Climatic Change and the Mediterranean

Environmental and Societal Impacts of Climatic Change and sea-level Rise in the Mediterranean Region

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Predictions of Relative Coastal Sea-Level Change in the Mediterranean Based on Archaeological, Historical and Tide-Gauge Data

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ABSTRACT

Prediction of relative sea-level change on the Mediterranean coast over the next 50–100 years requires an estimate of the global change of absolute sea level which may be caused by climate change, and the local vertical displacement of the level of the land at each point on the coast relative to absolute co-ordinates. Vertical land movements, which must be added to eustatic sea-level changes, can be defined by archaeological data (100 to 2000 years ago), and tide-gauge data (10 to 100 years ago); 335 coastal archaeological sites have been identified, but only 32 tide-gauge records are available. The tide gauge data are more accurate, and refer to the appropriate time-scale for extrapolation into the future. Data on earth movements at discrete points can be interpolated laterally for only a few tens of kilometres between data sites, and thus the widely spaced tide-gauge sites can only be used to indicate expected earth movements in limited regions along a coast of 45,000 km in length. By comparing tide-gauge and archaeological data from those sites where both are available, a correction rule is derived to compensate for the aliasing which occurs when noisy data are sampled over different time periods. As a result it is possible to suggest statistically probable estimates for the rate of vertical movement to be expected in the next 50–100 years for most sectors of the Mediterranean coast.

Field data from archaeological sites suggest that many sites are experiencing rapid erosion. Submerged ruins represent a unique record of ancient maritime technology and are being destroyed by wave action and human activities, with marked collapse and scattering of structures observable over 1–10 years. Assuming that most sites cannot be protected, they should at least be surveyed and photographed accurately as soon as possible. Older sites from the Neolithic and Palaeolithic are usually in deeper water, 8–30 m, and so are more protected from wave action.

1 INTRODUCTION

The tidal amplitude throughout most of the Mediterranean is of the order of 20–30 cm, with the exception of the immediate region of Gibraltar, where it is approximately 1 m. Wind forcing and variations in barometric pressure cause fluctuations in the level of the order of 30 cm over periods of several days and 10–12 cm in monthly mean sea-level during the year (Striem, 1974;

Rickards, 1985). Structures built close to the water, such as jetties, landing docks, boat slipways, etc., are naturally designed to resist the local wave conditions, but are not designed to resist an extreme sea-level change of more than 50 cm; in practice the expected annual range of extremes is of the order of 30–40 cm, being the sum of the seasonal and multi-day cycles. Similarly, natural coastal processes, the formation of stable beach gradients, marshes and wetlands, deltaic alluviation, etc., are adjusted to a near constant sea-level which fluctuates by only 30–50 cm.

Anthropogenic climate change caused by the release of so-called greenhouse gases at present is predicted to cause a global rise in sea-level of the order of 20 cm by 2030 and 44 cm by 2070 (Warwick and Oerlmans, 1990, p. 277); or 2–4 cm/decade (Houghton *et al.*, 1992), from thermal expansion of the ocean alone. Even at the lower estimate, such a change would bring wave action consistently into contact with structures or natural shoreline features that never previously had been exposed to wave forces. The upper estimate would cause massive inundation of low-lying structures and coastal landforms in many parts of the Mediterranean. However, no general prediction can be made for the Mediterranean coast because local vertical earth movements are of approximately the same magnitude, 10–50 cm/century (Pirazzoli, 1976a, 1976b; Flemming, 1978; Flemming *et al.*, 1978; Flemming and Webb, 1986; Flemming and Woodworth, 1988). Tectonic earth movements may be vertically up or down, and thus in some places the relative rise of sea-level over the next 100 years may be as much as twice the absolute rise of sea-level, whereas in others the local relative sea-level may even drop. From the point of view of planning defensive action, it is important to know the likely areas of maximum and minimum relative rises of sea-level.

2 METHOD

The Mediterranean lies across a major global plate tectonic boundary (Le Pichon and Angelier, 1981; Dewey *et al.*, 1973; McKenzie, 1972, 1978), and many parts of the coast are subject to regular earthquake activity. Volcanism is also active in south-west Italy, the Lipari Islands, Sicily and the central Aegean. These processes cause sections of the coast to be displaced vertically at varying rates (Schmiedt, 1972; Flemming, 1969, 1972, 1978; Pirazzoli, 1976a, b, 1987b; Vita-Finzi and King, 1985; Flemming and Webb, 1986; Flemming and Woodworth, 1988). Although parts of the Pacific rim (Indonesia, Japan and Alaska) have higher rates of movement, it is reasonable to say that the Mediterranean coast is amongst the most active in the world.

In addition to the up-and-down displacements due to tectonism and volcanism, the coast is liable to downwards movement due to the accumulation of alluvium in coastal plains and on deltas. The net subsidence may be caused both by the isostatic response to the weight of the alluvium and by compaction within the sediment column. Several areas of such subsidence have been documented both by identification of archaeological remains and through coring (Venice, Pirazzoli, 1987a; Messenia, Kraft *et al.*, 1975; Kraft and Aschenbrenner, 1977; Larnaca, Gifford, 1978).

In the most active regions of the Mediterranean sites separated by only 10–20 km can show different directions and rates of vertical movement. In the western Mediterranean, the variability is less pronounced. Nevertheless, the mechanisms being proposed for the tectonic movements in the crust suggest that spatial variability on the scale of 10–20 km would be expected. A description of the vertical movements to be expected in the future on the coast of the Mediterranean therefore would ideally be based on a data set which provided reliable data at 10–20 km intervals along the whole coast length of 45,000 km.

Such a data set is plainly unobtainable. Possible sources of data include tide gauges, erosional and solution formations, biological formations such as vermetid terraces or lithodomus borings, sedimentary accumulations with layers containing organic carbon which can be dated by radiocarbon methods, and archaeological structures on the coast (Van de Plaasche, 1986).

All the above types of data can be obtained for the last 2000 years in some parts of the Mediterranean coast, but the most widely spread data type is the archaeological, which provides sea-level estimates at 335 locations (Flemming and Webb, 1986). Other data sources could be integrated with the archaeological data over the same time-scale of 100–2000 years, but the present author does not have experience of the errors and corrections that would need to be applied to create a homogeneous data set. For the moment it seems better to rely on the internally consistent archaeological data for the time-span longer than that of tide gauges.

For periods of a few decades, tide gauges are extremely accurate, provided that the calibration and reference datum of the instrument is properly maintained. Standards for this procedure are maintained by the Permanent Service for Mean Sea Level (PSMSL), and the data referred to in this study have been obtained by various authors from the PSMSL. Pirazzoli (1987b) studied 22 tide-gauge records within the MAP area of which 16 provide reliable records; Flemming and Woodworth (1988) studied 16 sites in Greece. Emery and Aubrey (1985, p. 250) deduce rates of earth movement for northern and north-west Europe adjacent to the present study area.

Tide-gauge accuracy is of the order of millimetres (Rossiter, 1967; Pugh, 1987; Emery *et al.*, 1988; and others). The principal source of errors arises from undocumented changes in datum, or corrections or adjustments to the instrument calibration. Additionally, data may be "corrected" by authors before they are published to allow for presumed local earth movements. If this has occurred it is pointless to try to detect earth movements by studying the difference between adjacent tide gauges, which is the principal method. Various methods have been used to separate global or regional sea-level change from earth movements on the basis of statistical treatment of large numbers of tide-gauge records (Graaf, 1980; Gornitz *et al.*, 1982; Emery and Aubrey, 1985; Pirazzoli, 1987b; Emery *et al.*, 1988; Douglas, 1991), including regression analysis and eigen analysis. It is not the purpose of this chapter to discuss the virtues of the different methods. Suffice it to say that there is no reservation about the capability of modern well-maintained tide gauges to produce excellent records: the problem is simply that there are not sufficient instruments in the Mediterranean to give an accurate picture of the tectonic variability of the complex coastline. Furthermore, in the absence of existing records of a decade or more at a desired location, an instrument installed now will only provide a suitable time series in 10–20 years time. Several hundred tide gauges would be needed to show the true land movement at a sufficient number of sites.

2.1 Archaeological Methods

2.1.1 *Site selection*

The deduction of relative land/sea-level changes at a number of archaeological sites was attempted by several 18th and 19th century authors (cited by Flemming, 1969). Gnirs (1908) was the first author to attempt a complete synthesis for the whole Mediterranean, using field data from eight sites, referenced data on a further 34 sites, and very rough generalizations for another 25 sites based only on inspection of charts. Observations and deductions were based on the assumption of no earth movements. Very little attempt was made to estimate errors, and the probable errors at the sites where data were observed were of the order of 0.5–1.0 m or more. There was a strong tendency to force data into the simple model of constant rate of eustatic change. Data were concentrated in the Adriatic and Aegean.

A problem with early works is that the authors searched for "submerged ruins", and found them. It is a simple matter to list over 100 sites in the Mediterranean where masonry can be found to a depth of 1.0 m or more. The masonry may be part of a harbour wall built at that depth, but before the invention of inexpensive diving equipment, that was difficult to ascertain. On the principle of "no smoke without a fire", authors naturally assumed that the only question at stake was the measurement of the size of the sea-level change since Roman times, which was assumed to be at least 2 m. Hafemann (1960) lists well-known submerged sites and makes calculations accordingly.

Lehman-Hartleben (1923) provided an inventory of 303 sites in the Mediterranean, with descriptions of harbours derived from classical literature and archaeological sources. There was no estimate of sea-level change, but some useful site maps. In some studies the authors have tried to separate stable and unstable coastal areas, and use the "stable" areas to measure eustatic sea-level change. Schmiedt (1972), in a series of brilliant observations on fish tanks on the west Italian coast, deliberately avoided the areas around Naples and Mount Etna. And yet most of the Italian coast is liable to some seismic activity, and it is arbitrary as to what level of low seismicity can be classified as stable.

The present study is designed to measure earth movements, and therefore all possible sites with good data are included. The data set includes all valid sites, whether the data show relative submergence, constant relative sea-level or relative uplift. When this method is used (Flemming, 1968, 1969, 1972, 1978; Flemming *et al.*, 1973, 1978) it is apparent that a large number of sites are relatively stable or uplifted, and that the samples used in the papers prior to 1969 were biased towards selection of submerged sites.

Pre-1969 studies attempted to measure the sea-level at 2000 BP, an objective also assumed by Flemming (1969). This results in a partial data set, since many sites provide data for the Mediaeval, Norman, Arab, Byzantine, Minoan and other periods, but not the classical Roman. Given the limitations of computer statistics, earlier workers did not attempt to analyse the general problem, assuming random earth movements and eustatic sea-level change, utilizing a data set dispersed in space and time. However, by the early 1970s suitable statistical packages were available, and this generalized method has been used by the author since 1972 (Flemming, 1972).

To construct the MEDSITE database all known sites were identified from the multi-site sources already quoted, together with reports and data on single sites from the archaeological literature and atlases (Frost, 1972; Le Gall, 1981; Negris, 1904; Raban, 1981, 1983; Vrsalovic, 1974; Yorke and Dallas, 1968; Yorke and Davidson, 1969; and York *et al.*, 1973). So far as possible all sites were labelled with an ancient name and a modern name, and recorded with their latitude and longitude. A mid–19th century folio of Admiralty Mediterranean charts was used to locate many of the ruins that have not been visited, since early chart-surveyors were well-versed in classical geography and noted the existence of ruins with accuracy and detail. Of the sites listed by Lehman-Hartleben (1923) 18 named sites could not be located on any chart, and there has not been time to check the early German archaeological references which would be needed to locate the sites. Some discrepancy may be due to variations in spelling.

