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The Pass at Thermopylae, Greece

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Conflicts among historians over the battle at Thermopylae in 480 B.C. tend to center around supposed inconsistencies between ancient sources, particularly Herodotus, and the modern topography of the region. The area, however, is one of extensive tectonic activity, fluctuations in sea level, and sediment deposition. Any attempt to reconstruct ancient events on the basis of modern topography alone is therefore bound to be misleading. Precise paleogeographic reconstruction would require a large-scale drilling program. This study involved the drilling and analysis of seven core holes in sediments infilling the Gulf of Malia. Results clearly demonstrate a Holocene epoch marine incursion to the far west of the Malian embayment and subsequent considerable variation over time in the physiography at Thermopylae. We have reconstructed the shoreline for ca. 480 B.C. and examined variations in the morphology of the middle gate with respect to the width of the pass. Geological and geomorphic evidence suggest that the pass at Thermopylae was closed for long portions of recorded history and may therefore have had less relative importance as a route into southern Greece.

Introduction: Historical Studies

The heroic defense of Greece by Athenians and Spartans against multiple Persian invasions in the early 5th century B.C. has loomed large in studies of the origin of Western civilization, with Herodotus' work on the invasion of Xerxes serving as a focus of scholarly attention. Extensive efforts have been made to reconstruct details of these important historical events. One major event in the conflict was the stand against the Persians by the Spartans and allies under Leonidas at the narrow coastal "pass" between the mountains and the sea (Gulf of Malia) at Thermopylae (a Greek word meaning "hot gates," in reference to the thermal springs that issue there from the base of the mountains). Xerxes' route from northern Greece to Attica (Athens) supposedly followed the coast because he intended to keep in touch with his fleet and because Greece is mountainous and would have afforded difficult inland passage for such a large army. Readers not familiar with the details of Herodotus' account of the battle are advised to review it in the original

Figure 1. Location of the passes at Thermopylae on the Malian Gulf, eastern Greece, Aegean Sea.

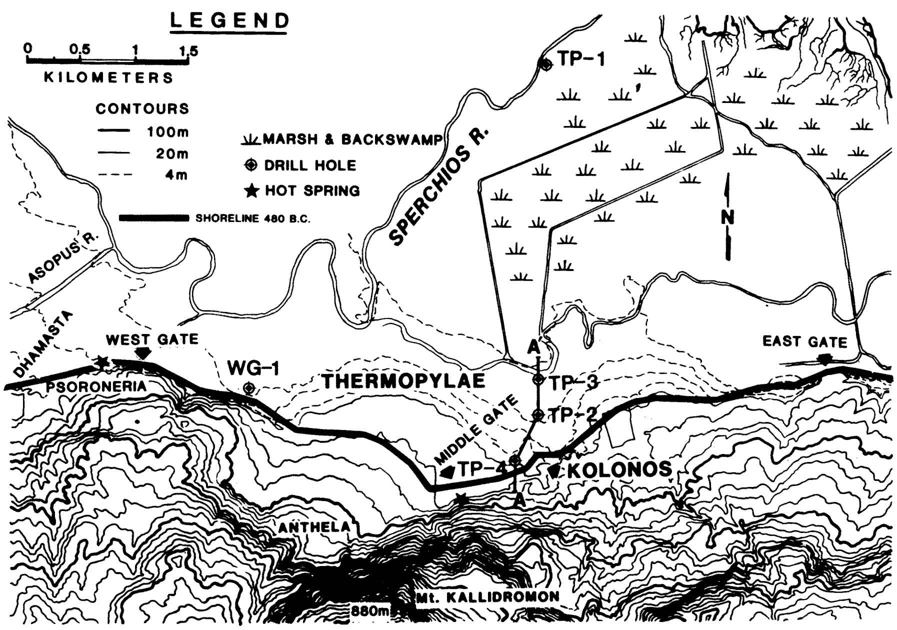

Figure 2. A geomorphic map of the area of modern Thermopylae showing the line of drill cores used in constructing cross-section, Figure 7. The relationship of the west, middle, and east gates, and the alluvial fan of the deep ravine emerging from Mt. Kallidromon, near the ancient site of Anthela, are shown.

or in one of the countless ancient and modern summaries.

