8

Nicholas Flemming
National Oceanography Centre, Southampton

Underwater Research

edited by

E. A. DREW *Gatty Marine Laboratory, St. Andrews, Scotland*
J. N. LYTHGOE *MRC Vision Unit, University of Sussex, Falmer*
J. D. WOODS *Meteorological Office, Bracknell, Berkshire*

1976

Academic Press
London New York San Francisco
A Subsidiary of Harcourt Brace Jovanovich Publishers

Archaeological Evidence for Eustatic Sea Level Change and Earth Movements in South West Turkey

N. C. FLEMMING
and
N. M. G. CZARTORYSKA

National Institute of Oceanography, Wormley, Surrey

1. Introduction

Allan (1966) uses bathymetric and gravimetric data to show that the arc of islands from the Peloponnese through Crete and Rhodes to South West Turkey is similar in many ways to a classical island arc feature, and stresses the importance of this arc as the southern boundary of the Aegean basin. McKenzie (1970) interprets the structure of the Aegean in terms of plate tectonics and indicates that the Cretan arc represents a plate boundary. The boundary is proposed as undergoing right shear movement and compression. Flemming (1968a, b) reported a broad tectonic doming of the Peloponnese associated with an actively folding anticlynal ridge trending south from the Elos peninsula towards Crete. The present work is concerned with a similar investigation of the eastern end of the island arc, with the purpose of revealing earth movements on the Turkish coast, and thus giving a more complete understanding of the plate boundary.

Negris (1904) and Haffemann (1960) conducted surveys of the coastal ruins of the Aegean in order to detect relative changes of land and sea level. Negris (1904) attributed the observed vertical movements entirely to tectonic factors, while Haffemann (1960) attributed them to eustatic change. Before commencing field work in this area we also had the benefit of studying the field notebooks of D. Blackman, University of Bristol Department of Classics, who had located a number of coastal ruins in the area.

2. Field Methods and Data

The sites investigated are shown in Fig. 1 and a typical ruin is shown in Fig. 2. The methods used to identify ruins, estimate dates, and derive relative local changes of level are described in Flemming (1969, pp. 6–13). Literary data on sites was gained from the Admiralty Pilot,

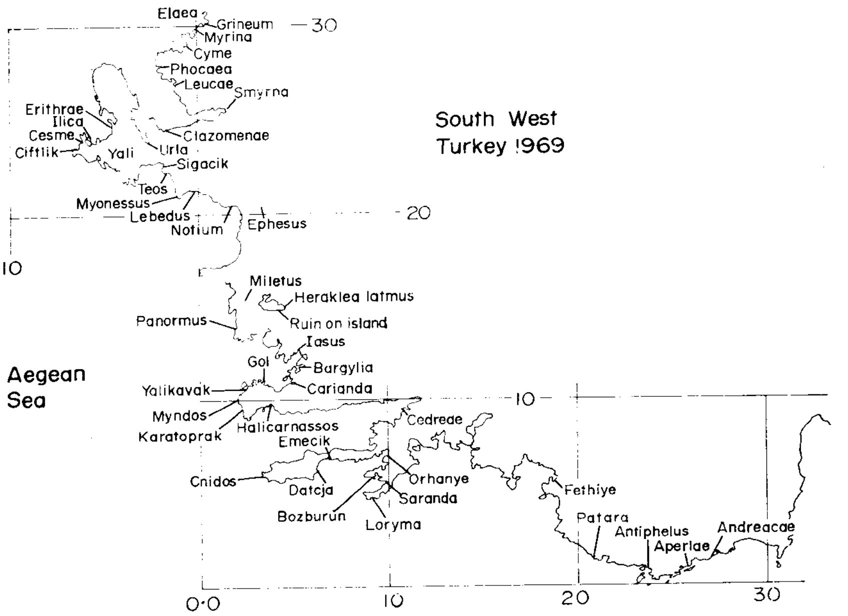

FIG. 1. Archaeological sites investigated for signs of change of relative sea level.

Admiralty charts, Bean and Cook (1957), Stark (1956), Bean (1966), and from archaeological reports on individual sites. The reliability of an estimate of change of level varies considerably from site to site, depending on the nature of the remains and their degree of preservation. It was considered undesirable to use a simple weighting procedure as this would inevitably be subjective, and might lead to reinforcement of preconceived hypotheses.