Of the 1053 sites, sea-level estimates and age were derived at 335 (Table 8.1). The sites for which data were not obtained constitute an unexploited reservoir of data that could be utilized to extend or improve the present study.

Large-scale site maps exist for most sites with data, and most sites are documented with land and underwater photographs. These files can be accessed separately from the MEDSITE database.

2.1.2 Observational methods

Field observations use echo sounding, snorkel diving, scuba diving, wading, aerial photography, underwater photography, and a wide range of simple and sophisticated survey methods depending upon time and budget. Methods and accuracy are discussed fully by Flemming (1969, 1978, 1979), Blackman (1973, 1982), Schmiedt (1972) and Guery *et al.* (1981). During the preparation of Flemming (1969) it became clear that certain ancient structures, such as ship slipways, mooring bollards and mooring rings, fish cultivation tanks, salt pans, docks, quays, sluice gates, etc., could provide a link to the sea-level at the time of construction with greater accuracy than previously obtained.

Data for over 270 of the present sites with conclusive data are based on field surveys by the author. For the majority of the other sites employed in the calculations, the present paper uses the same estimate of relative sea-level changes as cited by the original authors. However, the data of other published authors have been used as data only, and the conclusions with regard to eustatic or tectonic change may be different in the present paper. Additionally, the present data base contains estimates of the accuracy of

Table 8.1 Distribution of valid and invalid data records by region

Region number	Name	SIT	DTA	NON	A/S %	DDD	MLT	ONE	X km	Y km	AREA km²	CST km	DSP km	SSP km
1	Spain	64	24	40	38	24	2	2	1780	280	498400	2200	92	34
2	Balearics	5	2	2	40	4	2	0	310	130	40300	6500	325	130
3	Morocco	52	24	28	46	26	2	2	1600	280	448000	2200	92	42
4	Sardinia	16	3	13	19	3	9	9	180	599	90000	1400	467	88
5	W. Italy	102	42	60	41	45	4	0	1100	270	297000	1800	43	18
6	Adriatic	71	3	68	4	6	2	0	890	330	293700	3100	1033	44
7	Sicily	43	9	34	21	9	0	0	470	610	286700	900	100	21
8	Sirte	13	5	8	38	5	0	0	980	260	254800	1550	310	119
9	W. Greece	38	1	37	3	1	0	0	360	190	68400	600	600	16
10	Peloponnese	71	30	41	42	32	2	0	240	300	72000	1000	33	14
11	Crete	72	43	29	60	47	3	0	330	130	42900	650	15	9
12	N. Aegean	185	5	180	3	8	1	0	680	420	285600	–	–	–
13	S. Aegean	36	5	31	14	6	1	3	410	240	98400	–	–	–
14	S.W. Turkey	66	36	30	55	47	9	0	380	310	117800	–	–	–
15	Rhodes	25	17	8	68	20	3	0	200	80	16000	300	18	12
16	Cyrenaica	36	4	32	11	5	1	0	830	120	99600	950	238	26
17	E. Turkey	32	23	9	72	23	0	0	530	130	68900	700	30	22
18	Cyprus	36	17	19	47	20	4	0	250	170	42500	700	41	19
19	Egypt	4	0	4	0	0	0	0	450	110	49500	500	0	125
20	Syria/Israel	83	42	41	51	75	20	6	710	110	78100	650	15	8
21	Islands	3	0	3	0	0	0	0	–	–	–	–	–	–
					(mn)						(mn)	(mn)	(mn)	(mn)
Total/means (mn)		1053	335	718	32	406	56	13			162430	993	164	36

Notes: Codes as follows: SIT = number of sites; DTA = number of sites with valid data; NON = sites with no data; A/S = percentage of sites with data; DDD = number of valid data records; MLT = number of sites with more than one valid period; ONE = sites with one-sided records; X and Y = dimension of the region in km; AREA = area of region km²; CST = length of coastline in km; DSP = mean spacing between sites with valid data; SSP = mean spacing of all sites (note that regions 12, 13 and 14 have such complex coastlines that the length cannot be measured accurately); mn = mean value.

data, defined by a probable error bar. The error bar has been defined on the basis of the type of sea-level indicators used, and the inherent limits on accuracy described in the next section.

In the Bronze Age, (5000–3000 BP), and later archaeological periods, specialized structures were built in relation to the contemporary sea-levels. In earlier periods there do not appear to be identifiable water-line structures, although Aghios Petros (site number 964 in Table 8.2 and MEDSITE database) is a neolithic village facing directly onto a small estuary which was probably a harbour, and the data from the submerged site at Franchthi Cave (965) also suggest a waterside dwelling area. In general, data earlier than 5000 BP only indicate that an occupation site was dry land at a given date, but the sea-level may have been several metres lower, unless geomorphological evidence can be found for linking shoreline features and human artifacts into a contemporaneous assemblage. Sites that can be dated by artifacts, but can only be proven to be above sea-level, are termed "one-sided" in the present study. In statistical studies the "one-sided" data points sometimes were included and sometimes excluded in order to test different hypotheses. There are 14 one-sided sites, all older than 5000 BP.

The method of observing solution notches and comparing the present notch with higher or lower notches, has been used by many authors (e.g. Spratt, 1865; Günther, 1903a, 1903b; Hafemann, 1965; Pirazzoli *et al.*, 1981; Flemming *et al.*, 1973). In the open sea a solution notch is often 0.5–1.0 m in height, and the mean sea-level point can only be determined to an accuracy of about 0.2–0.3 m. Even in sheltered bays, the error is of the order of 0.2 m. Notches occasionally cut across structures, as at the Roman quays in Marseille (32), the harbour entrance at Phalasarna (365), or the Casa degli Spiriti at Posilipo (75). Because of wave exposure and unevenness of the substrate, the width of the notch is such as to leave uncertainty of exact mean sea-level of the order of 0.2 m (Guery *et al.*, 1981).

A rock-cut storage tank or fish tank can act as a stilling pool, with the long entrance channel acting as a filter to remove wave action. This occurs at Dor (199), Lambousa (382), and Caesarea, Israel (203/1051) where the tanks are not submerged below the level of the outer walls. In these circumstances the calm water surface, combined with the tidal range of 20–30 cm, results in a double-solution notch, with a small indentation at mean high tide, and a second at mean low tide. The W-shaped indentation has a profile that can be matched very precisely as between ancient and modern notch system, with an accuracy of 0.1 m. Since the notch system records mean sea-level averaged over several decades, this observation requires no correction for seasonal or barometric factors, provided that there is a similar double notch at present sea-level.

2.1.3 *Limits to accuracy*

Once the accuracy of individual observation approaches 0.3–0.2 m further limitations occur. Assuming that the tidal cycle is known, the relative change of level can be corrected, but often the state of the tide is not known in relation to the time and date of observation. The Mediterranean tides are of the order of 0.2–0.5 m, and so are not regarded as important for shipping and navigation. The only reliable way to obtain tidal data is

Table 8.2 List of sites used to compute earth movements and sea-level changes. The sites are those with valid data analysed by Flemming and Webb (1986)

1[a]	2[b]	3[c]	4[d]	5[e]
1	Belo	1	2.00	0.00
3	Carteia	1	2.00	0.00
13	Hemeroskopeion	1	2.50	0.00
17	Tarraco	1	2.00	0.00
21	Emporiae	1	2.00	1.00
25	Leuxos	1	7.00	−10.00
26	Narbo	1	2.00	0.00
29	Artemis	1	2.50	−1.00
30	Arelate	1	2.00	−1.00
31	Fossae Marinae	1	1.80	−4.00
32	Massilia	1	1.80	−0.40
37	Olbia	1	2.40	0.00
38	Forum Iulii	1	2.00	0.00
39	Insula Lero	1	2.00	−0.50
40	Antipolis	1	2.00	0.00
43	Albintimilium	1	2.00	0.00
49	Luna	1	2.10	−1.00
51	Populonia	1	2.00	−2.00
55	Cosa	1	2.20	−1.00
60	Alsium	1	2.00	0.00
62	Antium	1	1.90	−0.50
64	Astura	1	2.00	−0.60
65	Circeii	1	2.00	−1.00
66	Tarracina	1	1.80	0.00
68	Formiae	1	2.00	−0.50
71	Misenum	1	2.00	−3.20
72	Baiae	1	2.00	−5.50
72	Baiae	2	1.30	4.00
73	Puteoli	1	2.00	−4.00
73	Puteoli	2	1.30	5.80
74	Nesis	1	2.00	−4.00
75	Pausilypon	2	1.30	4.80
75	Pausilypon	1	2.00	−4.00
77	Herculaneum	1	2.00	−2.00
80	Surrentum	1	2.00	−2.00
84	Velea	1	2.50	0.00
93	Zankle	1	0.30	−0.50
96	Megara Hyblaea	1	2.30	−1.70
97	Thapsos	1	3.40	−0.90
98	Siracusa	1	2.50	0.00
104	Selinunte	1	2.50	0.00
105	Mazara	1	2.00	0.00
106	Lilybaeum	1	2.30	0.00
107	Motya	1	2.50	0.00
115	Leptis Magna	1	2.00	0.00
117	Sabrata	1	2.40	0.00
121	Thaenae	1	2.00	0.00
124	Alipota (Africa)	1	2.60	0.00
125	Thapsus	1	2.00	0.00
126	Leptis Minor	1	2.00	0.00
127	Ruspina	1	2.00	−0.30
128	Hadrumentum	1	2.00	0.00
129	Heraklea	1	2.00	−0.20
136	Carthago	1	2.30	−1.00
136	Carthago	2	2.00	−1.50
136	Carthago	3	1.30	−0.15
137	Utica	1	2.50	1.00
148	Rasguniae	1	2.00	−1.00
150	Tipasa	1	2.00	−0.50
151	Caesarea (Africa)	1	2.00	−1.00
160	Nora	1	2.40	−4.50
164	Neapolis	1	2.00	−1.00
168	Turris Libisonis	1	2.00	−1.00
174	Rosh Hanniqra	3	1.50	−0.50
175	Achzib	2	3.50	0.00
175	Achzib	4	2.00	0.00
176	Achzib, Islands	1	2.70	−0.40
176	Ros. Hanniqra Isle	1	2.50	−0.30
179	Shavei Zion (N)	1	2.00	0.00
180	Shavei Zion (S)	1	2.00	0.00
181	Yassif River	1	2.00	0.00
182	Acco	2	2.70	−0.50
182	Acco	6	0.80	−0.50
188	Tell Abu Hawam	1	3.30	0.00
190	Bat Galim	1	2.00	−0.40
191	Tell Shikmona	2	2.00	0.00
193	Atlit	1	10.00	−10.00
193	Atlit	2	6.00	−2.50
193	Atlit	3	3.80	0.00
193	Atlit	4	3.40	0.00
193	Atlit	5	2.70	0.00
193	Atlit	7	1.90	0.00
193	Atlit	8	0.80	0.00
194	Newe Yam	1	6.00	−2.00
195	Tell Nami	1	3.80	−0.50
195	Tell Nami	2	3.40	−0.50
197	Tell Nami (S)	1	0.80	−0.50
198	Dor (N)	1	2.00	0.50
199	Dor (Tantura)	1	3.20	−0.80
199	Dor	2	2.80	−0.90
199	Dor	3	2.60	−0.50
199	Dor	4	2.50	−0.40
199	Dor	5	2.40	−0.30
199	Dor	6	2.20	−0.10
199	Dor	7	1.90	0.20
199	Dor	8	1.50	0.80
199	Dor	9	1.30	0.50
199	Dor	10	0.80	−1.00
199	Dor	11	0.60	−1.00
199	Dor	12	0.20	−0.20
199	Dor	13	0.10	−0.10
200	Nahal Dalia	1	6.00	−4.00
201	Magan Mikhael	1	1.90	0.00
202	Crocodilopolis	1	2.20	−0.30
203	Caesarea (Israel)	2	2.00	−5.00
203	Caesarea (Israel)	3	0.80	−1.00
205	Mikhmoret	1	3.30	0.00
207	Apollonia (Israel)	1	1.90	0.00
207	Apollonia (Israel)	2	0.80	0.00
215	Palmachim	1	3.40	0.00
215	Palmachim	2	2.70	0.00
215	Palmachim	3	1.90	0.00
215	Palmachim	4	1.50	0.00
218	Tel Mor (Ashdod)	1	3.80	0.00