Historians tell us that the battle of Thermopylae in 480 B.C. (and many other battles) was fought there because of the narrowness of the passage between the sea and the steep slope of Mt. Kallidromon (FIGS. 1, 2) (Her. 7. 198–201, 211–213; Paus. 10.20). Further, we know that at least one Greek ship was able to remain in contact with the Spartan forces at Thermopylae until the end of the battle, suggesting water depths greater than 1 m immediately offshore (Her. 8. 21.1). Thus the pass at Thermopylae was usable in 480 B.C. Historians suggest that the pass was approximately 20 m wide or wider at the middle gate (see FIG. 2) but much narrower at the west gate and east gate (Leake 1836; Gell 1819). "Gate" refers to each of three narrow points in the pass where low cliffs of the mountains jutted out very close to the sea.

Historians have regarded the pass along the sea at Thermopylae as the most logical and relatively easy route from northern Greece south to Attica. Because Herodotus (and other ancient historians who discussed the battle at Thermopylae) wrote nearly a half century or more after the battle of 480 B.C., lively disputes have continued concerning the location where the Spartans made their stand, the width of the pass, and other aspects of the geography of the battle. Attempts by modern scholars to do topographic reconstructions of the battle area have been completely compromised by the infilling of the Gulf of Malia by sediments from the Sperchios River. Sedimentary processes have completely obliterated the ancient landscape of the Malian plain. It is not our intention in this paper to review and critique all of the points at issue in the geography of the 480 B.C. battle at Thermopylae but rather to set out new information on the paleogeographic constraints of the battle based on our three-dimensional geological reconstruction of the ancient physiography.

A battle similar to the one in 480 B.C. was fought in 191 B.C. between forces under Antiochus the Syrian, with Aetolian allies, and the Romans with Philip V and Macedonian allies. In this case, Antiochus entrenched his army at the east gate while the main Roman army under M'. Acilius Glabrio[1] camped within the pass near the hot springs at the middle gate (Livy 36. 15.3; 16.5). Although the Romans outnumbered Antiochus' forces approximately two to one, Antiochus was able to hold them off initially at the east gate. The Romans, however, made a direct flanking movement along the cliff-like slopes of Mt. Kallidromon, and M. Porcius Cato dropped down on the flank of Antiochus' army (a feat probably not deemed possible for even an integrated, disciplined regiment) with approximately 2000 legionnaires and routed them so completely that only 500, including Antiochus, escaped. Over several millennia, the Gauls, the Huns, the Bulgarians, and other peoples invaded Greece via the Sperchios-Malian plain.[2] Each time, when opposed in the pass at Thermopylae, the invaders made a flanking movement and the Greeks retreated. MacKay (1963: 241–255) records a large number of walls constructed in many areas on the NW side of Mt. Kallidromon, presumably to prevent such flanking movements. Perhaps no one ever successfully defended the pass at Thermopylae when a flanking movement was made. Both the Persians and the Gauls turned back and entered southern Greece via the pass at Vardhates between the Trachinian Cliffs and Mt. Oeta to the west of the Sperchios plain. It is possible that Greek strategy throughout ancient times was *not to win* battles at Thermopylae, but rather to turn the flanks of armies and peoples intending to enter Greece through the central corridor into the Valley of Doris. Pritchett (1985: 190–216) presents a summary of military actions related to the pass at Thermopylae, somewhat in contrast to our own thoughts.