Each site was therefore allocated a uniform weight of 10 units, and in the event of a highly probable accurate estimate of displacement all points would be allotted to this estimate. For less reliable estimates, weighting points were loaded in successive 25 cm bands above and below the best estimate of displacement so as to generate a probability histogram for vertical displacement of a single site. Such a histogram is shown for site 23 in Fig. 3. In the majority of cases a total of 10 units was allocated, but in three cases where the overall reliability was low, the overall weighting was reduced.

The histograms are not in general symmetrical. In some cases ruins originally constructed on land are found underwater indicating a minimum necessary relative change of level, but in the absence of

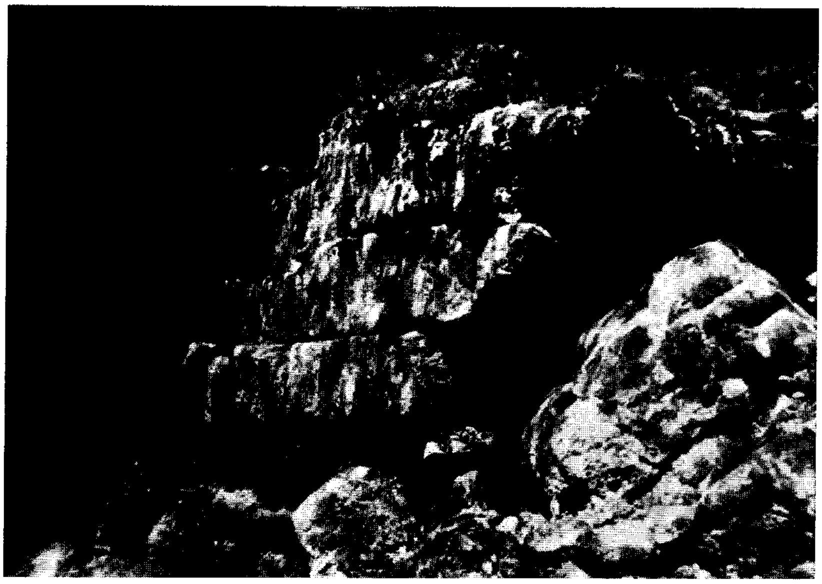

FIG. 2. Submerged Roman harbour fortification at the entrance to the harbour of Myndos.

other evidence the change might have been considerably larger. Alternatively, ruins such as a fish tank, water channel, or breakwater, may dictate a maximum possible relative change of level, but set no minimum. Thus histograms of estimates and their probabilities may be highly skew. In other cases a low probability may be allocated equally to a wide range of values.

The area was divided into a 2 cm rectangular grid superimposed on a 1:500 000 mercator projection, and the position of sites recorded in terms of X and Y coordinates with reference to an arbitrary datum zero. Age of sites was estimated from the literature, supported or modified by field observations. Estimates are expressed in thousands of years to the nearest hundred years, but in many cases an uncertainty of dating of the order of 300 years must be accepted. This is due to uncertainty as to date of foundation, date of last occupation, and submergence of the smaller sites. Sites with ruins of many ages produce two or more estimates of displacement and date.

The data are summarized in Table 1. The weighting values and total weights are shown in the right hand columns. The weighting numbers listed for each site show the weight allocated to each 25 cm band on either side of the best estimate. All positive values indicate submergence of the land relative to the sea, or a relative rise in sea level,

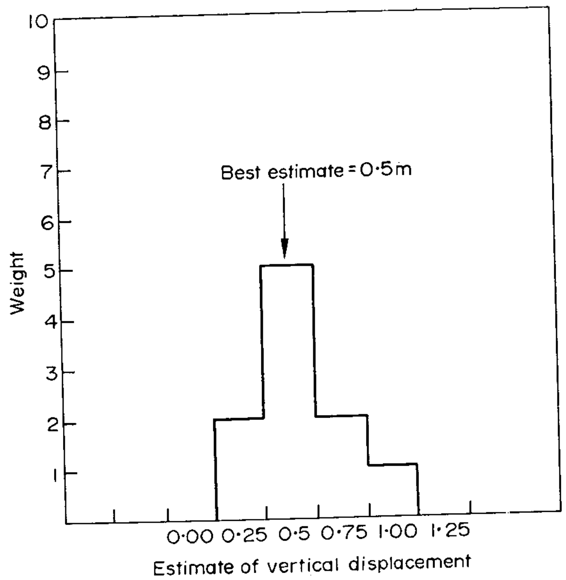

FIG. 3. Diagram illustrating the allocation of probability weighting to different estimates of the relative change of level at site 23, Karatoprak.

thus negative divergence from the best estimate indicates less submergence, and positive divergence indicates more submergence.