1[a]	2[b]	3[c]	4[d]	5[e]
218	Tel Mor (Ashdod)	2	3.40	0.00
220	Ashdod-Yam	1	1.40	0.00
221	Ashkelon	1	3.80	0.00
221	Ashkelon	2	0.80	0.00
223	Gaza Maiumas	1	1.50	0.00
224	Tell el Ajjul	1	3.80	0.00
225	Tell el Qatifa	2	2.80	−0.30
225	Tell el Qatifa	1	7.00	−1.00
226	Tell el Ridan	1	3.50	−0.50
229	Gytheum	1	1.50	−2.50
230	Trinasus	1	1.00	−1.00
231	Asopus	1	3.00	−3.00
231	Asopus	2	1.50	−2.00
232	Arkangelos	1	2.00	−0.20
233	Onugnathus	1	3.50	−4.00
234	Kythera	1	4.00	0.00
235	Antikythera	1	5.00	3.00
236	Boeae	1	1.50	−0.30
237	Minna	1	2.00	−1.00
238	Zarax	1	2.50	−3.00
239	Asine	1	3.00	−2.00
240	Halieis	1	2.40	−5.00
241	Lorenzon	1	1.00	−2.00
242	Epidaurus	1	2.00	−2.70
243	Cenchreae	1	2.50	−2.00
244	Lechaeum	1	2.00	−0.70
245	Phea	1	2.00	−1.00
246	Pylus Coryphasi.	1	2.00	−1.00
247	Methone	1	1.00	−1.50
248	Asine	1	0.60	−1.20
250	Cardamyle	1	1.00	−1.00
251	Leutra	1	2.00	−2.50
252	Pephnus	1	1.00	−1.00
253	Tigani	1	2.00	−0.50
254	Teuthrone	1	1.00	−1.00
255	Skoutari	1	1.50	−3.50
256	Acriae	1	3.00	−2.00
256	Elaea	1	2.30	0.00
258	Cyme	1	2.40	−1.00
259	Smyrna	1	4.00	−3.00
259	Smyrna	2	2.50	−1.00
260	Clazomenae	1	2.30	−1.00
261	Urla Beach	1	0.30	−0.50
262	Erithrae	1	2.40	−1.40
262	Erithrae	2	0.20	−0.50
262	Erithrae	3	0.10	−0.30
263	Yali	1	1.00	−0.50
264	Ilica	1	2.40	−0.50
265	Cesme	1	0.10	−0.20
266	Ciftlik	1	0.10	−0.10
267	Teos	1	2.30	−0.80
267	Teos	2	2.30	−0.80
267	Teos	3	0.10	−0.10
269	Notium (Claros)	1	2.60	−1.00
271	Miletus	1	3.20	−1.50
271	Miletus	2	2.00	−1.50
272	Heraclea Latmus	1	2.50	−1.50
273	Ghioucker I.	1	1.20	−1.50
274	Panormus	1	2.60	0.00

1[a]	2[b]	3[c]	4[d]	5[e]
275	Iasus	1	2.00	−0.50
275	Iasus	1	1.00	0.00
276	Bargylia	1	2.00	−0.50
277	Caryanda	2	0.30	0.00
277	Caryanda	1	1.50	−0.30
279	Myndus	1	2.00	−1.20
280	Karatoprak	1	1.00	−0.50
281	Halicarnassus	1	2.40	−1.00
282	Cedreae	1	1.50	−0.30
283	Cnidus	1	2.30	0.00
284	(Old Cnidus)	1	2.50	0.00
285	Orhaniye	1	1.00	−1.00
286	Bozburun	1	1.00	−1.00
287	Loryma	1	1.50	−1.00
288	Saranda	1	1.00	−0.50
289	Telmessus	1	1.50	−1.20
291	Antiphellus	1	2.20	−2.20
291	Antiphellus	2	1.00	−1.00
292	Myra	1	1.00	−1.00
293	Chersonissos	1	1.90	−1.00
294	Malia	1	3.60	−1.00
295	Spinalonga	1	2.00	−1.00
296	Port Kolokithia	1	1.00	−1.00
297	Olous	1	2.00	−1.90
298	Minoa	1	2.20	−1.50
300	Psira	1	1.90	−0.75
301	Gemili	1	1.40	−2.00
302	Simena	1	2.50	−2.20
302	Simena	2	1.50	−1.20
303	Phaselis	1	2.50	−0.20
304	Lara	1	1.70	0.00
305	Side	1	2.20	0.00
306	Kara Burun	1	2.00	0.00
308	Coracesium	1	0.70	0.00
310	Syedra	1	1.50	0.00
311	Sellinus	1	1.80	0.00
312	Hamaxia	1	1.50	0.00
315	Anemuriam	1	1.50	0.00
316	Mamuriye	1	0.60	0.00
317	Arsinoe	1	1.50	0.00
319	Mellaxia	1	2.00	0.00
320	Celendris	1	0.50	0.00
321	Holmus	1	0.60	0.00
322	Agalimani	1	0.60	0.00
323	Agalimeni Fort	1	0.60	0.00
325	Persente	1	1.50	0.00
326	Corycus	1	1.50	0.00
328	Soli	1	2.00	0.00
329	Megarus	1	2.00	0.00
330	Aegeae	1	2.00	0.00
331	Baiae	1	0.50	0.00
332	Fort Bannel	1	2.00	0.00
333	Seleucia Pieria	1	1.80	0.00
334	Amnisos	1	3.60	−1.50
335	Nirou Khani	1	3.60	−1.75
337	Mokhlos	1	3.60	−1.75
337	Mokhlos	2	1.90	−0.25
338	Eteia	1	1.80	−0.80
339	Itanos	1	2.00	−2.20

1[a]	2[b]	3[c]	4[d]	5[e]
340	Capa Plaka	1	1.00	−0.20
341	Zakros	3	1.50	0.00
341	Zakros	2	2.00	−0.50
341	Zakros	1	3.00	−1.00
343	Akri Goudara	1	5.00	3.50
344	Hierpatra	1	1.80	−0.50
346	Moni Arvi	1	0.50	−0.25
347	Metallon	1	1.90	0.00
347	Metallon	2	1.10	−2.00
350	Plakios	1	1.90	2.00
351	Leuce	1	1.90	2.20
352	Lasea	1	1.80	0.00
353	Agia Marina	1	1.90	2.00
355	Sphakia	1	1.90	3.50
356	Phoenice	1	1.90	3.50
357	Kalamydes	1	1.90	7.50
360	Plakaki Krio	1	2.20	8.00
362	Musagores	1	2.20	8.50
363	Khrysoskalitissa	1	2.20	7.50
364	Sphinarion	1	2.20	7.00
365	Phalasarna	1	2.20	6.60
367	Agneion	1	2.20	6.00
368	Kisamos	1	2.20	5.20
369	Napia	1	2.20	5.00
370	Dhiktinaia	1	2.20	3.00
371	Burdroae	1	2.20	3.00
372	Chor Fakia	1	2.20	1.10
373	Marathi	1	2.20	1.50
375	Amphimalla	1	2.20	1.50
376	–	1	2.20	1.00
377	–	1	2.20	0.80
378	Rethymme	1	2.20	−0.20
379	Panormus	1	0.50	−0.50
380	Varignano	1	2.00	−0.50
382	Lapethus	1	2.00	0.00
384	Cerynia	1	2.30	0.00
385	Vrisi	1	3.00	0.00
386	Platymeis	1	2.00	0.00
388	Agios Thyrsos	1	2.00	−0.25
389	Carpasia	1	2.00	0.00
392	Salamis	1	1.70	−2.00
392	Salamis	2	1.00	−0.30
393	Ammochostos	1	2.00	−0.50
395	Dades	1	2.00	−0.20
396	Kitium	1	5.00	−7.00
396	Kitium	2	2.00	−0.50
399	Amathos	1	2.50	−0.75
399	Amathos	2	0.50	−0.20
400	Curias	1	0.50	−0.10
401	Dreamer's Bay	1	1.80	−2.00
404	Paphos	1	2.00	−0.30
405	Drepanum	1	2.00	−0.30
409	Agios Nikolaos	1	2.00	−0.75
410	Marium Polis	1	2.00	−0.75
413	Bema	1	2.00	0.00
414	Camiras	1	1.00	0.00
415	Rhodus	1	5.00	1.75
416	Zimbule	1	0.70	−0.25
417	Calithea	1	5.00	3.70
417	Calithea	2	2.40	2.70
417	Calithea	3	0.70	−0.25
418	Aphandos	1	5.00	5.24
419	C. Teodoco	1	5.00	3.40
420	Tsambika	1	5.00	3.25
421	Lindus	1	5.00	2.00
422	Merminga	1	5.00	1.00
423	C. Istros	1	5.00	0.33
425	Lephkos	1	2.00	−1.00
426	Vurgunda	1	2.00	−0.75
427	Tristoma	1	0.80	−0.25
428	Palatea	1	1.00	0.00
430	Vathi Potamus	1	2.00	−1.10
431	Makriyalo	1	2.00	−0.90
431	Makriyalo	2	1.00	0.00
433	St. Rocchino	1	2.60	−1.80
433	St. Rocchino	2	2.50	−1.40
438	St. Liberata	1	1.90	−0.60
439	Orbetello	1	2.30	−1.00
440	Giglio I.	1	1.90	−0.60
441	Pianossa I.	1	2.00	−0.90
444	Martanum 1	1	2.00	−0.50
447	Torre Valdaliga	1	2.00	−0.60
448	Mattonara	1	2.00	−0.60
449	Punta St. Paolo	1	2.00	−0.50
450	Punta de Vipera	1	2.00	−0.60
451	Fosso Guardiole	1	2.00	−0.70
453	Grottacce	1	1.90	−0.60
457	Porto di Claudio	1	1.90	−0.50
458	Il Palazzo	1	2.00	−0.50
459	Casarina	1	2.00	−0.50
460	Lago di Paolo	1	1.90	−0.50
461	Pisc. di Lucullo	1	1.90	−0.40
462	nr. Sperlonga	1	2.00	−0.50
464	Nave	1	2.00	−0.50
466	Scauri	1	2.00	−0.40
467	Ponza (Pontia)	1	2.00	−1.00
468	Ventotene	1	2.00	−0.90
471	C. Ognina	1	3.40	−1.00
519	Aquilaea	1	1.80	−1.50
519	Aquilaea	2	0.70	−4.00
567	Phalerura	1	4.00	−2.00
604	Troy	1	7.00	−2.00
604	Troy	2	4.50	2.00
604	Troy	3	3.00	0.00
604	Troy	4	2.00	0.00
638	Mytilene	1	2.20	−0.50
646	Phylakopi	1	3.20	0.00
710	Ravenna	1	2.50	−3.00
710	Ravenna	2	2.00	−2.00
710	Ravenna	3	1.50	−1.00
743	Naupactus	1	2.40	0.00
798	Anthedon	1	1.50	−0.20
899	Paros	1	7.00	−5.00
899	Paros	2	2.40	−3.00
923	Ras et Tarf	1	2.00	−0.30
931	Aradus	1	3.00	−1.00