Concerning the ancient topography and the geography of the aforementioned battles MacKay (1963) has observed: "If, after only 150 years we have some difficulty following the journeys of English travelers, after 2000 years we must be extremely hesitant in rejecting the accounts of an ancient source simply because we cannot immediately determine his itinerary." MacKay is alluding to the large number of scholars in the last 250 years who have argued over details of the ancient topography at Thermopylae. Much of the argument is based on statements of Herodotus that are considered by many scholars to be factual. These scholars assume that the Persian army was camped on the Malian plain at the base of the NW edge of Mt. Kallidromon. Herodotus claims that the Persian flanking unit (the Immortals) started out by crossing the Asopus River and thence began its climb. A crucial statement is that the Persian Immortals, guided by Ephialtes, had the "Oetaean mountains on their right hand and the Trachinian on their left" when starting their climb around Mt. Kallidromon (Her. 7. 216, 217). A look at present geomorphology (FIGS. 3, 4) makes the problem clear. Because the Asopus River is at the foot of Mt. Kallidromon and in ancient times may have coursed between part of the Persian encampment and the mountain, a dilemma is created. The Asopus River must be crossed and yet a path with the mountains of the Trachinians on the left and the Oetaeans on the right must be accounted for. These two conditions are *not* necessarily contradictory as to the flanking route of the Persian Immortals (MacKay 1963; Pritchett 1962, 1965, 1982a-d). Further, Herodotus noted that the Asopus River flowed past Anthela, near the west gate (only possible a minimum of 3 km WNW of Anthela townsite) (Her. 7. 200).

We know from various historic sources that ships were able to approach Greek positions at the middle gate. Indeed, two centuries after 480 B.C., archers on ships fired arrows at the attacking Gauls (Paus. 10. 21.4). A

1. "M'." is an abbreviation for the praenomen "Manius"; "M.", however, stands for "Marcus."

2. The battle of 480 B.C. vs. the Persians; 279 B.C. vs. Brennus and the Gauls; 207 B.C. Philip vs. the Aetolians; 191 B.C. saw Antiochus of Syria vs. the Romans; A.C. 395 Alaric (unopposed); 6th century A.C. fortifications by Justinian; A.C. 1204 Boniface of Monferrat (unopposed); and even the Germans in 1941 (by this time, however, the pass was no longer narrow). It is probable that the pass at Thermopylae was *never* successfully defended.

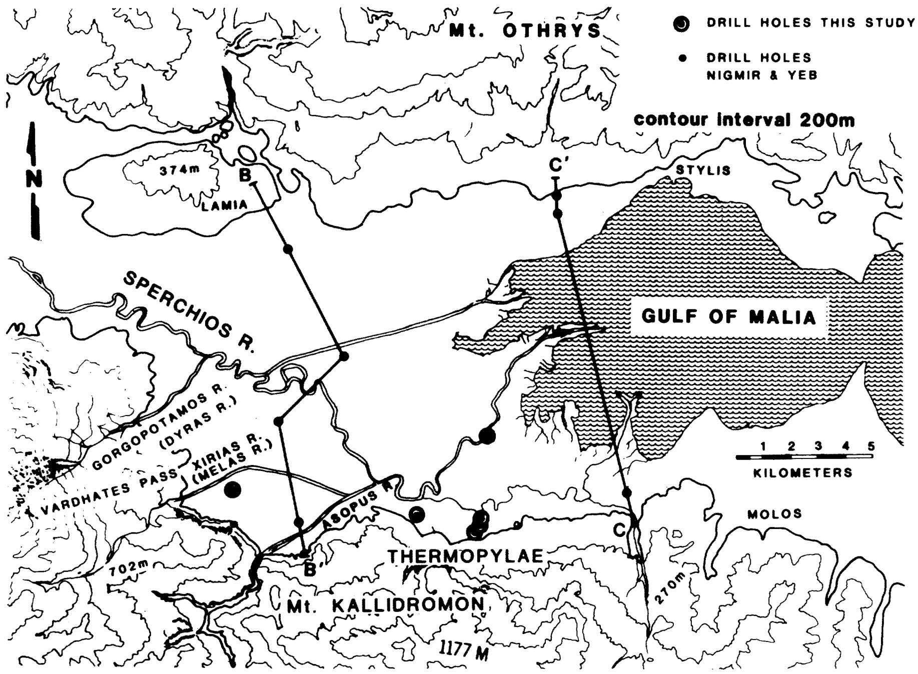

Figure 3. An index map to the topography of the Gulf of Malia and the Sperchios River delta plain showing lines of cross-section and drill sites (Stahl, Aust, and Dounas 1974; Aust et al. 1980, 1984; Tziavos 1977, 1978).