3. Analysis

Figure 4 shows the best estimates of displacement for each site plotted against age of site, together with the best fit least squares third degree curve. The mean displacement of sites and the variation in displacement both increase with age. This is compatible with earth movements of randomly varying rate combined with some eustatic change of sea level, but presentation of the data in this form provides no means of separating the factors.

The magnitude of displacement and the mean rate of displacement were then correlated with coordinate positions, taking into account weighting. The best fit was obtained with a fourth degree surface in terms of rate of displacement, indicating that earth movements are either continuous and gradual, or, if discontinuous, of short periodicity compared with the time span of the observations, that is about 2000 years. This analysis indicates a strong correlation with geographical location, but does not exclude the possibility of a small eustatic change. further statistical analysis designed to separate the eustatic and tectonic factors and quantify them will be published elsewhere.

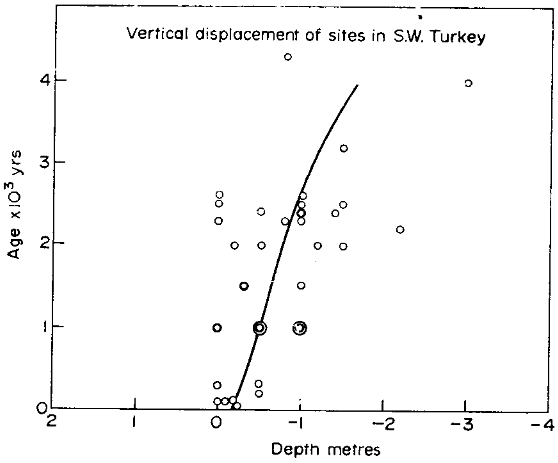

FIG. 4. Plot of the vertical displacement of sites against the age of the sites. The best fit third degree curve indicates the mean displacement increasing with age; this could be accounted for either by eustatic change or by net submergence of the coast over the whole area. The wide variation in rate of displacement of sites indicates that earth movements are of general occurrence.

This preliminary analysis indicates that the dominant features of earth movement are a general seaward depression combined with active anticlynal fold patterns leading west by the Cesme peninsula and South West across the Cnidian peninsula towards Rhodes (see Fig. 5). A surprising feature is the apparent increasing depression landwards, suggesting that the present coast is a fold axis, but this may be a spurious effect resulting from the surface-fitting programme having no control points of data inland.

4. Discussion

The bathymetric map produced by Giermann (1960) shows the continuous nature of the island arc from Greece to Turkey, with a

Table 1. Age, position, and estimate of vertical displacement for sites in the area shown in Fig. 1. Names followed by Roman numerals indicate estimates based on ruins of different ages at the same site. The weighting numbers in each case define a probability histogram of the type shown in Fig. 3.

Name	Age $\times 10^3$ yrs	Coordinates X	Coordinates Y	Best Estimate E	Depth in Metres: Weighting in 25 cm intervals −75	−50	−25	E	+25	+50	+75	Total Weight
Antiphellus I	2.2	23.60	0.85	2.2	—	—	—	8	1	1	—	10
Antiphellus II	1.0	23.60	0.85	1.0	—	—	1	7	1	1	—	10
Andriake	1.0	27.50	1.60	1.0	—	1	2	4	2	1	—	10
Bargylia	2.0	5.10	11.60	0.2	—	—	1	7	2	—	—	10
Bozburun	1.0	9.20	5.80	1.0	—	3	3	4	—	—	—	10
Caryanda I	0.3	5.05	10.90	0.0	—	—	—	8	2	—	—	10
Caryanda II	1.5	5.05	10.90	0.3	—	—	—	7	3	—	—	10
Cedreae	1.5	10.70	9.45	0.3	—	—	3	6	1	—	—	10
Cesme	0.1	−6.10	23.85	0.2	—	—	—	5	—	—	—	5
Ciftlik	0.1	−6.30	23.55	0.1	—	—	—	5	5	—	—	10
Clazomenae	2.3	−1.85	24.50	1.0	—	1	1	4	2	2	—	10
Cnidos	2.3	3.25	5.90	0.0	—	1	1	7	1	—	—	10
Cyme	2.4	−0.45	28.85	1.0	—	1	2	4	2	1	—	10
Datcja	2.5	6.15	6.20	0.0	—	—	1	8	1	—	—	10
Elaea	2.3	0.50	30.85	0.0	—	—	3	3	2	—	—	8
Erithrae I	0.05	−4.55	24.65	0.25	—	—	5	5	—	—	—	10