1[a]	2[b]	3[c]	4[d]	5[e]
931	Aradus	2	2.80	1.00
939	Sidon	1	2.80	−1.00
939	Sidon	2	2.00	1.00
940	Sarepta	1	1.70	0.00
941	Tyre	1	2.40	0.00
949	Apollonia (Africa)	1	2.40	−2.10
949	Apollonia (Africa)	2	2.00	−2.70
950	Ptolemais	1	2.00	−1.50
952	Euhesperides	1	2.00	0.00
956	Phycus	1	1.50	−1.50
957	Cercina	1	2.20	−0.50
958	Governor's Beach, Gibraltar	1	12.00	−10.00
963	Saliagos	1	7.00	−4.50
964	Agios Petros	1	7.00	−10.00
965	Franchthi	1	6.50	−10.00
966	Hof Dado	1	6.00	−1.20
967	Kefar Samir	1	5.70	−5.40
969	Lagoon of Thau	2	5.20	−1.00
980	Vieille-Couronne	1	2.20	−0.50
981	Meryem	1	2.70	0.60
982	La Gaillarde	1	2.00	−0.40
985	Bouar	1	2.00	0.80
986	Machroud	1	3.00	−1.00
987	Akovitika	1	5.00	−11.00
987	Akovitika	2	2.80	−2.00
988	St. Cecile	1	2.50	−1.00
990	Son Real	1	4.00	0.00
990	Son Real	2	0.50	0.00
994	Port de Carro	1	2.20	−0.50
995	Anse de Verdon	1	2.20	−0.50
996	Beaumaderie	1	2.20	−0.50
997	St. Croix	1	2.20	−0.50
998	Lixus	1	2.00	0.00
999	Cotta	1	1.80	0.00
1000	Asilah	1	0.60	0.00
1001	Sidi Kacem	1	4.00	0.00
1002	Cave of Hercules	1	10.00	−10.00
1004	Malabata	1	0.60	0.00
1005	Ksar es Seghir	1	0.60	0.00
1006	Lattes	1	5.00	−3.00
1027	Sullectum	1	2.00	−1.00
1028	Bizerta	1	2.00	−0.50
1030	Koutsoundri	1	2.00	−0.20
1031	Tell Harez	1	6.00	−2.60
1039	Oikonomos I.	1	5.00	−3.00
1040	Aperlae	1	2.40	−2.50
1040	Aperlae	2	1.30	−2.50
1042	Naousa Bay	1	2.50	−3.00
1043	Venice	1	2.00	−0.90
1044	Tabbat el Hamman	1	2.90	0.00
1045	Phoukeri	1	1.60	−2.00
1048	Minturnae	1	2.20	0.00
1049	Can Picafort	1	2.00	0.00
1049	Can Picafort	2	0.50	0.00
1051	Caesarea B (Israel)	1	2.20	0.00
1051	Caesarea B (Israel)	2	2.00	0.00
1051	Caesarea B (Israel)	3	0.80	0.00

to install a tide gauge during the period of measurement, and very few observers have done this. I know of no case where this factor has been taken fully into account, although Flemming (1983, unpublished report) recorded fluctuations of daily mean sea-level of 0.4 m during a six-day study of Tel Qatif (225). I know of no case where the tidal/seasonal/barometric factor has been taken fully into account with long-term measurements of the state of the tide, or use of tide tables.

So far as is known to the author, the only sites at which observations were corrected by on-site short-term measurement of the state of the tide are the data reported by Schmiedt (1972), and Lambousa (382), Salamis, Cyprus (932), Kenchreai (244), Tel Qatif (225), Aghios Petros (964), Tel Nami (195), Dor (199), Caesarea (203/1051) and Pavlo Petri (970).

The most accurately observed data set assembled so far is that published by Schmiedt (1972). Schmiedt (1972) observed numerous fish tanks along the west coast of Italy and made hundreds of measurements at each tank, defining the height of the boundary walls, depth of floor, height of internal dividing walls, level of sills and sluice gates, level of channels, etc. He referred all measurements to mean sea-level, but did not state how mean sea-level was established locally. If it were the true annual mean sea-level, then correction factors should have been introduced to allow for the season with the highest or lowest monthly mean sea-level. Conversely, if the mean sea-level used as a reference were the mean level at the time of observation, then there is an uncorrected factor for barometric effects at that time, and the seasonal difference between that season and the highest and lowest monthly mean sea-levels. The need for these corrections was acknowledged and analysed by Schmiedt (1972), but the application of the corrections to the data was not shown.

The previous paragraph does not detract from the brilliant observational detail of Schmiedt's work. However, the table of measured sea-level changes (Schmiedt, 1972, p. 213) lists the estimates to the nearest 0.01 m, with no estimate of errors. From the present analysis it must be implicit that there are unresolved errors of the order of 0.2 m.

Since many structures were in use for two centuries or more, and since expected relative rates of sea-level change are of the order of 0.05–0.1 m per century, a time error bar of two centuries is equivalent to a vertical error bar of 0.1–0.2 m.

Given the seasonal, interannual, storm and barometric changes of sea-level that may endure for days or months or result in annual variations in mean sea level, uncertainty arises from our lack of knowledge about acceptable frequencies of flooding or drying out of structures. When a particularly useful type of building stone can be obtained conveniently by quarrying on the shore directly into a cliff, would the quarry-master find it acceptable to have the quarry floor flooded once a year? for the whole of

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◀ *Notes on table 8.2:*

[a] = site number in MEDSITE database

[b] = site name, ancient name where known, otherwise modern name

[c] = sequence number of archaeological levels of different dates at the same site

[d] = age in thousands of years

[e] = vertical displacement relative to present sea-level, in metres, negative means site now submerged

one month during each year? or never? It is an observable fact that quarries were cut down in almost every case very close to sea-level: but were they cut to highest spring high tide, mean spring high tide, mean sea-level, or what? Even if we add a constant wave exposure factor, the uncertain range remains.

Good observation and instrumental methods result in an accuracy of the order of ±0.2–0.3 m in the best cases, but refinement beyond this point would require full tidal, storm, barometric and seasonal correction at every site, combined with subjective estimates of permissible frequency of flooding. No site has yet been observed in such detail.

In addition to those artifacts or structures that produce precise data, many other features can be classified as to whether they must have been dry (e.g. a road surface, mosaic floor, tomb, etc.); part in the water and part out (e.g. mole foundation, quay, slipway, etc.); or wholly submerged (e.g. floor of an entrance channel to a harbour, floor of a fish tank). If many structures exist at a single site, the assemblage may provide a very accurate bracket. Flemming and Webb (1986, Fig. 1) show an idealized cross-section of a site with structures that indicate sea-level. At some sites (e.g. Atlit, 193; Dor, 199) structures from different archaeological periods provide a relative sea-level time curve.

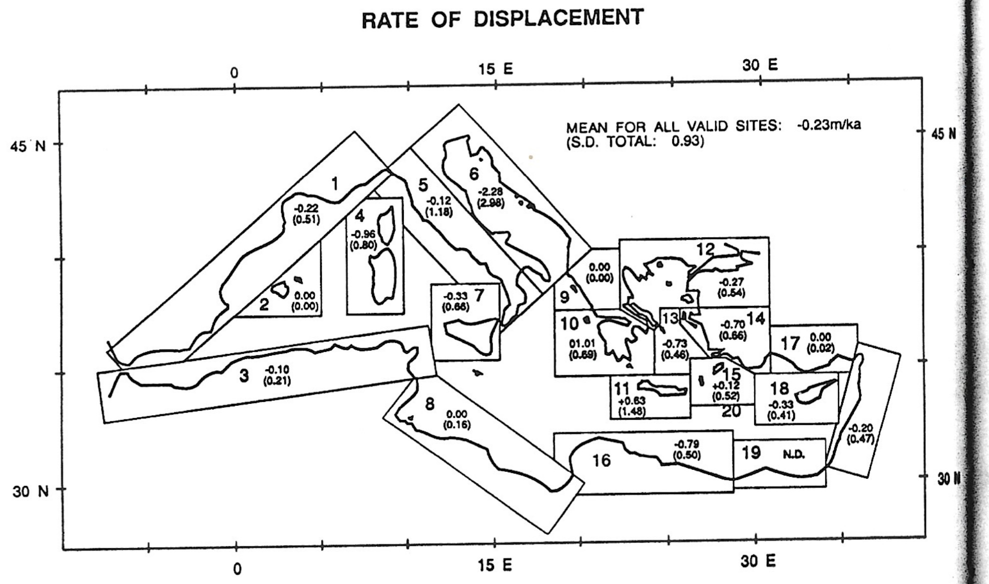

Fig. 8.1 Mean rate of vertical displacement of regions studied. The rectangles and polygonal boxes show the boundaries of the regions within which site data were analysed separately. The large numbers are the region identifiers, which are also used in Table 8.1 and Fig. 8.2. The mean rate of displacement for each region is shown in metres per thousand years (m/ka) with negative meaning land subsidence relative to the sea. The figures in brackets indicate standard deviation. The calculation is based on raw data without correction to remove eustatic sea-level change.

In reassessment of early data by the present author (especially Flemming 1968, 1969, 1972) derivations of sea-level and error bars have been revised, in some cases on the basis of subsequent experience, and further data on the site.

The accuracy of vertical displacement and time estimates may not be symmetrical. For example, a site may have been built at a known date or destroyed at a known date, but not both. The date error bar is therefore firmly limited on one side, but extends with diminished probability on the other. Similarly, a key structure, such as a mole foundation, may place a lowest possible level on sea-level, but there may be no data to limit the highest estimate. The method for allocating probability histograms to such data is given in Flemming (1972) and Flemming *et al.*, (1973). In the present paper, since many of the sites have not been personally visited by the author, a more conventional estimate of errors is used, based on symmetrical error bars.