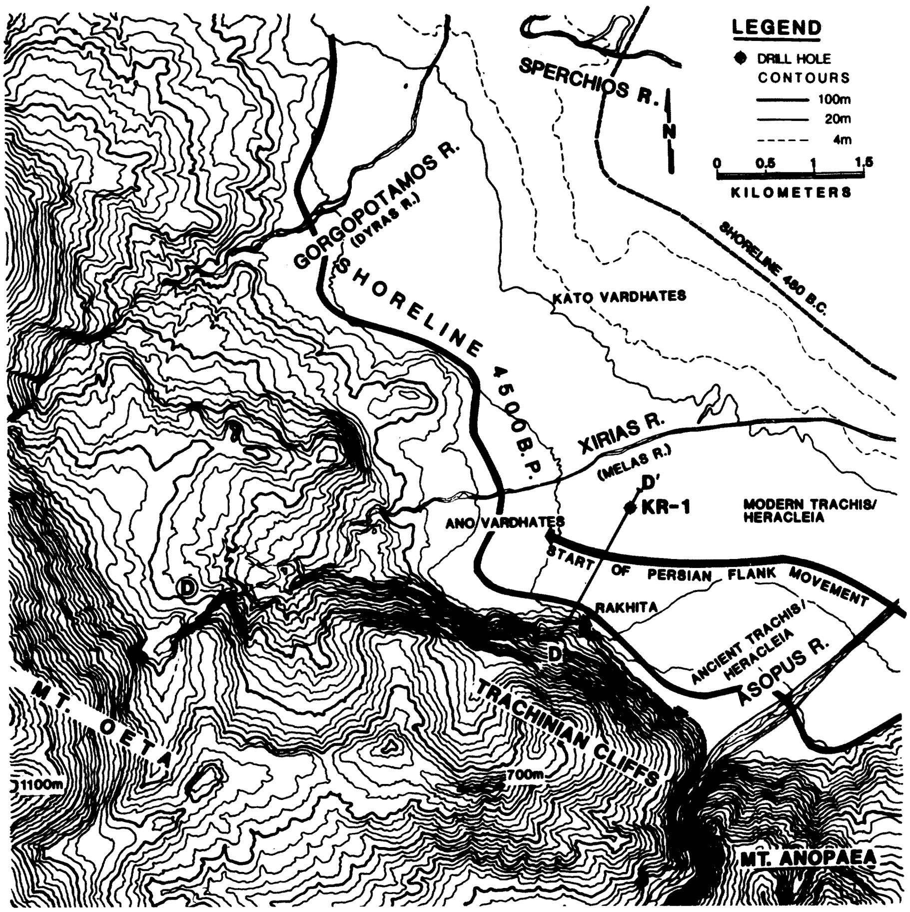

Figure 4. A topographic contour map of the SW corner of the Malian plain including the area of Mt. Oeta, the Trachinian Cliffs, and the present locations of the Asopus, Xirias (Melas), and Gorgopotamos (Dyras) Rivers. Shorelines for 480 B.C. and 4500 B.P. are shown. Alluvial fans and the pass at Vardhates are emphasized by the topographic contours. Start of Persian flanking movement as described by Herodotus (8. 21.1) and Wallace (1980) is shown. Recently, a drainage ditch from springs at the foot of the Trachinian Cliffs flowing past drill site KR-1 has been renamed "Melas" after the ancient name of the Xirias River 1–2 km to the north. D = Dehma Gap.

century later, the ground between fortifications and the sea was an impassable stretch of swamp and quicksand (Livy 36. 18.4). Yet we also know that during Leonidas' last desperate fight, many Persians drowned in the near-shore waters of 480 B.C. (Her. 7. 223.4). At the end of the battle, an Athenian warship under Abronichus left the beach near Kolonos and returned to the allied Greek fleet at the north end of Euboea. On the other hand, in 279 B.C., in the battle with the Gauls, only with great difficulty could the Athenian fleet rescue the trapped Greek defenders of the middle gate. From 480 B.C. to 279 B.C., either local relative sea level had dropped slightly or else shallow marine muds of the Sperchios River pro-delta formed muddy offshore shoals that afforded naval vessels only poor access to the middle gate.

