Mediterranean Quaternary River Environments

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CHAPTER 1

Quaternary fluvial systems in the Mediterranean basin

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1. INTRODUCTION

This introductory chapter has three principal aims. First, in broad physiographic terms, to define and delimit the Mediterranean basin. Second, to examine the nature and controls of Quaternary environmental change (natural and anthropogenic) in the region and consider how this has affected fluvial processes and drainage basin development. Third, to provide both a valley-reach and catchment-scale synopsis of alluvial settings in the Mediterranean basin, highlighting some of the distinctive elements of past and contemporary river environments.

The Mediterranean basin, demarcated by the watersheds of rivers that border and drain to the Mediterranean Sea (Fig. 1) (excluding the Nile whose catchment extends well to the south of the region), lies between 30°-47°N and between 5°W-37°E. It covers an area of similar proportion to the conterminous USA or Australia and, in terms of geology, geomorphology, climate, vegetation and culture, is equally diverse. The Köppen definition of a Mediterranean climate is one where winter rainfall is more than three times summer rainfall. This definition, however, includes areas such as Iran and Iraq that have winter precipitation of a cyclonic origin but which have no Mediterranean littoral. The distribution of the olive, where it is grown without the aid of irrigation, together with the northern limit of the palm (Fig. 2) have also frequently been used as the yardstick for the typical Mediterranean climate (Braudel 1972). Using these criteria it is clear that the area with a ‘truly’ Mediterranean climate is quite restricted although, conveniently for the purpose of this review, its boundary largely coincides with the watershed of river systems that flow into the Mediterranean Sea (Fig. 1).

The present day configuration of the Mediterranean basin results from the interplay between three major series of relief-forming factors. These are crustal mobility (directed in both horizontal and vertical directions), periodic climate and sea-level change and, in more recent times, human action. These allogenic, or extrinsic controls of river behaviour and development are now reviewed.

2. TECTONICS AND TECTONIC HISTORY OF THE MEDITERRANEAN BASIN

The Mediterranean basin is not only a zone of transitional climate and vegetation, but also forms the boundary zone between the Eurasian, African and Arabian plates (Fig. 3). The interaction of these plates has produced the Alpine fold belt that extends from Gibraltar to the Middle East. It has, however, an extremely complex and variable structure and is composed of a number of smaller secondary or microplates that have, in some cases, very different tectonic and stratigraphic histories to the adjoining Eurasian and African cratons (Dewey et al. 1973).

During the Cenozoic the Mediterranean region has been affected by generally north-south compression that culminated in the Late Miocene. This was followed by a tensional phase during which large areas of the crust founded and sank (Dewey et al. 1973). In the Aegean, for example, roughly north-south extension initiated in the Middle Miocene has resulted in a tectonic province characterized by approximately east-west trending horsts and grabens. The complex and dynamic situation along the boundary of the Mediterranean basin is the result of two types of horizontal relative motion affecting the Eurasian and African plates (Smith and Woodcock 1982). If it is assumed that the African plate is fixed, the Eurasian plate has moved to the east, as a consequence of different spread velocities since the opening of the Atlantic, and also to the south. Plate movement, however, is complicated by the presence of partially independent microplates or small blocks. The first type of motion produces strike-slip right lateral movement along the Azores, Gibraltar and Anatolia faults (Fig. 3). The second produces collision of the two plates, and formation of orogenic belts at the Calabrian and Hellenic subduction zones and also along the compressional belts of the Coast of Cadiz, the Tellian Atlas and the Dinaric Alps (Fig. 3). In all of these areas, oceanic crust of the African plate is being underthrust beneath the margin of the European plate. Along the Alpine chain, Pyrenees and Betic ranges, both sides of the contact are formed of continental crust.

The result from this tectonic framework as far as landforms are concerned is to produce three rather distinct environments around the Mediterranean. First, the Precambrian African plate underlying North Africa. Generally this is a low elevation desert environment. In the
Figure 1. Relief and river drainage network of the Mediterranean basin.
eastern Mediterranean it is diversified by rifting in Sinai and the Jordan Valley, whilst the higher mountains of Lebanon reach 3086 m (west) and 2659 m (east) of the Beqaa Valley. Second, the folded and partly metamorphosed Variscan Massifs in the Iberian Peninsula, Corsica and Sardinia. In eastern Spain these are covered by flat-lying or gently folded Mesozoic and Cenozoic sediments. The Spanish Meseta (tableland) can also be elevated (2592 m near Madrid). Third, the Alpine fold belts in the Maghreb, Pyrenees, the Apennines and Sicily, and the Alps proper extending eastward to Greece and Turkey. A major characteristic of these Mediterranean lands is their high relief. Before Alpine orogenesis, these areas formed part of an extensive shelf sea in which limestones were deposited. Their uplift has produced limestone mountains and karstic features, as in former Yugoslavia from which many of the technical terms for limestone landforms are derived. These hard-rock massifs commonly are juxtaposed with syn-orogenic and post-orogenic zones of marine (molasse) and subaerial (flysch) sediments, whilst active Late Cenozoic uplift has elevated such highly erodable materials to give high rates of erosion, as in the ‘young’ landscapes of the Italian Apennines and Calabria where there is highly active slope instability (Ergenzinger 1992).

Tectonics and structural controls have exerted a strong influence over fluvial systems in the Mediterranean basin in terms both of large-scale drainage basin morphology (size and shape) and river development. In tectonically active parts of the Mediterranean (Fig. 4), faulting, folding and tilting have resulted in significant recent drainage network disruption including drainage reversal, stream capture, dissection or ponding (e.g. Bailey et al. 1993; Harvey and Wells 1987). The Ebro and Po rivers, two of the largest river systems in the Mediterranean basin, show a strong relation to structural controls (Figures 1 and 3) and can be described as intra-orogen in type (sensu Summerfield 1991; p. 419, Table 16.5) draining along strike between mountain belts. More typically, in areas subject to active normal faulting or compressional folding (e.g. northeastern Mediterranean and Betics), Mediterranean rivers are of a trans-orogen type (Summerfield 1991) that drain across the strike of a mountain belt and have a characteristic basin and mountain range morphology. In these areas active structures produce a series of local folds, or uplifted blocks, separated by troughs with river profiles that alternate between stretches of downcutting of uplifted structures and aggradation in the subsiding regions between them. Climatically-induced cycles of incision and aggradation are superimposed on this but tectonic processes provide the underlying long-term determinants on the pattern of river erosion and sedimentation in the landscape (e.g. Lewin et al. 1991).