3 INTERPRETATION OF ARCHAEOLOGICAL RESULTS

The present author has been most directly concerned with the analysis of archaeological data, and these will be described before the tide-gauge data. The principal results have been summarized by Flemming and Webb (1986).

The principal result, which can be deduced from the archaeological sea-level indicators after statistical analysis, is that the mean sea-level for each 200-year period has varied by less than 30 cm during the last 2000 years, and that each coastal region has a characteristic mean rate of vertical displacement, combined with very different local variability. The mean and standard deviation of vertical earth movement for each region in the study are shown in Fig 8.1.

The following discussion refers to Figs 11 and 12 taken from Flemming and Webb (1986) and reproduced here as Figs 8.2 and 8.3.

For the long narrow regions in Fig. 8.1 the predicted pattern of mean earth movements is shown in Fig. 8.3. There are no data south of the Bay of Naples in Italy, but much data from the Bay area itself. The result is that the data from this volcanic region severely distort the plot for western Italy. At this highly smoothed level, with a wavelength of hundreds of kilometres, the effects of local faulting are concealed, and these show up as high residuals. The most obvious effects are the broad subsidence of the Golfe du Lion-Rhône Delta region, uplift in Tunisia, and slight uplift in Syria. These phenomena are not altered, relatively speaking, by the application of small corrections from the eustatic curves (see Flemming and Webb, 1986 for details of the corrections).

The highest residuals, and/or rates of earth movement, are concentrated around Caesarea in Algeria, Naples, south-western Crete, the Cesme Peninsula of west Turkey, the Kekova-Kas region in south Turkey and Caesarea-Acco in Israel.

Regional patterns of earth movement have been plotted previously for the equiaxial Regions 10, 11, 14 and 15 in Fig. 1 (Flemming, 1978). The techniques used in the present study are similar to those used previously for these regions, although the computer software was different. Plots from

N. Flemming - 1992

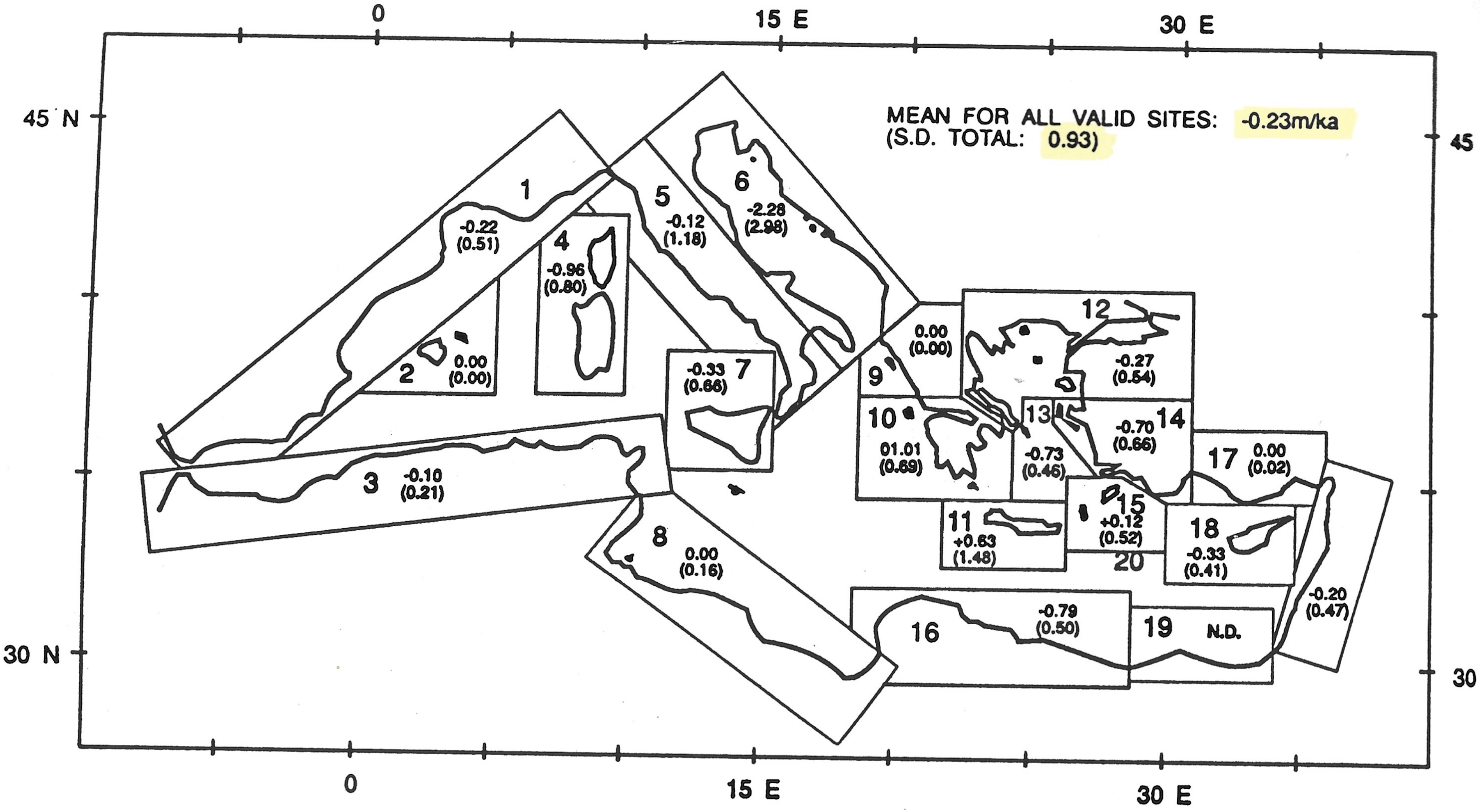

Fig. 8.1 Mean rate of vertical displacement of regions studied. The rectangles and polygonal boxes show the boundaries of the regions within which site data were analysed separately. The large numbers are the region identifiers, which are also used in Table 8.1 and Fig. 8.2. The mean rate of displacement for each region is shown in metres per thousand years (m/ka) with negative meaning land subsidence relative to the sea. The figures in brackets indicate standard deviation. The calculation is based on raw data without correction to remove eustatic sea-level change.

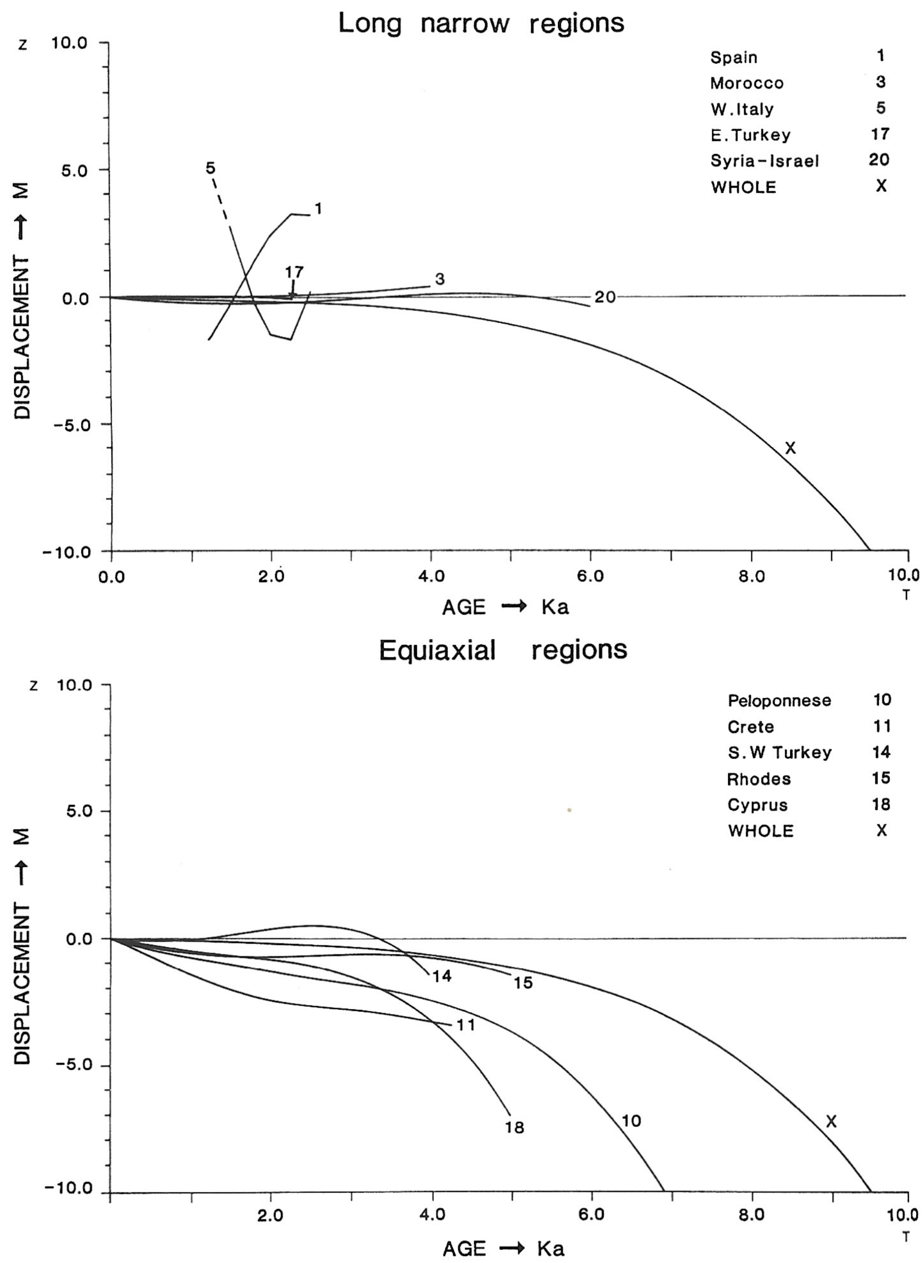

Fig. 8.2 Best-fit curves showing the relationship $Z = f(T^n)$, for site records for each region, after removal of geographically dependent components representing earth movements. Z = vertical displacement in metres; T = age in ka; A = curves for long narrow regions, uncorrected for transfer of linear component of rate of change between eustatic factor and earth movements; B = equi-axial regions, uncorrected for transfer of linear component of rate of change between eustatic factors and earth movement.