Erithrae II	0.2	−4.55	24.65	0.5	—	—	5	5	—	—	—	10
Erithrae III	2.4	−4.55	24.65	1.40	—	1	2	6	1	—	—	10
Halicarnassos	2.4	3.75	9.75	1.0	—	—	1	6	2	1	—	10
Heraklea Latmus	2.5	4.55	14.95	1.5	—	1	1	1	1	1	—	5
Iasus I	1.0	5.25	12.35	0.0	—	—	—	7	3	—	—	10
Iasus II	2.0	5.25	12.35	0.5	—	1	3	6	—	—	—	10
Ilica	2.4	−6.70	23.9	0.5	—	2	2	2	2	2	—	10
Karatoprak	1.0	2.25	9.40	0.5	—	—	2	5	2	1	—	10
Loryma	1.5	9.05	4.65	1.0	—	1	3	6	—	—	—	10
Miletus I	2.0	2.45	15.30	1.5	—	2	3	5	—	—	—	10
Miletus II	3.2	2.45	15.30	1.50	—	—	2	5	2	1	—	10
Myndos	2.0	2.05	10.0	1.2	—	—	1	8	1	—	—	10
Myonessus	2.6	−1.15	20.85	1.0	—	1	2	4	2	1	—	10
Orhaniye	1.0	10.05	6.80	0.0	—	—	—	5	5	—	—	10
Panormus	2.6	1.95	13.90	0.0	—	1	2	4	2	1	—	10
Saranda	1.0	9.60	5.70	0.5	—	—	5	5	—	—	—	10
Sigacik I	2.3	−1.85	22.50	0.8	—	1	2	7	—	—	—	10
Sigacik II	0.1	−1.85	22.50	0.0	—	—	—	5	5	—	—	10
Smyrna I	2.5	1.50	25.65	1.0	—	—	—	6	3	1	—	10
Old Smyrna	4.0	1.50	25.65	3.0	2	2	3	3	—	—	—	10
Teos	4.3	−1.75	22.30	0.8	—	—	2	7	1	—	—	10
Urla Beach	0.3	−2.65	23.9	0.5	—	1	3	6	—	—	—	10
Yali	1.0	−4.95	24.10	0.5	—	—	—	6	3	1	—	10

succession of sills at depths of the order of 500 m separating depths to north and south of the order of 2000 m. Allan (1966) and McKenzie (1970) show that the seismicity associated with this ridge is distributed so as to leave an aseismic zone or plate in the southern Aegean. Although lateral movements have been postulated by McKenzie (1970), no assessment has been made of the vertical movements to be expected at the plate boundary.