3 THE MEDITERRANEAN CLIMATE AND QUATERNARY CLIMATE RECORD

3.1 Present day Mediterranean climate
The present day wet-winter, dry-summer climate of the
Figure 3. The present lithospheric plate configuration and types of plate boundary in the Mediterranean basin together with the distribution of pre-Alpine continental basement. Arrows refer to plate motions relative to the Eurasian plate (after Dewey et al. 1973 and Windley 1984).
Mediterranean results from the seasonal expansion and contraction of the circumpolar vortex and the consequent displacement and withdrawal of the upper westerlies that guide the tracks of the rain-bearing depressions. The Mediterranean basin lies within the boundary between subtropical and mid-latitude atmospheric patterns and in common with southern California, western and southern Australia, the central Chilean coast and the Cape Town region of South Africa, which are similarly interposed between temperate maritime type and arid subtropical desert climates, it is particularly sensitive to a shift in this boundary. What sets the Mediterranean lands apart from these other west coast subtropical regions of the world is the influence of the Mediterranean Sea, which results in the extension of this climate type for more than 3000 km into Eurasia and North Africa. The intrusion of this large body of water into this continental area has an important effect on the climate of the bordering land. During the summer the effect is mainly one of moderating temperatures while in the winter the juxtaposition of cold and dry continental air with a relatively warm sea causes strong evaporation and atmospheric instability and this leads to local cyclone genesis (Gat and Magaritz 1980). There are, however, marked regional contrasts in annual rainfall (Fig. 5) and rainfall regime (Fig. 6) within the basin. These are partly determined by large-scale synoptic disturbances (e.g. cyclones advected from the North Atlantic or anticyclones that form over adjacent continental land masses), partly by interaction between orographic and land-sea controls, and partly by more local effects (Wigley and Farmer 1982). Rainfall amount in the Mediterranean, and duration of the rainy season, decreases from west to east and also from north to south across the basin (Fig. 5). The summer drought increases in the same direction both in length and intensity (Fig. 6). This primarily reflects the location of the southern and eastern Mediterranean littoral close to the southern margin of the depression tracks during the winter months. Rainfall amounts are also augmented by altitude most notably along the northern part of the basin on the western flank of mountain areas such as the Apennines, Dinaric Alps and Pindus Mountains (Fig. 5). Conversely, areas to the lee of these relief features tend to be correspondingly drier.

There exists, as a consequence of large-scale atmospheric-oceanic circulations in the region, a marked contrast between the pressure conditions over the eastern and western (Italian Peninsula and westwards) parts of the Mediterranean in winter and summer (Wigley and Farmer 1982). In summer both areas are comparatively stable though the western basin is mainly under the influence of a strong high pressure ridge which pushes east from the Azores subtropical high over the Mediterranean. The eastern basin falls under a low pressure area which extends from the Persian Gulf northwest towards Greece and which is associated with the Indian summer monsoon. In winter, pressure over the eastern basin is generally much higher than the west, with the former area affected by the Siberian high and associated polar continental air mass. In contrast, the western basin in winter is
normally an area of almost permanent low pressure—the result of relatively high sea temperatures and incursions of moist polar maritime air from the northeast Atlantic. Winter rain is mainly associated with cyclonic disturbances that originate in the Mediterranean basin (very few surface cyclones can be traced back to Atlantic origins) though their development is strongly influenced by orographic effects (e.g. the Mistral and Bora winds and associated weather). The vast majority of rainfall in the Mediterranean, especially in the southern and eastern parts of the basin, occurs when the upper westerlies are in their low index or blocked mode, and the polar front jet stream exhibits a strong meridional character allowing southerly transport of cold air which favours cyclogenesis (Perry 1981). On rare occasions monsoon air masses may bring summer rain to the eastern Mediterranean (Gat and Lagaritz 1980).

3.2 Mediterranean Quaternary Palaeoclimates

In general terms, climate in the Mediterranean during historic and prehistoric times has varied between relatively dry and relatively humid phases, distinguished by differences in amplitude and duration. As outlined above, the main factors which control weather patterns in the region are sea surface temperatures, in both the North Atlantic and Mediterranean, and the strength and latitudinal position of the mid-tropospheric circumpolar westerlies which principally determine the geographic distribution and amount of rainfall. Analysis of instrumental rainfall records, in conjunction with studies of recent changes in atmospheric circulation, are particularly useful in this respect as they provide a framework for interpreting past variations of climate in the Mediterranean and their likely synoptic controls. Winstanley (1973), for example, has demonstrated a link between increased winter-spring rainfall over the Mediterranean in the middle decades of this century and a low zonal index associated with a general cooling in the northern hemisphere. He attributes this to an ‘expansion’ of the circumpolar vortex and to changes in the strength and wave pattern of the upper westerlies. With a relatively weak zonal circulation there are relatively short, large amplitude waves in the circumpolar westerlies and the strongest westerly flow tends to be shifted southwards. Weather systems in the mid-latitudes are slower moving and periodic anticyclones develop which ‘block’ the eastward moving depressions and deflect them to the north and the south resulting in heavy rainfall over the Mediterranean. Regional variations of seasonal rainfall are determined by the preferred longitudinal position of the troughs and ridges. Recent enhanced blocking frequency over northwest Europe resulting in an increase in the percentage of the total Mediterranean precipitation falling in the warm seasons (North and Jones 1977), has also been shown to correspond with negative sea surface temperatures in the western Atlantic (Perry 1981).

Recent climate changes in the Mediterranean basin, especially the emerging link between rainfall and variation in the position and intensity of semi-permanent fea-
tures of both atmospheric and oceanic circulation, provide
a useful basis for interpreting Quaternary climate
fluctuations in the region. These climatic changes have
been reconstructed primarily from pollen and plant-
macrofossil records, and lake level changes. Although, in
practice, the relatively small number of sites investigated,
and the lack of geochronological control beyond the
effective dating range of radiocarbon, has restricted de-
tailed palaeoclimatic reconstruction to the Last Glacial to
Interglacial transition through to the present day (e.g.
Pérez-Olías and Julià 1994). Even over this period,
pollen- and lake level-based climate reconstructions do
not always match, especially during cold stages of the
Quaternary when vegetation and climate analogues are
particularly problematic (Prentice et al. 1992). Fur-
thermore, poor dating precision and the relative insensitivity
of many vegetation formations to modest, short-term,
climate events usually results in long-term, major
changes in climate (trends over several millennia) being
more reliably recorded than lower order climate variabil-
ity.

Lake level data for the Mediterranean as whole (Fig. 7)
show high lake levels around the time of the Last Glacial
Maximum (LGM) (c. 18,000 years BP), indicating that
the climate was wetter than today (Harrison and Diger-
feldt 1993). This is, however, at variance with pollen
evidence for widespread Artemisia steppe in the region at
this time, considered to reflect increased aridity (cf. Bot-
tem 1978; Bailey et al. 1983). Prentice et al. (1992) have
addressed this apparent contradiction and suggested that
increased seasonality of precipitation was a key factor,
with the LGM climate of the Mediterranean region char-
acterised by cold winters, intense winter precipitation and
summer drought. Markedly reduced winter temperatures
resulted from strong westerly advection from the cold
North Atlantic and the development of a fixed anti-
cyclone over the northern European ice sheet. The drying
and cooling effect of these may have been counteracted
in winter by increased storm frequency under a southward-
shifted jet stream. This may account for greater runoff
and high lake levels, while at the same time a growing
season soil moisture deficit and low winter temperatures
would have maintained an open vegetation.