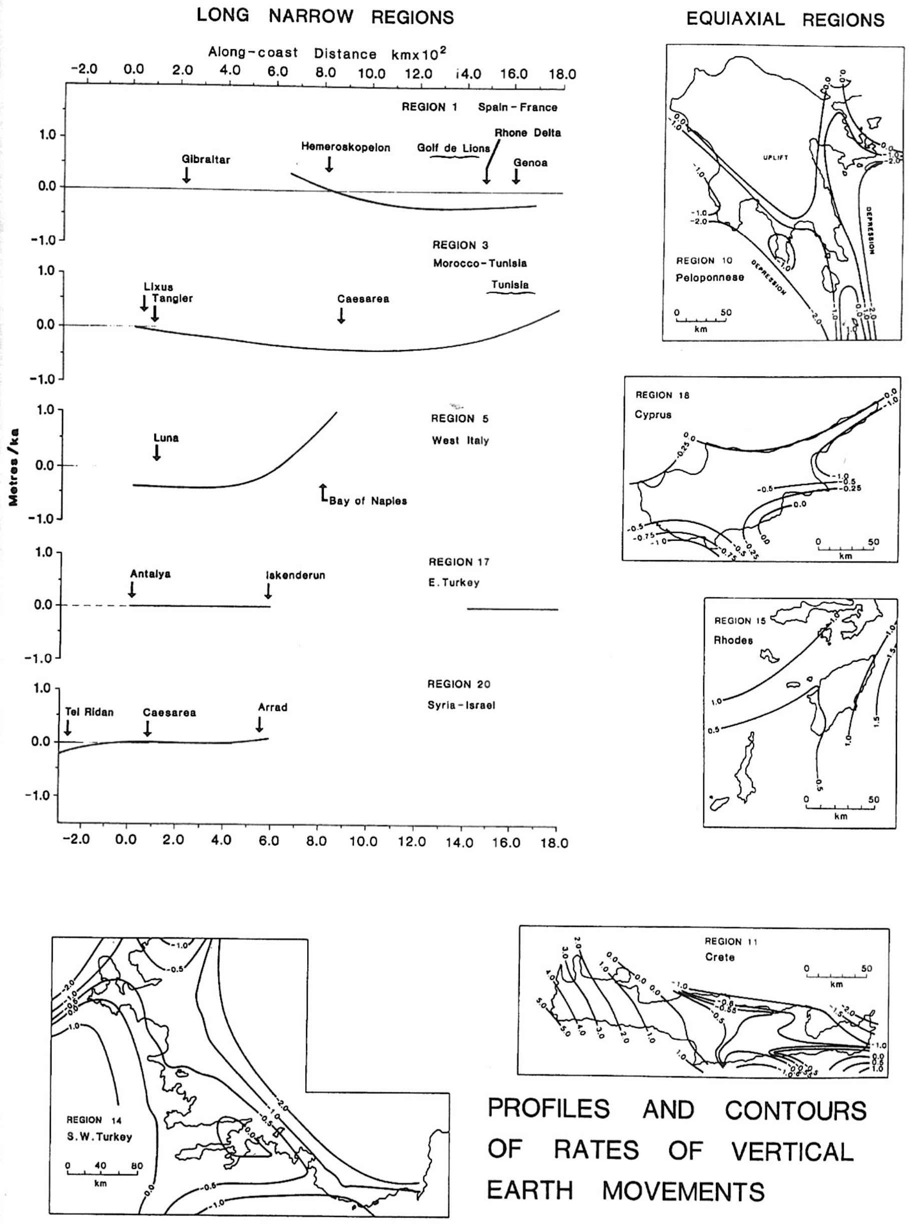

Fig. 8.3 Plots of regional earth movements, after removal of the eustatic component. For the long narrow regions the mean rate of displacement in m/ka is plotted along the coast as a function of distance in hundreds of kilometres. Distance is measured along the X-axis of the Region. For the equi-axial regions, plots are shown as contours of rates of vertical movements in m/ka.

the present study have been compared with the earlier results and are very consistent. Since the earlier work contained more detailed considerations than can be set out in the present work, the curves from Flemming (1978) are reproduced in Fig. 8.3.

The pattern of earth movements may be correlated with any of the following factors: plate boundaries in general; subduction zones; strike-slip faults; volcanism; continental shelf width/narrowness; continental marginal tilting; sedimentary isostatic loading; sediment compaction; aseismic warping. The factors listed above will be discussed briefly after the methods and results have been compared with those of other researchers.

3.1 Other Methodologies

Other field methods reveal sea-level data for the same time span as archaeological data. These include study of alluvial sediments (e.g. Kraft *et al.*, 1975; Kraft *et al.*, 1980; Gifford, 1978); study of solution notches (e.g. Hafemann, 1965; Flemming, 1978; Higgins, 1980; Guery *et al.*, 1981; Pirazzoli *et al.*, 1981); vermettus reefs and trottoir (Sanlaville, 1977; Paskoff *et al.*, 1981; Paskoff and Sanlaville, 1983); and the study of organic materials dateable by C14 (Newman *et al.*, 1980; Richards and Vita-Finzi, 1982; Marcus and Newman, 1983); and the study of low-level raised erosion terraces (e.g. Angelier, 1976; Le Pichon and Angelier, 1981; Peters, 1985).

Even if each of these methods is perfectable and produces internally consistent results, there is no reason why all the methodologies should calibrate identically with each other until proven. In the present study the only non-archaeological data used are when solution notches can be traced on cliffs between archaeological sites, and can be identified at some point intersecting archaeological structures with a before/after indication. All other types of indicator have been omitted. This may seem to be an arbitrary rejection of valid data, but in the present circumstances it is preferable to demonstrate that the restricted archaeological data set produces consistent results with a measurable error, and the merging of different data types can be carried out later when calibration is sure.

The different data types each have a bias towards certain sites of occurrence. Solution notches only occur on massive calcareous rocks; vermettus shelves only occur in the southeeast Mediterranean; alluvial accumulations are strictly local forms. As an example of the relative bias which this can produce, one can cite the differences between most of the data reported in this chapter and that cited by Kraft and Aschenbrenner (1977). The data observed personally by the present author are restricted almost entirely to archaeological remains that can be seen with the naked eye, whether above or below present sea-level, and without excavation. This tends to exclude material buried in recent sediments, or even visible data separated from the present shoreline by prograding sediments, since there is seldom opportunity to level accurately across miles of marsh. The data are therefore biased slightly by the omission of such sites, probably amounting to a few per cent of the total number of sites (e.g. Oeniadae (541) and Ephesus (270), etc.).

Conversely, Kraft *et al.* (1975), Kraft and Aschenbrenner (1977) and Rapp and Kraft (1978) have gathered data almost exclusively from sites in alluvial and prograding areas. These zones in the Mediterranean are likely to occur in structural depressions which are themselves active grabens. Because the sediment may be liable to compaction, data from these areas would be expected to plot consistently below the data observed by (Flemming, 1968, 1978; Flemming *et al.*, 1973), and this is indeed the case. With regard to their own data, Kraft and Aschenbrenner (1977, p. 39) state "Note the problem of the overwhelming variable tectonic effect". The purpose of this comparison is not to show that one or other method is incorrect, but to draw attention to systematic bias inherent in most sampling procedures that are dictated by methodology.

3.2 Correlation with Plate Boundaries

Figure 8.4 is a simplified diagram representing the location of plate boundaries in the Mediterranean, derived from the synthesis by Peters (1985) based on the work of several authors. The most extensive quiet zones revealed by the present study, Gibraltar to Genoa (Region 1) and Antalya to Iskenderun (Region 17), are both far from active plate boundaries. The Gulf of Sirte (Region 8) is probably also quiet, but there are insufficient data to be sure. Cyrenaica (Region 16) appears to be anomalous in view of its active depression, reversal of direction at Apollonia (949) and distance from the Hellenic subduction zone. However, it is probable that the compressive forces caused by the Mediterranean Ridge and the subduction process extend to the African foreland, causing tectonic activity (Biju-Duval, 1974).

Plate boundaries extend through northern Algeria, central Italy and the Yugoslav coast, all of which show some vertical activity. In general there is a broad correlation between proximity of a plate boundary and degree of vertical tectonic motion averaged over several thousand years.

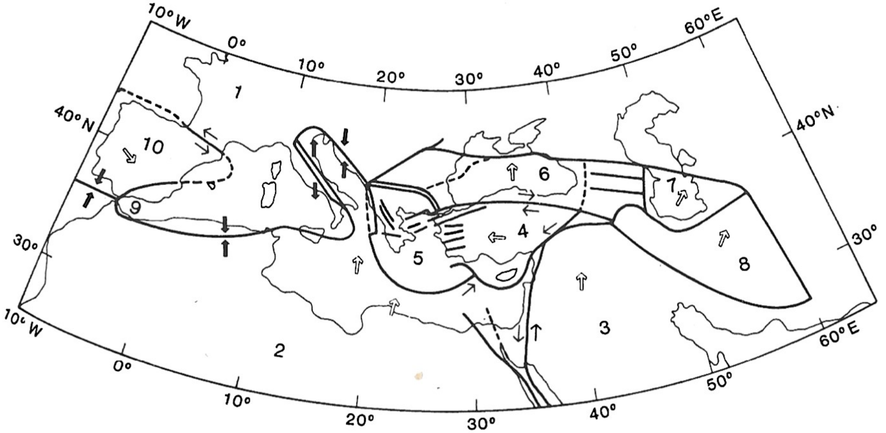

Fig. 8.4 Boundaries of plates and sub-plates simplified from Peters (1985), based on various authors. Arrows represent direction of movement. Numbers on plates as follows: 1 = Eurasian; 2 = African; 3 = Arabian; 4 = Turkish; 5 = Aegean; 6 = Black Sea; 7 = Caspian; 8 = Iranian; 9 = West Mediterranean; 10 = Iberian.

3.3 Correlation with Subduction Zones

There are two major arcuate subduction zones in the Mediterranean, the Calabrian Arc (Ghisetti and Vessani, 1982; Caputo, 1983) and the Hellenic Arc (Galanopoulos, 1973; Angelier, 1976, 1977, 1979; Dewey and Sengör, 1979; Pichon and Angelier, 1981; Peters, 1985). Neither arc is a simple subduction zone in the Pacific sense, since the radius of curvature is too sharp to allow for a coherent descending slab of lithosphere, and the proximity of approaching continents forces the back-arc area to develop anomalously (McKenzie, 1978; Dewey and Sengör, 1979). Notwithstanding these anomalies, the two areas do appear to be the principal zones of recent crustal consumption, and will be discussed as such.

The Hellenic Arc is associated with consistent evidence for rapid uplift on the outermost islands (Antikythera, Crete, Karpathos and Rhodes), the most rapid rates of movement observed anywhere in the Mediterranean (9.5 m in 2000 years, in south-western Crete). Pirazzoli *et al.* (1981) fitted a continuous contoured surface to the data for Antikythera and Crete to indicate a progressive distortion and tilt along the arc. At the suggestion of McKenzie (pers. comm.) Flemming tested computer-fitted regressions to the archaeological data for Antikythera and Crete, considering the data first as a single data set, and secondly as two data sets separated at the Antikythera Channel. The results are published by Flemming (1978). The residuals are much lower when the islands are considered separately, and it is therefore logical to consider them as de-coupled by the active faulting in the Antikythera Channel (see McKenzie, 1972, for evidence of recent seismicity). One concludes that the islands of the Hellenic Arc are broken into coherent slabs of typical dimension 50–100 km, which are tilting as monolithic de-coupled units in response to the underthrusting of the subduction zone. Peters (1985, p. 208) reports similar tilting on the Quaternary time-scale for the eastern region of Crete.

The evidence for the Calabrian Arc is less clear. Apart from the Messina earthquake of 1908, and the obvious volcanism of the Lipari Islands and the Bay of Naples, the majority of archaeological sites in the area fail to produce data. The Bay of Naples shows the greatest range of vertical movement, after south-western Crete, but this is associated with volcanism rather than the immediate effects of subduction (Günther, 1903a; Flemming, 1969).

The incidences of most rapid upward movement of the Mediterranean coast are thus from the arc areas, with rates of the order of 5 m/ka.