The structural geology of the highly indented coast of Turkey is not

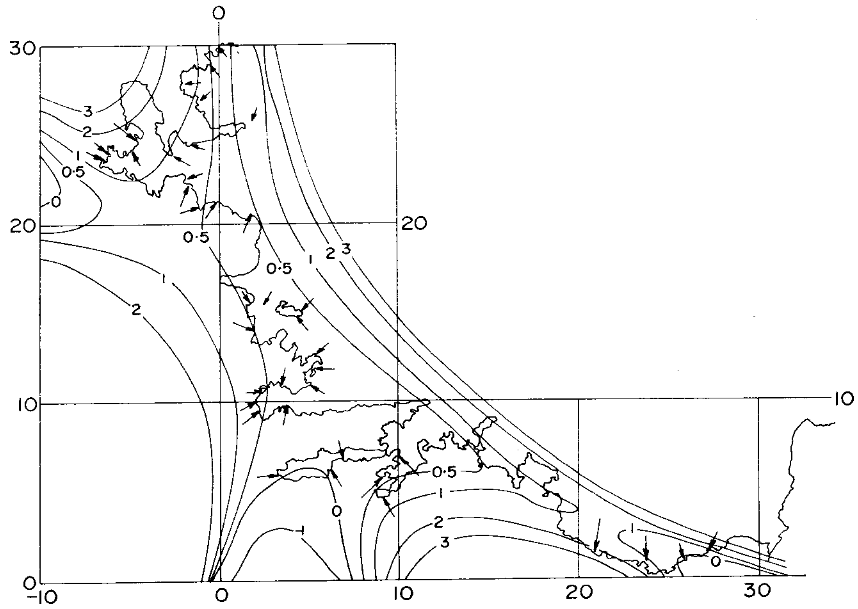

FIG. 5. Contour diagram relating rate of displacement of sites to geographical location. The figures represent relative submergence in metres per millenium. The arrows mark sites from which data were obtained; the names of the sites are given in Fig. 1.

known in detail, but there are a very large number of visible recently active faults. Thus the present contours of mean rate of earth movement can only be taken as very much smoothed averages both in time and place, indicating broad regional trends. Nevertheless, it is significant that the most marked feature of the contour pattern is the anticlynal fold trending west of south, directly on the axis of Rhodes, Karpathos, and Crete. This is compatible with the concept of an actively folding ridge along the axis of the island arc. The anticlynal pattern near the Cesme peninsula is less expected, but may be associated with the shallow plateau bordering Chios, and the sill at the southern margin of the northern basin of the Aegean, where there is a marked change in topography and relief.

The landward depression indicated by the present study may, as already noted, be a mathematical fiction. However, Ambraseys (1970) states that the main earthquake zone in historical times in this area was back from the coast in an arc from Izmir to Antalya, while McKenzie (1970) suggests that the eastern plate boundary of the Aegean is also set well back from the coast, though on a more north-south line. These two observations suggest that the coastal block between Izmir and Antalya is in a very unstable position, and it is just possible that the landward depression is genuine. This proposal is supported by the observations of Wendel (1968) who suggests that the extreme volumes of sediment accumulated in the estuary of the Meander and other rivers can only be explained if there has been ponding due to a landward tilting of the coast.

References

Allan, T. D. (1966). Recent geophysical studies in the Aegean and Eastern Mediterranean by the R/V Aragonese, *NATO Subcommittee on Oceanographic Research, Technical Report* **18**, p. 19–26.

Ambraseys, N. N. (1970). Some characteristic features of the Anatolean fault zone, *Tectonophysics* **9**, 143–165.

Bean, G. E. (1966). *Aegean Turkey*, 288 pp. Ernest Benn, London.

Bean, G. E. and Cook, J. M. (1957). The Carian Coast, *Annual of the British School at Athens* **52**.

Flemming, N. C. (1968a). Archaeological evidence for sea level changes in the Mediterranean, *Underwater Association Report*, 9–12.

Flemming, N. C. (1968b). Holocene earth movements and eustatic sea level changes in the Peloponnese, *Nature, Lond.* **217**, 1031–2.

Flemming, N. C. (1969). Archaeological evidence for eustatic change of sea level and earth movements in the western Mediterranean during the last 2000 years: Geological Society of America, Special Paper 109, 125 pp.

Giermann, G. (1960). Bathymetric chart of the Aegean, *Musée Oceanographique de Monaco.*

Haffemann, D. (1960). Ansteig des Meerespiegels in Gesichtlicher Zeit, *Die Umschau* **60**, n. 7, 193–196.

McKenzie, D. P. (1970). Plate Tectonics of the Mediterranean Region, *Nature* **226**, 239–243.

Negris, P. (1904). Vestiges antiques submergés, *Athenischer Mitteilungen* **29**, 340–363.

Stark, F. (1956). *The Lycian Shore.* John Murray, London.

Wendel, C. A. (1968). Tilting or silting? Which ruined ancient Aegean Harbours? *Archaeology* **22**, 322–4.