Lake levels in the Mediterranean region began falling
soon after 18,000 years BP (Fig. 7) though there are some
systematic differences between lake level changes in the
Balkans and in the Iberian Peninsula (Harrison and Diger-
feldt 1993), and also between the western (Maghreb) and
eastern (Libya – Egypt) North African coast where arid
and humid phases during the Holocene are opposed
(Rognon 1987). In the western Mediterranean, the peak
of Late Glacial aridity occurred at 16,000-15,000 years
BP and the lake levels were already high again by 12,000
years BP. In the east, maximum Late Glacial aridity
occurred between 10,000-11,000 years BP. These dry
conditions seem to have resulted from the periodic north-
ern movement and strengthening of the subtropical high
pressure cells and with the general poleward shift of the
climatic zones during deglaciation. The northerly displace-
ment of the jet stream axis as the ice sheets receded, and
the low sea surface temperatures, would have removed
the additional source of winter precipitation. In the west-
ern Mediterranean conditions remained significantly
wetter than at present throughout the early to middle
Holocene. An abrupt transition to more arid conditions
occurred after 5000 years BP. In the east there was a
slower return to moister conditions with high lake levels
at 6000 years BP and a more gradual transition to drier
conditions between 5000 years BP and the present (Har-
ison and Digerfeldt 1993). Along the southern Medi-
terranean littoral a wet phase in the Maghreb after 6000-5000
years BP corresponded to a period of extreme aridity
along the eastern North African coast. Conversely, an arid
phase in the Maghreb around 12,000-6000 years BP was
mirrored by rainfall extension in the Egyptian-Libyan
desert (Rognon 1987). These differences in regional Ho-
locene climate histories are probably explained by gra-
dual changes in the number and location of meanders in
the jet stream which directly control the storm tracks and
precipitation in the southern Mediterranean area (Rognon
1987). In addition, enhanced early to middle Holocene
precipitation in the eastern Mediterranean is believed to
have been caused by a northern shift in the Inter Tropical
Convergence Zone (ITCZ), and its associated rains,
related to an “orbitally” strengthened monsoonal system
(Kutzbach and Street-Perrott 1985). Indeed, increased

Figure 7. Lake-level variations during the last 18,000 years in
(a) the Mediterranean region as a whole, (b) the western Medi-
terranean (the Iberian Peninsula), and (c) the eastern Mediterr-
anean (the Balkan Peninsula). The histograms indicate the relative
number of lakes with high, intermediate and low levels in
each region at 1000-year intervals (after Harrison and Diger-
feldt 1993).
summer rainfall may have been a key factor in the relatively high lake levels over most of the Mediterranean basin during the first half of the Holocene (Roberts 1989). Pollen and lake level evidence both suggest increasing summer dryness after 6000 years BP with the replacement of subhumid deciduous forest by drought-adapted sclerophyll evergreen trees and shrubs. The lake level data support the hypothesis of Huntley and Birks (1983) which argues that this was primarily controlled by climatic change.

To summarise, Quaternary climate fluctuations in the Mediterranean basin can be related to shifts in the boundaries, and influence of, mid-latitude and subtropical weather systems, which resulted in significant changes in the seasonality and geographic distribution of precipitation in the region. Humid and arid phases of climate have been a characteristic of both the Late Pleistocene and Holocene, although the synoptic conditions that controlled precipitation were significantly different during these two periods. Thus high lake levels during the LGM appear to have been in response to an increased winter storm frequency under a southward-shifted jet stream, displaced by the orographic barrier presented by the north European ice sheet. High lake levels during the early to middle Holocene, by contrast, can be explained by warmer sea surface temperatures, in both the Mediterranean and North Atlantic, increasing atmospheric moisture availability and precipitation, and also more frequent tropical air mass incursions into the region. Conversely, lower precipitation during the Last Glacial to Interglacial transition, and over the last 5000 years, can both be related to a northerly shift of the main upper westerly flow reducing the length of the rainy season. Greater aridity during the period of deglaciation reflects significantly lower sea surface temperatures than at present, reducing evaporation and atmospheric instability that leads to cyclone genesis over the sea. Climate during the middle to late Holocene, however, appears to have been spatially and temporally more variable due to periodic expansion and contraction of the circumpolar vortex and variation in its strength and wave pattern in the manner outlined by Winstanley (1973). Generally lower lake levels during this period indicate a progressive contraction of the circumpolar vortex and movement of the belt of westerlies northwards away from the region, although since around 3000 years BP it is difficult to differentiate between aridification and anthropogenic desertification.

4 RIVER RESPONSE TO QUATERNARY CLIMATE CHANGE

4.1 Climate change: sensitivity of geomorphic and vegetational systems

The climate of the Mediterranean basin over the Quaternary Period has been controlled by slow ($10^3-10^6$ years) insolation changes driven by orbital cycles and also by abrupt ($10^2-10^3$ years) shifts in atmospheric-oceanic circulation. These latter, decadal to century-scale oscillations in the thermohaline circulation of the North Atlantic have been attributed to outflows of glacial meltwater (Broecker and Denton 1989) and icebergs (Bond et al. 1992) during the transition from the last ice age to the present interglacial, and in the Holocene to variations in solar radiation, influencing temperature, precipitation and salinity in that part of the North Atlantic where deep water formation is important (Stuiver and Braziunas 1993). There is also considerable empirical evidence to suggest a link between short term climate change (decades or less) and volcanic activity (e.g. Bailie and Munro 1988). Geomorphic and vegetational systems do, however, differ greatly in their sensitivity to climate change particularly with respect to magnitude and duration. For example, vegetation generally responds to mean conditions with the distribution of vegetation types at the sub-continental scale reflecting average climate. Thus, major vegetation changes between interglacial and glacial stages have been primarily controlled by, and tracked, long-term insolation changes resulting from orbital forcing. River systems, on the other hand, can respond immediately to variations in the character, frequency and magnitude of extreme events, such as floods, that need not necessarily modify vegetation within a catchment. Quaternary climate change has had a profound effect on sea level, vegetation development and catchment hydrology, all of which directly influence river processes and environments. These major controls of short and long-term fluvial dynamics are now briefly examined.

4.2 Sea-level change

It is well known that the alternating growth and shrinkage of Pleistocene ice sheets resulted in large (of the order of 120-150 m) global (eustatic) sea-level change. The coast of the Mediterranean during the LGM was significantly different from that of the present (Fig. 8). With sea level lowered to around 120 m, large plains existed off the coast of Tunisia, fringed most of Italy, southern France and much of Greece (van Andel 1989). During periods of falling sea level rivers adjusted through drainage network extension across the newly exposed shelf surface and by limited channel degradation near the former coastline. At times of sea-level rise, network contraction and valley back-filling took place. Away from the coast, however, the steep valley floor gradients of most Mediterranean rivers ensured that base-level changes, associated with fluctuations in sea level, had very little impact on channel and floodplain development inland. The main effects were to shift the position of deltas found at the mouths of a number of major rivers including the Ebro, Nile, Po and Rhône, and to change rates and patterns of sediment delivery to the shelf-slope depositional systems. In the Gulf of Argos, Greece, for example, fluctuating Quaternary sea levels resulted in the formation of thick wedges of coastal sediments comprising marine sediments intercalated with floodplain and alluvial fan deposits (cf. van Andel et al. 1990). Relative sea level changes related to alternating climatic conditions are complicated by changes resulting from tectonic activity. For example, in
Greece conglomerates which are of Late Pliocene or early Quaternary age can be found at over 1000 m above present sea level. In western Crete, coastal archaeological features dated to around 2000 years BP have been uplifted as much as 9 m (Mourtzas 1990).