3.3.1 Correlation with strike-slip plate boundaries

The two major strike-slip plate boundaries are the Anatolian fault, running east–west across northern Turkey, and the Dead Sea fault, running north–south through the Gulf of Eilat/Aqaba and the Dead Sea. Neither fault is immediately adjacent to the Mediterranean coast, and the present survey has not included possibly helpful data from the Black Sea. The coast of Israel is moderately active, with vertical movements of 5 m at Caesarea (203/1051) and possibly 2 m at Dor (199) and 1 m at Acco (182). But these movements seem to be localized around the Carmel-Qishon Graben, rather than being direct effects of the plate boundary.

3.3.2 Correlation with local faulting

The southern and central Aegean probably should be regarded as an intensely faulted region, criss-crossed with normal extensional faults forming multiple horst-and-graben features (Flemming, 1978; Dewey and Sengör, 1979; Le Pichon and Angelier, 1981; Rotstein, 1985). The same model, in very broad terms, extends into the Gulf of Corinth (Brooks and Ferentinos, 1984; Vita-Finzi and King, 1985), where vertical movements at rates of 1–3 m per 1000 years are recorded for upward motion within 10 km of sites which have submerged at similar rates. Unfortunately, the present survey has revealed insufficient reliable data to construct a good model for the Aegean area. From such data one would expect to find upward and downward vertical displacement on adjacent islands, or on adjacent blocks separated by normal faults within an island. Flemming (unpublished report) noted a fault in the cliff at Vurgunda Karpathos (site 426) with a throw of 1 m, dislocating solution notches which were post-Roman. Similar but smaller faults can be seen in cliffs on Crete.

Other locations where vertical site displacement is associated with known faulting are Caesarea (203/1051), Dor (199) and Acco (182) near the Qishon Graben; probably Apollonia in Cyrenaica (949); Ruspina (127); Fethiye (289) to Kekova (302) south Turkey, Nora (160) southern Sardinia. King and Vita-Finzi (1981) analysed the fault structure associated with a modern seismic event near the coast of Algeria, just inland from Caesarea (151), which has the highest rate of subsidence in Region 3. In all cases the observed data indicate submergence, with the exception of one period at Dor. Vita-Finzi and King (1985) note that submergence is more easily detected than emergence even by contemporary observers of an earthquake event, and the same phenomenon is true of historical and archaeological data. Except for gross examples of uplifted harbour-works, uplift can go unreported. Nevertheless, the existing data do show a correlation of submergence with local faulting, although this may require further interpretation.

3.3.3 Correlation with modern and historical seismicity

Seismicity is associated with active faulting, plate boundaries and volcanism, so it is not independent of the other factors under discussion. The association is not exact in terms of the surface expression of these phenomena, and so direct evidence of seismicity should be reviewed.

The British Geological Survey provided a computer print-out map of modern seismicity of the Mediterranean showing earthquake events classified in terms of depth and magnitude. It is theoretically possible to compute the total number of large and small earthquakes expected over a prolonged period on the basis of recorded events over a few decades (Main and Burton, 1984), and hence to typify areas in terms of total energy release. Similar generalizations can be obtained from assessment of slip rates (North, 1974). For the present analysis, correlation was made subjectively with the BGS plots. It should be borne in mind that the seismicity refers only to the recent decades, and the distribution is not necessarily identical with the average over several thousand years.

Subjectively the correlation is evident. In the eastern Mediterranean, southern Turkey and northern Cyprus are aseismic and correlate with vertical stability. The Levant coast and Cyrenaica are moderate on both counts. The Hellenic Arc shows dramatically high rates of seismicity, with the greatest concentrations of large events in Rhodes and south-western Crete, where the highest rates of vertical movement are measured. We do not have sea-level data for the Ionian islands and Achaia, where similar seismicity is recorded. The vertical activity of the Gulf of Corinth correlates with that of high current seismicity.

As noted above, the data for the Calabrian Arc are not good enough to provide sure correlation, though this may be partly due to the occurrence of most epicentres offshore between the Lipari Islands and Naples. A belt of seismicity cuts across Tunisia and Algeria, intersecting the coast in the neighbourhood of the submerged sites of Sullectum (1027) and Caesarea (151). There is no recorded seismicity relating to the faults in southern Sardinia close to Nora (160), whilst the seismicity of south-east Spain is not correlated by data for vertical movement.

Although the present data set is not complete in some of the most interesting areas, observed relative vertical displacements apparently are correlated with local seismicity during recent years. Flemming (1978, p.444) showed that the data for the north-eastern Mediterranean correlate with the evidence from Ambraseys (1961, 1970) for historic seismicity. Historical seismicity for France (Vogt, 1979; Gagnepain-Beyneix *et al.*, 1982, p. 274) and Italy (ENEL, 1977; Caputo, 1981) provide source material for further historical comparisons.

3.3.4 Correlation with continental shelf characteristics

The Mediterranean continental shelf is generally very narrow, with the exception of the Golfe du Lion, the northern Adriatic and the Gulf of Sirte. The narrowest shelf and deepest water are associated with the Hellenic Arc on the south side and, in this location, with high rates of vertical movements. In contrast, the very steep shelf off the French Côte d'Azur is associated with vertical stability.

The wide shelf of the Golfe du Lion is apparently subsiding; the Gulf of Sirte, at least in the region of Gabes, is associated with uplift; whilst the Adriatic is associated with submergence. Thus there is no general correlation.

If the coast is tilting about an axis parallel to the coast, high-sea-level indicators will be biased in one sense, and low-sea-level indicators in the opposite sense. Since the relief of the Mediterranean area is increasing, down-faulting or down-warping of the shelf relative to the hinterland is, on average, probable. On crenellated coasts, such as the west coast of Cyprus, the headlands will tend to show submergence (or at least lower rates of uplift) relative to the backs of the bays (Richards, 1984, field report). Contamination of the data due to coastal and shelf tilting is liable to introduce an average bias into sea-level studies, especially over periods longer than 5000 years. Many of the present data values may be determined by their location landward or seaward relative to a near-coastal axis of tilt.

The possible bias towards tilting of the continental margin is shown in some regions by the rapid subsidence of the outer end of the Cesme peninsula (sites 262 and 266); the subsidence of the headlands of western Cyprus (Richards, field report); subsidence and tilting of the shelf off Atlit (193) Adler (1985); and the general doming pattern of the Peloponnese (Fig. 8.3).

3.3.5 Correlation with sedimentary isostatic loading

Sedimentary isostasy and sediment compaction would both tend to occur on large deltas and the large alluvial infilling of re-entrant bays and graben valleys. In locations where valid sites occur the correlation is confirmed, with depression below average eustatic curve in the Rhône Delta (sites 30, 31, 971, 978) and Po Delta (sites 588, 773, 1125, 1128). It is difficult to separate isostasy from compaction, but the data exist in some cases. For example, some Roman quarries in the Rhône area are on bedrock, where an isostatic factor might be detected independently of compaction. Sites in the Golfe du Lion (25, 969, 1006) are also submerged more than the adjacent coasts, which is compatible with long-term sediment accumulation and aseismic subsidence.

4 Analysis of Tide-Gauge Data

Tide-gauge data have been used to estimate earth movements in Europe and the Mediterranean by Emery and Aubrey (1985), Pirazzoli (1987b), Emery *et al.* (1988) and Flemming and Woodworth (1988). Tide-gauge data provided by the Hellenic Navy (Flemming and Woodworth, 1988) show that the residual trend of earth movements, after removal of seasonal and interannual variability, is of the order of 5–20 mm/yr at 15 Greek ports, with movement of the coast as likely to be up as down. Pirazzoli (1987b, Table 5.1) provides data for 16 tide gauges in the Western Mediterranean and Adriatic, showing rates of sea-level change over 50–100 years averaging 0.3 to 2.3 mm/yr, all with relative subsidence of the coast with one exception. These data have not been corrected to separate earth movements from eustatic sea-level change.

Pirazzoli (1987b, p. 175) points out that the rate of rise indicated by the tide gauge at Marseille is much higher than the average over the last 2000 years, and that the rate of rise indicated by two closely dated archaeological features at Marseille approximately 2000 years ago also is higher than the average.

This effect, probably caused by aliasing, was studied explicitly by Flemming and Woodworth (1988). Decadel tide-gauge measurements of relative rate of change of sea-level are two to eight times the average rate over archaeological time intervals; archaeological estimates of average rates of vertical change exceed geological estimates averaged over 0.2–2.0 million years by a further order of magnitude. If a timeseries of relative sea-level change at a point on the coast consisted of a series of oscillations, with different frequencies the average rate of movement measured over different time-spans would tend to decrease with increased averaging interval. In theory the short-term rate could be in the opposite sense to the long-term average rate, and Flemming and Webb (1986) report sites showing reversal of direction. The great majority of sites with multi-purpose data show the same direction of movement on all time-scales. This suggests that the spectrum of vertical earth movements at a point is biased towards monotonic movement in one direction over time-scales of hundreds to tens of thousands of years. Reversals in direction are sufficiently short-lived not to show up often in tide-gauge records.

Flemming and Woodworth (1988) show that, in general, rates of vertical earth movement in the Aegean averaged over 2000 years are ⅙ x the rate of those measured at the same sites by tide gauges over 10–20 years. From this a general equation can be deduced for the region. Table 8.3. shows this correlation.

Emery and Aubrey (1985) deduce a rate of vertical movement from tide gauges on the Scottish coast that is only twice that based on Carbon-14 dating of beach deposits over several thousand years (Flemming, 1982). This suggests that the spectrum of variability of earth movements is much less noisy and has fewer high-frequency components for a region dominated by isostatic recovery. The process of isostatic post-glacial rebound is also probably slowing down.

The aliasing ratio for different regions gives a general indication of the reliability of trying to extrapolate from short records to longer periods.

Table 8.3

Assume equation $$\frac{\text{Rate-}T}{\text{Rate-0}} = \left\{\frac{T_0}{T}\right\}^{0.4}$$

Where T = period of time over which rate of vertical movement is averaged, many tens to thousands of years; T_0 = a few years over which rate is measured by tide gauge; Rate – T = rate of vertical movement averaged over time T; Rate – 0 = rate of vertical movement averaged over a few years.

A. Ratios linking tide-gauge time-scales to archaeological time-scales

T_0 years	T years	Ratio = Rate-0/Rate-T
100	1000	2.51
100	2000	3.31
80	1000	2.73
80	2000	3.61
50	1000	3.31
50	2000	4.36
10	1000	6.3
10	2000	8.3

B. Ratios linking short tide-gauge time-scales to future multi-decade sea-level changes

T_0 years	T years	Ratio = Rate-0/Rate-T
10	40	1.74
10	50	1.90
10	60	2.04
10	70	2.18
10	80	2.30
10	90	2.41
10	100	2.51

The more high frequency components present, the higher the ratio. Large tectonic events separated by time-spans of the order of 500–1000 years would be very difficult to detect or predict.

Table 8.3a shows the ratios that would be expected by comparing tide-gauge records of several decades with archaeological periods of 1000 or 2000 years, if the equation for the Aegean were applied to all data. The ratios range from a minimum of 2.5 when 100-year tide-gauge data are compared to 1000-year archaeological data, through to 4.36 when 50-year data are compared with 2000-year data; and a maximum of 8.3 when 10-year data are compared with 2000-year data.