Figure 5 is a photograph taken from Kolonos looking toward the middle gate, showing a large expanse of the travertine fan. It is important to realize that this view in 480 B.C. would have been looking downhill approximately 20 additional m under the present land surface to the actual battle site, at a slight widening in the pass of approximately 20 m between the cliff and the waters of the Malian Gulf at the middle gate. Thus, modern observations can be extremely deceiving in the interpretation of ancient historic events and geographies.

A similar problem occurs in considering the site of the city of Anthela (FIG. 2), which is located in an indentation or cul de sac to the SE of the west gate. The ancient village was located at the easternmost point of the territory of the Amphictyonic League. One might question why it was placed in its present position. Study of possible eustatic fluctuations of sea level (FIG. 6) shows that at certain times, e.g., early-middle third millennium B.P., Anthela would have overlooked the sea with an extremely narrow beach, if not completely cut off from the middle gate. Possibly Anthela was located in this site because it was a natural geological and geomorphologic limit of access to the territory of the Pylaean Amphictyony (Kase and Szemler 1983).

Xerxes may have watched the battle from the low spur of Mt. Kallidromon above and to the west of Anthela. As Herodotus states: "During these onsets the King (it is said) thrice sprang up in fear for his army from the throne where he set to view them" (Her. 7. 212.1). The hill west of Anthela is the only place from which the battle could be watched by a Persian king who presumably required a large number of troops to protect him. No other geomorphic feature of 480 B.C. fits these requirements.

A large wide pass at Vardhates (FIGS. 3, 4) extends through the so-called Dhema Gap into the Valley of Doris from which easy passage may be made southward via Chaeronea and Thebes or via the narrow defile at Gravia through the mountains to Amphissa and thence to the Gulf of Corinth (Kase 1973; Kase and Szemler 1983). P. W. Wallace (1980: 14–23) analyzed the strategic problems of flanking the Greek army entrenched in the pass at Thermopylae in 480 B.C. He noted that the

Figure 5. The middle gate at modern Thermopylae, photo taken from the top of Kolonos Hill looking west to the battlefield of 480 B.C. Up to 20 m of travertine and other sediment overlies the surface of the battlefield. The shoreline of 480 B.C., likewise buried, was situated in the center of the photograph.

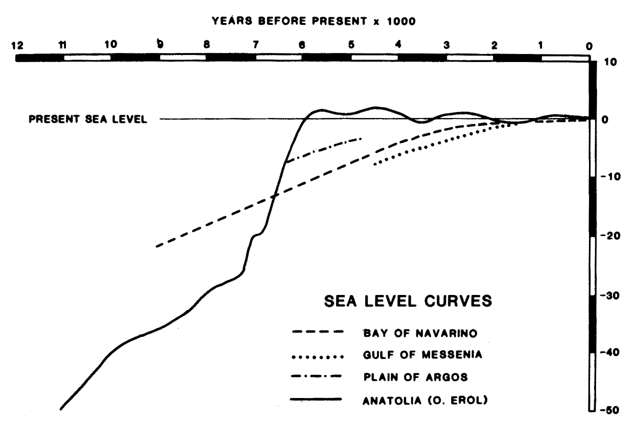

Figure 6. Local relative sea-level curves from some of the graben-like embayments in Peloponnese, as contrasted with eustatic or absolute sea-level interpretation based on evidence from the nearby coasts of Anatolia determined by Professor O. Erol and synthesized in part from a global curve constructed by Fairbridge. The sea-level curves from the various grabens are different because the tectonics are different. There is considerable controversy regarding the eustatic sea-level curve, but the curve correlates well with similar curves established elsewhere in the world (Fairbridge 1961, 1981). Subsidence rates for the Gulf of Malia graben are not known because of minimal data on relative sea-level positions.

valley at Vardhates (near the Dhema Gap) was wide enough for an army to march through to the higher elevations, thence turn southward, join the Anapoea path, descend to the east of the pass at Thermopylae, and outflank the Greeks entrenched near the hill of Kolonos west of the middle gate. Pritchett, however, has located the flanking movement of the Persian Immortals under Hydarnes in a much more direct route: from the head of the Malian plain at the foot of Mt. Kallidromon up the edge of Mt. Kallidromon's western end, thence to the Anapoea trail and down to the Gulf of Malia to outflank the Greeks.