4.3 Vegetation change

Vegetation in the Mediterranean basin, as elsewhere in the world, is largely controlled by climate in the absence of human interference. Pollen studies (e.g. Pons and Reille 1988; Wijmstra 1969) indicate alternations between forest and open vegetation communities over the Quaternary in response to shifts from 'warm' to 'cold' climate modes. Generally speaking, glacial (stadials) in the Mediterranean were characterised by Artemisia-dominated steppe, interstadials by forest steppe to open pine-oak forest and interglacials by mesic or evergreen oak forests (e.g. Tzedakis 1993). The critical climate variable governing these vegetation changes is believed to be differences in precipitation with changes in temperature being of secondary importance. In the northern part of the basin, and in mountain areas, temperature changes and a resistance to cold (as well as drought) are likely to have been equally important. The Mediterranean basin, most notably in the mountains of the Iberian, Italian and Balkan Peninsulas, also provided refugia for the temperate tree flora of Europe during glacial periods (Bennett et al. 1991).

The Mediterranean forest, typified by evergreen trees such as cork-oak (Quercus suber), holm-oak (Quercus ilex), Aleppo pine (Pinus halepensis), stone pine (Pinus pinea) and olive (Olea europeae) forms a narrow peripheral coastal belt transitional between the mid-latitude deciduous (summer green) forest and the desert biome (Fig. 9). Towards temperate environments (in latitude,
altitude and inland location) deciduous trees mix with the holm oak. Towards low latitudes, holm oak is replaced by trees more resistant to drought (thuja) and to cold at altitude (conifers, including cedar) (Quezel 1977). Of the major plant formations found in the Mediterranean basin today, only sclerophyll evergreen forest, scrub (maquis) and dry heath (garrigue) are distinct to that ecotype. All are adapted to survive through the long summer drought and are fire resistant. The Mediterranean maquis and garrigue are not generally considered to be natural formations, except in particular drought-prone areas where maquis could have been the primary vegetation (Tomasselli 1977). More usually they are stages in the degeneration of the Mediterranean sclerophyll evergreen forest, a degeneration almost always due to human intervention (see below).

Given that erosion is largely controlled by vegetation cover, significant changes in biomass, litter amounts and stem density in response to climatic (or human) perturbation may be expected to lead to accelerated hillslope runoff and erosion and increased sediment delivery to rivers. The impact vegetation change has on the fluvial system, however, depends on three factors (Thornes 1989). First, there is the location of vegetation change within a catchment as this affects the relevant delivery ratio through the nature of possible intervening stores. Second, the density of vegetation is an indication of the effectiveness of vegetation cover as a protection against raindrop impact and runoff. Above 70% cover the effect of changes in cover is far less significant than below that level, beyond which soil loss increases dramatically. Third, a steady state can neither be reached, nor maintained, if the relaxation time of the system is longer than the mean recurrence time of the disturbance to it. This third factor is probably the most contentious and certainly the least well understood. Until recently it was generally assumed that climate change during the late Quaternary was relatively gradual, occurring over millennia, and that vegetation would probably have had enough time to adjust to new climatic conditions. However, recent results from the European Greenland Ice Core Project (GRIP) and the US Greenland Ice Sheet Program II (GISP 2), together with analysis of sea floor sediments in the North Atlantic, have shown that climate change was neither smooth nor gradual, but occurred very rapidly with a change from interglacial to glacial conditions taking place, in some instances, in less than a decade (e.g. Bond et al. 1993). An abrupt or step-functional change of this nature would undoubtedly have exceeded both vegetation and soil systems' capacity for adjustment, triggering a period of landscape instability with high erosion rates, valley floor aggradation and river metamorphism (cf. Knox 1972). Unfortunately, even though this scenario appears intuitively very probable, there are at present no well-dated, high-resolution Late Pleistocene fluvial chronologies in the Mediterranean to test this hypothesis.

4.4 Hydrological change

There have been considerable changes in catchment hy-


drology and river regime over the Quaternary Period in the Mediterranean basin. Present day river regimes in the region bear the stamp of the Mediterranean climate with a strong late autumn, winter or early spring peak and minimum flow in the summer unless rivers are fed by groundwater in limestone areas. This runoff pattern largely results from rainfall alone (Fig. 10), though prominent early spring peak flows in the mountain areas of the Iberian Peninsula, Balkans and Anatolia relate to storage of some winter precipitation as snow which is then released in spring to give a thaw peak (Bekinsdale 1969). During the summer months thunderstorms (frequently orographically enhanced) can cause localised flooding, especially in small mountain basins with high relief. On rare occasions, northward intrusion of tropical air masses in the eastern Mediterranean can also generate large summer floods (Gat and Magaritz 1980). Some of the most notable recent floods, however, such as the famous Tunisian flood of 1969 (Stuckmann 1969), the flood disaster in southeast Spain in 1973 (Bork and Bork 1981) and the 1977 floods in Piedmont and Liguria (Perry 1981), occurred during the transitional seasons, especially in September and October when the air-sea surface temperature difference is at a maximum and potential atmospheric instability is high.

General circulation modelling (GCM) simulation experiments (Kutzbach and Guetter 1986) indicate that temperatures in the Mediterranean region during the LGM were 5-10°C lower that at present in winter and 1-3°C lower in summer. They also show a year-round strengthening, and equatorial shift, of the jet stream and increased winter precipitation along the jet stream axis at or over the latitude of the Mediterranean (COHMAP 1988). This is likely to have had two principal effects on catchment hydrology. First, it probably increased seasonal snow cover in mountain areas, particularly in the northern Mediterranean littoral and provided favourable conditions for ice accumulation and glacier development (Fig. 11). Second, in internally draining, tectonically-controlled basins, higher runoff created sizeable lakes or significantly increased water levels where lakes were already present (Bottema 1978; Pons and Reille 1988). In rain-fed basins principally draining the southern and eastern margins of the Mediterranean basin, and unaffected by snow or ice, seasonal flow fluctuations would have been especially pronounced with a considerably extended dry season in the summer half of the year. Glaciated catchments and those with significant seasonal snow cover would have had a strong spring/early summer nival flow peak. In contrast to present hydrological regimes, winter rather than summer would have been the time of minimum flow in these systems. On the west facing flanks of coastal mountains, autumn storms bringing heavy rain on shallow snow could have induced very large floods. Overall, river regime in the Mediterranean basin during cold stages of the Quaternary was probably not only more seasonal than at present but also exhibited greater spatial and temporal variability.