There is no region outside the Aegean where so many tide gauges can be compared accurately with co-located archaeological sea-level data. We therefore are reduced to comparing the average rate of displacement of regions over two time periods.

Region (1) (Flemming and Webb, 1986) contains seven tide gauges listed by Pirazzoli (1987b). The average length of tide-gauge records is 76 years, and the average relative displacement is 0.685 mm/yr relative rise of sea-level. The archaeological data are based on an average age of about 2000 years, and shows a relative subsidence of 0.23 mm/yr. The ratio is almost exactly 3.0. Table 8.3 shows that the aliasing ratio from 80 years to 2000 years would be 3.6 if the area were as active as the Aegean, which it is not.

Examination of the data from Pirazzoli (1987b) shows no other regions in which even this crude average comparison can be made with confidence. Region 5 contains only two reliable tide-gauge records, and Region 3 contains four. None of the available tide gauges co-locates exactly with an archaeological sea-level indicator site, and the distances of approximation become unacceptable.

Emery *et al.* (1988) list 29 tide gauges with records longer than 15 years, producing 18 records not included in Pirazzoli (1987b). Seven of these sites, in Israel, Turkey, and Italy, co-locate with archaeological data. The directions of movement correlate in every case, and the aliasing ratios vary from 2.1 to 11.0.

5 PREDICTIONS OF FUTURE COASTAL EARTH MOVEMENTS

An irregular time series of earth movements is not attributable to a single physical cause, and therefore cannot be described by a simple spectrum relating amplitude or rate of movement to frequency. Nevertheless, rate of movement does correlate negatively with period. The constants in this empirical relationship would probably vary from region to region, with regions exhibiting different ratios between high-frequency and low-frequency events. This model suggests a way of predicting the probable rate of earth movements in each region during the next 50–100 years, even in the absence of long-term tide-gauge data.

The method of prediction, and the certainty, depends upon the type of data available locally and the known characteristics of the spectrum of earth movements in time and space. The different conditions of data availability are as follows:

1) tide-gauge data with 50–100 years of accurate well-calibrated data at the study site;
2) tide-gauge data with 50–100 years of accurate well-calibrated data available at a site within 10–20 km of the study site;
3) tide-gauge data with 10–20 years of well-calibrated data at the study site;
4) tide-gauge data with 10–20 years of modern well-calibrated data within 10–20 km of the study site;
5) archaeological estimate of relative sea-level change and deduced earth movements over 1000–2000 years available at the study site;
6) archaeological estimate of relative sea-level change and deduced earth movements over 1000–2000 years within 10–20 km of the study site;
7) no tide-gauge or archaeological data within 10–20 km of the study site.

Each condition above will be considered in turn:

1) A typical tide-gauge record of annual mean sea-level shows fluctuations that may be due to inter-annual variations in absolute mean sea-level, or faster and slower changes of land level. In order to determine the earth movement component, the global mean sea-level change over the same time-scale should be subtracted. The best estimate of this is subject to some debate (Gornitz *et al.*, 1982; Barnet, 1984; Douglas, 1991) and I do not intend to recommend a best estimate. The residual earth movement then can be extrapolated for the same period into the future with reasonable confidence.

   Various cross-checks should be applied. If the area is tectonically active and if archaeological data suggest that the long-term rate of change is faster than would be suggested by the general $1/T^{0.4}$ aliasing relationship, then some allowance should be made for the probability that rapid rates of movement can occur from time to time, which have not manifested themselves in the last 100 years but may occur in the next 100.

   In all cases of tectonic movement it is possible for the direction of movement to reverse for periods of decades to centuries. Flemming and Woodworth (1988) show that for co-occurring pairs of tide gauges and archaeological data sites the direction of movement is the same in every case. The probability of reversal would be increased if the archaeological record provides clear evidence of reversals in the past (e.g. Matala (347), Caesarea (203/1051), Zimbule (416)), or if the average rate of movement is significantly less over the archaeological time-scale than suggested by applying the aliasing factor to the tide-gauge data.

   If the cause of earth movement at a site is sediment compaction or isostatic subsidence under sediment loading, this probably will proceed at a more even and steady rate than tectonic subsidence. On the other hand, deltaic sediments may actually slump on rare occasions.

2) If there is no long tide-gauge record at a site, but one exists within 10–20 km, then the prediction can be extended laterally with reasonable confidence but some caveats. The lack of coherence between nearby sites of course is more marked in areas of extreme tectonism than in areas which are aseismic. The data provided by Flemming (1969), Pirazzoli (1976b), Flemming (1978) and Flemming and Webb (1986) show that there are regions of the Mediterranean coast that are stable and laterally coherent (e.g. southern Turkey from Antalya to Iskenderun); regions that are moderately stable and coherent (e.g. Spain and southern France); regions that are inherently noisy and laterally incoherent (e.g. much of Greece and the Aegean coast); and finally regions that are unstable, but tilting or warping in coherent blocks, that can be contoured for trends in rate of vertical movement (e.g. Crete).

   The factors mentioned above, together with knowledge of local geology, should be used to see if it is justifiable to extrapolate the predicted rate of earth movements from the site of a known tide gauge for a distance of 10, 20 or 30 km along the coast. Knowledge of local faulting, presence of alluvium, settlement of sediments in deltas, etc. should be taken into account on the basis of immediately local geological data.

3) A tide-gauge record of less than 20 years is relevant, but prediction from such a record for 50–100 years into the future is statistically less certain than with a longer record. The short record may exaggerate the rate of movement through aliasing, or fail to reveal movement if it is periodic with a period longer than the record. If a consistent rate of movement of the earth is detected over a period of the order of 10 years, it is likely to be an overestimate of the rate of movement to be expected over 50 years by a factor of 2, and an overestimate of the rate to be expected over 100 years by a factor of 2.5 (see Table 8.3B). These ratios apply to tectonically active areas, such as the Aegean, and probably the coast of Yugoslavia and Albania, and parts of Italy and Algeria. In areas of subsidence and sediment loading, the overestimate from short tide-gauge records is probably less exaggerated.

   A short tide-gauge record should be cross-checked against co-located or nearby archaeological data if possible (see below).

4) If neither short-term nor long-term tide-gauge records are available on site, but a short-term tide-gauge record exists within 10–20 km, then further approximations must be adopted. Archaeological and geological data permit the region to be characterized in terms of local lateral coherence as in (2) above. The short-term tide-gauge estimate of the vertical rate of movement of the coast should be corrected for the extrapolation in time on site, and then for the extrapolation laterally along the coast. Archaeological data should be used wherever possible to cross-check the tide-gauge prediction, using appropriate correction factors from Table 8.3.

5) If there are archaeological data on site, then a fairly accurate assessment should be available of the vertical rate of earth movement averaged over 1000–2000 years. This average figure, in some cases, will be accurate to better than 0.2 mm per year. The problem is that the average can severely underestimate possible short-term movements, and therefore the archaeological indicated rate should be increased by a conversion factor (Table 8.3). The conversion factor is derived from the Aegean, and therefore should be conservatively safe for other areas.

6) If there are no archaeological data available at the site, but such data exist within 10–20 km, then the regional pattern should be studied, as in (2) above. Flemming (1972, 1978) and Flemming and Webb (1986) show pronounced regional patterns in crustal tilting, so that the rates of vertical movement can be interpolated with some confidence between sites in some areas. The interpolated values then should be corrected for aliasing, as in (5) above.
7) If there are no tide-gauge data and no archaeological indicators of sea-level within 10–20 km of a site, the prediction becomes much more subjective and less certain. This is, however, the most general case. Examination of regional geological data, seismicity, faults, alluvium, etc. provides a general view of the expected level of vertical movement in the region within say 100–200 km of the site. Archaeological sea-level data within the region, cross-checked with tide-gauge data where possible, will confirm the general picture. Publication by Vita-Finzi and King (1985), Le Pichon and Angelier (1981), Flemming and Webb (1986), Sanlaville (1977), Paskoff and Sanlaville (1981) and others provide general information on the regional rates of crustal deformation, tilt, faulting, etc.

6 CONCLUSIONS AND RECOMMENDATIONS

1) Tide-gauge data are the most accurate source of information on vertical coastal land movements, but a record of at least 10–20 years is needed before a reasonable prediction on the 50–100 year time-scale can be made; the record should preferably be of the order of 50–100 years. There are only 16 published long records, and 15 short records in the Mediterranean Action Plan area, with adequate quality control.
2) Because of the lateral variability in coastal earth movements, data at one site can only be interpolated or extrapolated laterally for a distance of the order of 10–20 km. If a large number of data sites is available for a region, then deduction of trends, tilts, general stability, etc. enables more certain prediction between data points, but even then local anomalies cannot be ruled out.
3) There are 335 good estimates of sea-level change based on archaeological data over the 1000–2000 year time-scale, with an average spacing for the whole Mediterranean Action Plan area of 134 km. In practice the regions with good archaeological data are much more densely sampled, whereas some regions are almost totally without data. If the coasts of Jugoslavia, Albania, Egypt and the north and central Aegean are excluded, the published archaeological data provide a sampling density of one site per 75 km of coast. This is quite close to an adequate sample.
4) If a predictive study is urgently needed to cover the whole coast of the Mediterranean Action Plan area, the following steps are recommended:
   a) Obtain further tide-gauge data from ports where records exist but have not been published, e.g. Ashdod, Haifa, and others.
   b) Calculate the ratios of rates of movement for co-located tide-gauge and archaeological data for other regions than Greece, so as to find the correction ratios to be applied in different regions.
   c) Obtain archaeological-historical data for the poorly documented regions. A regional study of a national coastline several hundred kilometres long can be conducted in one or two years, and is not expensive. Although the data are not as accurate as tide-gauge data, they are available almost immediately, whereas a tide-gauge installed now will have to be maintained for at least 10 years before it provides valid data on coastal earth movements.
5) The methodology suggested in this chapter has been worked out rather quickly and could be considerably refined. The data sets available for each region should be carefully assessed, and the best regional principles derived for prediction of the vertical rate of movement predicted over the next 50–100 years, with confidence limits.
6) The precise gradient of the shore at each point should be recorded in a database so that the extent of land flooded can be calculated for each additional 10 cm rise of relative sea-level, summed for eustatic and earth movement causes.

7 GENERAL NOTE

The present author has worked personally on over 300 coastal archaeological sites during the last 30 years. Several sites have been revisited at intervals during that period. The rate of destruction of coastal and submerged archaeological sites from both natural and human causes is considerable. Whilst some sites are probably well protected for natural reasons, and have remained unchanged for centuries, others have been seriously damaged in 1–10 years. The submerged classical city of Apollonia in Libya was severely damaged by winter storms between 1958 and 1959; the Bronze Age walls and Classical Theatre at Plitra-Asopos in Greece were destroyed by wave action between 1968 and 1979. Neolithic remains near Atlit (Israel) are exposed by natural sand movements each year on the sea bed, and organic materials are damaged when exposed. In other areas, classical slipways, harbour works and buildings in shallow water have been damaged or destroyed by the construction of coastal roads, yacht marinas and land reclamation.

If the unique record of the origins of marine technology in the Mediterranean is to be preserved for humanity, it is recommended that most threatened sites should be identified and a decision taken as to whether they should be protected, or whether detailed surveys and records should be made.

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