In the eastern Mediterranean Sea the formation of extensive layers of black mud rich in organic matter,
Figure 10. Rainfall regimes in the Mediterranean basin (after Huttary 1950). This map also provides a useful approximation of the range of river regimes found across the Mediterranean region. The Mediterranean watershed is also shown (see Fig. 1).
Figure 11. Pleistocene glacial features and sediments in the Mediterranean basin and southern-central Europe (after Messerli 1967).
called 'sapropels' has been shown by Rossignol-Strick and others (1982; 1985) to be related to periods of high discharge from the River Nile, caused primarily by increased monsoonal precipitation and runoff from the northern Ethiopian highlands. Such floods deliver large volumes of freshwater which, being less dense than seawater, form a low salinity surface layer that stratifies the ocean and prevents thermohaline convection. This results in oxygen depletion in bottom waters allowing organic-rich sapropel muds to be deposited on the sea bed. In this way, Mediterranean sapropels constitute a unique proxy record for the longer-term variations in the African monsoon (Rossignol-Strick 1985). Eleven discrete basin-wide sapropels have been identified in the eastern Mediterranean Sea and were formed at various periods during the last 465,000 years. The two most recent sapropels, deposited in the intervals 11,800-10,400 and 9000-8000 years BP, have been related to major flooding along the Nile as a consequence of the intensification and northward displacement of the African monsoon during the Late Glacial to Holocene transition (Rossignol-Strick et al. 1982).

5 HUMAN IMPACT

5.1 Historical and geographical context

One of the singular characteristics that sets the Mediterranean basin apart from other parts of the world which also have a Mediterranean climate, such as central Chile, western and southern Australia, South Africa and California, is the long history of human interference and management of the environment. Whereas all the other 'Mediterranean' areas experienced major human modification only during and after the era of European colonization (post 1500 AD), environmental change in the Mediterranean basin induced by human action can be traced back to the Neolithic agricultural revolution in the Near East around 8000 BC. Indeed by about 5000-4000 BC agro-ecosystems had been established along the entire Mediterranean coast, in all areas suitable for farming, and since then they have been continuously subject to human influence (Ammerman and Cavalli-Storza 1971).

Human environmental impact can be considered as inadvertent when arising, for example, from deforestation or land use change, or direct when interference is planned, as in the case of river regulation for irrigation or construction of embankments for flood protection.

5.2 Inadvertent change

Beginning in the southeastern Mediterranean, extensive deforestation in advance of agriculture created an open landscape as early as 3000 BC, which proved highly susceptible to erosion. The first major basin-wide assault on the forest occurred with the establishment of the Roman Empire and by the time of the end of the Roman Period more than half of the Mediterranean forests had been devastated (Tomuselli 1977). Since then the forest balance has hardly changed, at least in the most populated regions where forests have remained concentrated on ground unfit for cultivation. In the Middle Ages there was renewed clearance notably in Arab-held Spain and Sicily and large parts of the eastern Mediterranean governed by the Byzantine or Ottoman Empires. By the middle of the...
nineteenth century at least three quarters of the Mediterranean forest had disappeared (Tomaselli 1977).

Not surprisingly, therefore, large-scale vegetation destruction and land misuse, which accelerated rapidly in classical times, are generally held to be the principal causes of environmental degradation in the Mediterranean region (cf. van Andel et al. 1986). Even in the absence of humans, high relief and steep slopes, large areas of friable soils and unconsolidated sedimentary rock, and high-intensity rainfall events are all factors that make Mediterranean river basins naturally prone to erosion. Suspended sediment load data is not available for many Mediterranean rivers especially those draining southshore catchments between Algeria and the Nile. Elsewhere, however, a few nations have long-established sediment monitoring networks which provide some useful insights into regional contrasts in fluvial suspended sediment transfer rates within the Mediterranean environment (Fig. 12). Jovanoviv and Vukcevic (1957) have mapped sediment yield data in the former Yugoslavia and report values ranging from <100 to over 600 t km\(^{-2}\) yr\(^{-1}\) with the latter figure associated with severe sheet and gully erosion in the humid montane zone to the east of Albania. Elsewhere the highest suspended sediment yields are often associated with those steepland terrains that experience high intensity precipitation events (Fig. 12).

By removing, or modifying, the natural vegetation cover, which usually provides effective protection against erosion, human activity has led to a reduction in evapotranspiration and increased surface water drainage during storms causing accelerated rates of soil erosion, piping, gullyying, gravitational movement and, in some cases, deflation. This is well illustrated in Figure 13 which shows that present suspended sediment yields in the Mediterranean have the highest anthropogenic component of any climatic-vegetation zone, underlining the inherent fragility of the Mediterranean ecosystem and its vulnerability to human disturbance. The widespread anthropogenic acceleration of erosion rates is partly reflected by the presence of gully networks and badlands terrain in many parts of the Mediterranean region. Table 1 lists some published examples of gully and badlands development from across the region which span a wide range of precipitation regimes (c. 90 to 2000 mm). In most cases the erodible substrates are unconsolidated silt-rich materials of Tertiary age (see Bryan and Yair 1982; Campbell 1989). Changes in catchment vegetation cover (e.g. excessive burning, overgrazing, increases in the size of cultivated areas) are one of the most commonly cited causes of increased runoff and channel network extension, though short-term climate fluctuations or possibly the occurrence of threshold-exceeding storm events may also be important (Alexander et al. 1994). Despite the erodible nature of many Mediterranean soils, the marked regional variations in suspended sediment yield discussed above indicate that many areas are undergoing relatively low fluvial erosion at the present time. In some situations, however, these figures may be accounted for by low sediment delivery ratios and high rates of colluvial and floodplain storage. Alternatively, in some areas, a longer-term sediment exhaustion effect is evident where the pace of soil replenishment has outstripped soil formation during the historical period. Sparsely vegetated bedrock slopes and thick sequences of stratified slope deposits containing large volumes of fine sediment are a characteristic feature of the Mediterranean landscape. Recent work by Gilman and Thomes (1985) for example, suggests that, despite the widespread presence of gully systems, only limited amounts of soil erosion have taken place in parts of southeast Spain since the Bronze Age.

In general flooding and flood peaks, river sediment loads, rates of valley floor and coastal alluviation also usually increase following disturbance, or destruction, of vegetation by human activity (cf. Butzer 1982). At the same time, erosion and compaction of soil causes reduced soil depth, soil water storage and infiltration capacity, often resulting in a decrease in groundwater recharge and lower dry season flows. The appearance of Mediterranean landscapes bears witness to the contrasting impact of accelerated erosion on different terrains. On limestones, the removal of shallow soils may produce bare rock surfaces. Extensive grazing by goats may extend the effects of human occupancy widely into mountain terrains (cf. McNeill 1992). On readily-erodible bedrock, including flysch deposits, vegetation degeneration may lead to extensive gullying and slope instability. Fine sediments generated by these processes may become a major component of alluvial materials accumulating in the lower parts of river catchments (Macloed and Vita-Finzi 1982; Woodward et al. 1992).

5.3 Planned change

Since antiquity the three primary elements of river regulation in the Mediterranean basin have been irrigation,
Table 1. Some examples of badland and ‘semi-badland’ development on a range of lithologies and under various rainfall regimes in the Mediterranean region (largely after Campbell 1989 with additions).

<table>
<thead>
<tr>
<th>Reference</th>
<th>Mean annual rainfall (mm)</th>
<th>Location</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alexander (1982)</td>
<td>450</td>
<td>Agri basin, Basilicata, Italy</td>
<td>Plio-Pleistocene marine clays, silt clays, interbedded sands, soft shales and mudstones</td>
</tr>
<tr>
<td>De Ploey (1974)</td>
<td>350</td>
<td>Kasserine area, central Tunisia</td>
<td>Clays, loams and sandy lithosols developed on Cretaceous marls</td>
</tr>
<tr>
<td>Harris and Vita-Finzi (1968)</td>
<td>1500</td>
<td>Kokkinotipos, Louros valley, Epirus, NW Greece</td>
<td>Red silts and clays of uncertain age and provenance</td>
</tr>
<tr>
<td>Harvey (1982)</td>
<td>170-350</td>
<td>Almeria-Alicante region, Spain</td>
<td>Cenozoic (mostly Tertiary) and Triassic marls, silts, shales and sandstones</td>
</tr>
<tr>
<td>Imeson et al. (1982)</td>
<td>300</td>
<td>Rif Mountains, Morocco</td>
<td>Villarfranchian, Phocene and sub-recent marine sediment, alluvial and colluvial deposits</td>
</tr>
<tr>
<td>Woodward et al. (1992)</td>
<td>2000</td>
<td>Pindus Mountains, Epirus, NW Greece</td>
<td>Miocene flysch sediments: alternations of sandstones and fissile silstones</td>
</tr>
<tr>
<td>Yair et al. (1982)</td>
<td>90</td>
<td>Northern Negev, Israel</td>
<td>Palaeocene marls and soft shales</td>
</tr>
</tbody>
</table>

land reclamation and flood control. Deliberate, or direct, modification of the river environment and river basin hydrology in the Mediterranean region probably began in Egypt where there is evidence that floodplain agriculture was supplemented by elaborate gravity-fed irrigation systems as early as 3,000 BC (Harmad 1961). Irrigation was, and still is, required by nearly all agriculture in the semi-arid and arid areas of the Mediterranean basin. In land adjoining mountain areas such as the Sierra Nevadas of Spain, the Taurus Mountains of Anatolia and the peaks of Lebanon, snowmelt has also been used for irrigation. Floodwater farming (often called rainwater harvesting) has also been extensively practised in certain parts of the region (cf. Evenari et al. 1982). Irrigation has often been associated with the reclamation of mountain slopes by terracing in mountainous regions such as Greece where agricultural land is limited in extent (cf. Pope and van Andel 1984). In contrast, flood-prone and naturally waterlogged valley bottoms, lake basins, coastal lowland and deltaic flats required land drainage and flood abatement measures. In some of the larger river and coastal wetlands, such as the Ebro Delta and Pontine Marshes, this proved to be impracticable until the present century. In smaller river systems, structural approaches to flood control have long been employed and were common practice among the Hellenic Greeks (Braudel 1972). In the face of repeated disastrous floods, frequently exacerbated by catchment deforestation and poor agricultural practices, two basic forms of regulation were used. They used the first utilized flood storage dams in smaller tributaries of the catchment to reduce flood peaks and to slow down runoff to the main stream. Stored water could also be used for irrigation purposes. The second type of flood control was designed to protect floodplain areas directly through the construction of artificial levees and embankments or to accelerate runoff by channel straightening.

Although irrigation, land reclamation and flood control have all increased agricultural productivity in the Mediterranean basin, and provided additional land for settlement and farming, designed modification of channels and drainage networks not in sympathy with natural river dynamics have had a number of adverse environmental impacts. Ultimately, irrigation systems in drylands suffer from two undesirable effects: salinization and waterlogging of the soil. As a result large areas of once fertile soil deteriorate into waste land. Problems can also arise from flood irrigation works. For example, construction of artificial levees along rivers with large sediment loads frequently leads to aggradation resulting in channels becoming perched well above the level of their former floodplain. This not only makes drainage of riparian fields almost impossible but also significantly increases the risk of disastrous floods if embankments are breached. Even agricultural terraces, though of great value in soil and water conservation in steepland environments, by decoupling slope-channel sediment transport significantly reduce river loads which in the long term promotes channel incision and lowering of valley bottom water tables (cf. Wise et al. 1982; van Andel et al. 1986). To summarise, the Mediterranean basin is an ecologically fragile environment which has been deeply marked, and often irrevocably damaged by millennia of human activity. Echoing the views of Grenon and Batisse (1989), perhaps nowhere else has nature done so much for humankind and human’s have in turn so transformed nature.

6 FLUVIAL PROCESSES AND ALLUVIAL SETTINGS FOR MEDITERRANEAN QUATERNARY RIVER ENVIRONMENTS

6.1 Background

By world standards rivers draining to the Mediterranean Sea, with the notable exception of the exogenous River Nile, are relatively minor. This primarily reflects tectonic plate configuration in the region with areas of uplift tending to be located close to the coast thereby constricting inland drainage. The Ebro (84,230 km²), Po (70,090 km²) and Rhône (95,590 km²), by far the largest rivers in the region which have their headwaters entirely within
the Mediterranean basin, are dwarfed in terms of discharge, sediment load and drainage area by the major rivers of the World such as the Amazon (7,050,000 km²), Mississippi (3,248,000 km²) and Yangtze (1,175,000 km²). Nevertheless, active tectonics (including volcanism), periodic climate change and human activity over the Quaternary Period have, to varying degrees, induced significant variation in rates and patterns of sediment and water yield, and created a highly diverse suite of active and relict Mediterranean riverine landscapes. Although a comprehensive model of river response to environmental change has yet to be defined, several broad generalizations can be made about fluvial processes, sedimentation styles and resultant alluvial architectures in the region.

6.2 Steepland river systems

Taking the 500 m contour as the mountain-lowland boundary (Fig. 1), it is clear that most of the Mediterranean basin (especially its northern and western margins) is drained by steepland river systems. These usually have steep, boulder- or cobble-bed channels which are very often deeply incised into older alluvial or colluvial fills and, in some instances, bedrock. These entrenched channels are termed Wadis in the Near East and North Africa, Fuimaries in Italy and Ramblas in Spain. They carry high sediment loads derived from channel scours, bank erosion or direct inputs (e.g. mass movements) from valley slopes. In the wetter and cooler mountain environment on the northern Mediterranean littoral (e.g. Iberian Peninsula, Italy, Balkans) high magnitude floods, resulting in rapid channel changes, are often associated with snowmelt and summer thunderstorms. A significant number of these catchments (Fig. 11) were glaciated in the Wiirm and in earlier Pleistocene cold stages resulting in the formation of extensive outwash plains in some areas (e.g. Lewin et al. 1991). Formerly glaciated drainage basins have had to adjust to markedly different flood and sediment delivery regimes in the Holocene. Many have followed a ‘paraglacial’ (see e.g. Church and Ryder 1972) course of development with decreased sediment supply rates resulting in progressive channel incision and the formation of a staircase of valley floor terraces. However, in steepland catchments severely modified by forest clearance and agriculture, rates of valley floor incision have slowed, or have even been reversed, during the late Holocene as a result of accelerated slope erosion. It is also very likely that mountain drainage basins in the Mediterranean have been affected by second-order, relatively modest, climatic fluctuations during the Holocene, most probably shown by changes in flood regime and mass movement rates. Unfortunately the provision of dating control for Holocene alluvial fills in steepland river systems within the region, at the moment, is generally inadequate to be able to test a causal link between river activity and recent climate change.

Upland and mountain streams in the presently semi-arid (mean annual rainfall 250-500 mm) and arid (mean annual rainfall 50-250 mm) environments of North Africa and the Near East have ephemeral regimes characterized by rare, high magnitude, short-lived flood events. Following intense convective storms, hydrographs can rise and fall almost instantaneously with ‘walls of water’ often reported racing down channels (Schick 1988). These floods commonly transport very large volumes of clastic bedload (Laronne and Reid 1993) and yield high amounts of suspended sediment. Evaporation and transmission losses are often high, resulting in a marked decline in flow rates downstream and rapid depletion of sediment loads. Semi-arid and arid upland river environments in the Mediterranean basin have been especially sensitive to Quaternary climatic variations, primarily in response to precipitation-related changes in vegetation cover and sediment yield (e.g. Macklin et al. 1994). In general terms, a shift to a wetter climate in these areas increased vegetation density, reduced sediment delivery to valley floors and resulted in enlargement and incision of trunk channels. Conversely, slope degradation and valley floor aggradation would appear to be more characteristic of periods with lower rainfall and decreased vegetation cover. Emptying of hillslope sediment reservoirs, and greater flashiness of runoff resulting from increased areas of exposed bedrock are, however, likely to have provided negative feedback mechanisms limiting valley floor aggradation (cf. Bull 1991). Sediment exhaustion effects may therefore have induced degradation under stable climatic conditions. One particularly distinctive type of steepland Mediterranean river system are those which drain active volcanoes (Fig. 4). Quaternary-age volcanoes in the Mediterranean basin are restricted to the Hellenic and Calabrian areas (Fig. 4), though the only river systems affected by explosive volcanic activity that have been studied in detail are the Alcantara and Simeto Rivers which drain Mount Etna, Sicily (Chester and Duncan 1982). Here, several episodes of volcanism-induced sedimentation and erosion are documented dating back to Middle Pleistocene times. Aggradation occurred during short periods when eruptions produced sediment-choked streams, and these were separated by longer periods of non-deposition and incision as streams adjusted to a diminished sediment load.

6.3 Alluvial fans

Where steepland river systems issue from faulted or tectonic mountain fronts, or at valley-tributary junctions, alluvial fans commonly develop. Alluvial fans form important sedimentary environments and are one of the most widespread fluvial depositional landforms in the Mediterranean basin. The majority of the larger alluvial fans in the region, particularly those developed at the mountain-coastal plain junction (e.g. Crete, Nemec and Postma 1993; southern and southeast Spain, Harvey 1990), have been shown to be relict Pliocene forms which presently display low activity rates. Currently active fans tend to be restricted to steep mountain environments and intensely dissected badlands, sometimes in regions of tectonic activity (Sorriso-Valvo and Sylvester 1993). It is generally believed that alluvial fans in the Mediterranean region accumulated during Pleistocene
cold stages with relatively high rates of weathering in their mountain catchments and a greater effectiveness of storm runoff than today (Rohdenburg and Sabelberg 1980). Climatic amelioration and stabilisation of slopes by vegetation saw a reduction in sediment supply, fan trenching and, in some cases, limited progradation of the distal fan area (Harvey 1992).

6.4 Basin and range environments

Downstream of the mountain-piedmont junction the recurrent relief pattern in the middle and lower reaches of many Mediterranean drainage basins (particularly those in current or former compressional or extensional tectonic terrains) is one of mountain and basin topography (cf. Bloom 1991). Narrow, deep bedrock canyons cut in uplifted blocks, alternate with lower gradient alluvial plains accommodated in downstream basins within which active gravel-bed, braided river systems are commonly developed. Many of the larger Late Pleistocene 'pluvial' lakes (e.g. Padul, Spain; Ioannina, Greece) were also formed in intermontane basins where, as the result of long-term subsidence, thick interbedded fluvial, paludal and lacustrine sedimentary sequences are preserved. Faulting and folding associated with active tectonics has generally restricted the development of extended alluvially-formed channel reaches in the Mediterranean basin. Instead, extensive alluvial channel systems only occur on coastal plains and in the larger drainage basins such as the Ebro and Po which are developed in transitory tectonic settings. Even in these areas of relatively low seismic activity, slow ongoing deformation can result in the disruption of drainage networks. This is well shown in the middle Ebro Valley near Zaragoza where localised uplift has resulted in progressive channel entrenchment and partitioning of an extensive alluvial plain into a series of smaller alluvial basins separated by bedrock-controlled reaches (Ramirez Merino et al. 1992).

6.5 Coastal alluvial plains and deltas

At the coast, in the absence of serious tidal scour in the Mediterranean Sea, impressive deltas have been formed at the mouths of many river systems. The four major Mediterranean deltas (in order of size) are the Nile (delta area 22,000 km²), the Po (770 km²), the Rhône (720 km²) and the Ebro (350 km²). Sedimentary sequences that comprise these emerged deltas, and those accumulated on adjacent continental shelves, constitute the thickest and most extensive Pliocene-Quaternary deposits in the Mediterranean basin (Got et al. 1985). Deep penetration seismic profiling, and drilling by the oil industry, have established Pliocene-Quaternary series thicknesses of more than 5000 m and 3500 m on the Po and Nile delta shelves, respectively, and depocentres of between 1000-2300 m in the Ebro and Rhône deltas. In the indented coastlines of Greece and Turkey, historical alluviation has wrought considerable changes to the coastline and the development of coastal alluvial plains has transformed the settings of many historical and earlier archaeological sites (cf. Vita-Finzi 1978). For example, the ancient site of Troy, in Anatolia, western Turkey, is now well inland (Kraft et al. 1980), whilst the battle site of Thermopylae, north of Athens (at the time, 480 BC, a narrow coastal pass around 100-200 m wide at the foot of Mount Kallidromon) is now 4 km from the sea in the Gulf of Malia (Kraft and Rapp 1988).

The Ebro (Maldonado 1975), Nile (Warne and Stanley 1993), Po (Got et al. 1985) and Rhône (Duboulay-Razavet 1954) deltas have experienced rapid growth in historic times. In the case of the Ebro and the Po, progradation of the delta front in the Medieval and post-Medieval periods approached 5-7 km per century (Got et al. 1985; Maldonado 1972). Accelerated deposition in these and many other coastal delta plains resulted in the silting up of a considerable number of ancient harbours including Ephesus (Eisma 1978; Ering 1978) and Ostia Antica, the former port of Rome. This has been attributed to deforestation and poor agricultural practices in catchment areas (Brücker 1986), and the construction of artificial levees inland increasing sediment delivery to the coast. Interestingly, recent work on the Rosetta and Damietta promontories of the Nile Delta has indicated that the switch from a predominantly prograding to an eroding state can take place relatively rapidly on such major delta systems. Such a change took place on the Nile Delta as recently as 1900 following precipitation changes in East Africa and a marked decrease in Nile flood magnitude (Frihy and Khafagy 1991).

7 INTRODUCTORY REMARKS AND STRUCTURE OF THE VOLUME

Nineteen papers on river basins from more than half of the countries (Algeria, France, Greece, Italy, Libya, Spain, Tunisia and Turkey) that border the Mediterranean Sea are included in this volume (Fig. 14). In Tables 2(a) to 2(d) their climate, geomorphology and tectonic regime are summarised together with the time periods and topics of investigation. Two studies, by James and Chester in southern Portugal and Roberts in north-central Turkey, fall outside the watershed of the Mediterranean basin sensu stricto. However, southern Portugal is encompassed by the classic definition of the Mediterranean based on the distribution of the olive (Fig. 2). From Table 2 it is clear that coverage of the northern Mediterranean basin in this book is more comprehensive that the southern and eastern Mediterranean littoral. Significant omissions in this respect are river systems in the Middle East (Israel, Lebanon, Syria), western Maghreb (Morocco), Cyrenaica (Libya) and Egypt, as well as the former Yugoslavia and Albania. Nevertheless, a wide spectrum of river environments and histories are presented which, in terms of climate, tectonic activity and human impact, are generally representative of the Mediterranean basin as a whole. Climatically they extend from the hyper-arid Tripolitanian valleys of west Libya to the humid, formerly glaciated river basins of the northern Pindus Mountains, Greece. With reference to tectonics, the vo-
Figure 14. Map of the Mediterranean basin showing locations of study areas in the volume.
Table 2(a). List of authors, climatic and geomorphic details of study basins, time periods and topics of investigation in the Iberian Peninsula.

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Country</th>
<th>River basin(s)</th>
<th>Climate</th>
<th>Present tectonic activity</th>
<th>Fluvial setting</th>
<th>Time period of investigation</th>
<th>Topic of investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>James &amp; Chester</td>
<td>Portugal</td>
<td>Arade, Enxerim, Lombois, Odeleouca, Quarteira, Aguas, Fecs, Sorbas</td>
<td>Semi-arid</td>
<td>Sub-humid</td>
<td>Basin and range, coastal alluvial plain</td>
<td>Quaternary</td>
<td>River-sediment catchment source linkages, alluvial soil chronologies</td>
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<td>Middle-late Quaternary</td>
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Table 2(b). List of authors, climatic and geomorphic details of study basins, time periods and topics of investigation in France and the Italian Peninsula.

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<th>Author(s)</th>
<th>Country</th>
<th>River basin(s)</th>
<th>Climate</th>
<th>Present tectonic activity</th>
<th>Fluvial setting</th>
<th>Time period of investigation</th>
<th>Topic of investigation</th>
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<td>Provansal</td>
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<td>Arc</td>
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<td>Relationship between climate, sea-level and land-use change and delta plain development Catchment, land-use change and valley floor alluviation</td>
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<td>Basin and range</td>
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<td>Steepland, basin and range</td>
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Table 2(c). List of authors, climatic and geomorphic details of study basins, time periods and topics of investigation in Greece and Cyprus.

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<th>Time period of investigation</th>
<th>Topic of investigation</th>
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<td>Collier et al.</td>
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<td>Arakthos, Luras, Peneios, Sperchios</td>
<td>Semi-arid to humid</td>
<td>High to very high</td>
<td>Steepland, alluvial fan basin and range, fan-deltas Basin and range</td>
<td>Pliocene-Quaternary</td>
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<td>Gali-Papanastassio &amp; Maroulkan</td>
<td>Mainland Greece</td>
<td>Berbadiotis, Dafniotena, Havos, Kouleouvinas, Ksirias, Megalo Rema Pouzi, Tremithios, Xeropozzzi</td>
<td>Sub-humid</td>
<td>Very high</td>
<td>Steepland, alluvial fan</td>
<td>Quaternary</td>
<td>Tectonic, climatic and anthropogenic influences on river erosion and sedimentation</td>
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<td>&amp; Maroulkan</td>
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<td>Semi-arid</td>
<td>High</td>
<td>Alluvial fan basin and range, coastal alluvial plain</td>
<td>Quaternary</td>
<td>Facies sequences and allochthonous/ autochthonous controls of fluvial sedimentation</td>
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<td>(Chapter 8)</td>
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<td>Stevens &amp; Wedel</td>
<td>Cyprus</td>
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<td>Semi-arid</td>
<td>High</td>
<td>Alluvial fan basin and range, coastal alluvial plain</td>
<td>Quaternary</td>
<td>Facies sequences and allochthonous/ autochthonous controls of fluvial sedimentation</td>
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<td>(Chapter 20)</td>
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lume includes papers on seismically quiescent river basins, such as those that drain the northern flank of the Iberian cordillera, as well as river systems presently experiencing high rates of uplift or subsidence (e.g., Greece or southeast Spain). The intensity and duration of human impact has also varied widely in the river basins examined, ranging at one extreme from thinly-populated sub-Saharan Libya, which has been little affected by human activity, to the more populous Italian Peninsula whose rivers have been regulated since antiquity and catchments totally transformed by many thousands of years of intensive farming. Alluvial settings that are characteristic of the Mediterranean basin (see Section 6) including alluvial fans, basin and range environments and coastal alluvial plains are well represented. Steepland river systems (developed within upland/mountain environments), coastal deltas and large alluvial rivers (e.g. Ebro, Po and Rhône) are not considered in detail. Notwithstanding these minor limitations, largely new results from over 50 river basins are presented which in itself represents something of a benchmark for Quaternary river studies in the Mediterranean region.

Three major themes provide a common thread to the papers in the volume. Firstly, there is the influence of tectonics and base-level changes on drainage network evolution. Secondly, human-river environment interactions have assessments of the archaeological record, with particular reference to the impact of land use change on soil erosion and valley floor alluviation. Thirdly, dating and correlating fluvial stratigraphies are used to establish the causes of river aggradation and incision. Reflecting these themes, the volume has been divided into three parts. Papers in Part 1, 'the impact of Quaternary tectonic activity on river behaviour', focus on the seismically active area of the Alps, southeast Spain and the Aegean basin. In Part 2, 'archaeology and human-river environment interactions', two further sub-themes emerge. First, investigations (primarily concerned with the Palaeolithic) which have sought either to reconstruct fluvial environments contemporary with human settlement in river valleys, or have used fluvial stratigraphies to provide a temporal framework for the archaeological record. Second, studies (primarily concerned with the Neolithic and later periods) that have tried to quantify the response of river systems to human disturbance. Papers in part 3, 'geochronology, correlation and controls of Quaternary river erosion and sedimentation', explore approaches for dating fluvial sequences and identifying the major intrinsic and extrinsic controls of river development. Finally, in the concluding section, some of the research needs in Quaternary river studies in the Mediterranean basin are highlighted and suggestions are made for possible future lines of inquiry in the region.

8 ACKNOWLEDGEMENTS

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REFERENCES


Quaternary fluvial systems in the Mediterranean basin


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