MacKay (1963: 241–255) has also studied the problem of the battle of Thermopylae and the path of the Immortals in great detail. Both he and Pritchett (1962, 1965, 1982a-d) have little question that the shortest possible route was up the NW flank of Mt. Kallidromon from the Malian plain, west of Dhamasta. As Pritchett noted, it makes no sense for an army and camp within sight of its objective to make a lengthy circular route northward, westward, then south, then east, almost doubling the distance of the most direct route around Mt. Kallidromon to the middle gate. On the other hand, a heavily-armed force of more than 5000 men climbing a mountain at night for a frontal assault would surely have been heard by the defending Phocian outposts at the top of Mt. Kallidromon. Wallace's argument was based on the fact that, at the time, the countryside was open forest and the path at Vardhates was wide enough that an army could easily march along this route. Wallace (1980) made the trip with a flashlight in one night and arrived at dawn at the top of Mt. Kallidromon heading down the Anapoea path to the rear of the Greek position in the same amount of time recorded by Herodotus. Most recently, E. W. Kase and G. J. Szemler (1982: 357) have shown that the access through the Dhema Gap was used by Xerxes on his way to Athens, and not (as generally assumed) the access through Thermopylae.

Background: Geological Considerations

The Gulf of Malia is a deep marine embayment formed as a graben, a rapidly subsiding block of the earth's crust (FIG. 3). It is flanked on the north by Mt. Othrys and on the south by Mt. Kallidromon (geologically-upthrown blocks of the earth's crust). To the NW lies the broad valley of the Sperchios River, to the west Mt. Oeta, and to the SW the Trachinian Cliffs. It is an area that has been extremely active tectonically throughout the Quarternary Period (Maratos 1972). With the waning of the last major ice age more than 10,000 years ago, sea level began to rise and enter the Gulf of Malia. Evidence of local relative sea-level rise obtained in our geological studies shows that the Gulf of Malia and areas of the present Sperchios River floodplain and delta were almost completely covered by the sea at approximately 4000 B.C. At that time, the river fans and deltas of the Asopus and Sperchios Rivers and other minor streams flowing into the Gulf of Malia began to infill the western end and alluvial fans began to infill the flanks of the Gulf of Malia.

A curve established by Erol (Kraft, Kayan, and Erol 1980) suggests that relative sea level was somewhat higher than that of the present day for much of the past 6000 years in the Aegean area (FIG. 6). Local tectonic evidence and studies in grabens elsewhere suggest that the graben or basin of the Gulf of Malia continued to subside throughout the Holocene epoch (past 10,000+ years) (Kraft, Rapp, and Aschenbrenner 1980). Studies in the graben of the Gulf of Malia and sea-level data from grabens elsewhere in Greece show that local relative sea level has varied somewhat while the sediments in the grabens continued to subside (Kraft, Aschenbrenner, and Kayan 1980).

Approximately 14,000 years ago, near the end of the latest glaciation, sea level was approximately 100 m below its present level. With the waning of the last major glaciation, world sea level began to rise to its present elevation and, according to many authors, above its present level (Fairbridge 1961, 1981). From the onset to about 6000 years ago, at the time of the "Climatic Optimum," sea level rose rapidly, inundating the valley systems of the Mediterranean. There is disagreement about sea levels since 6000 B.P. One school of thought holds that sea level rose slightly above present level and then fluctuated above and below present elevations to its current position. Another school of thought states that the rate of rise dropped sharply about 6000 years ago and further slowed down about 3000 to 2000 years ago.

Figure 6 presents several sea-level curves. Those from the Bay of Navarino, Gulf of Messenia, and Gulf of Argos are local relative sea-level curves constructed with information from radiocarbon dates on sediments in subsiding grabens. Therefore, although these curves can be accurate for their local setting, they cannot be projected with accuracy to other embayments with different tectonic settings. They are merely examples of what a local relative sea-level curve in the Malian embayment might look like without added eustatic sea-level fluctuation. The eustatic curve constructed by Professor Erol (University of Ankara) is based on data obtained along the shorelines of Aegean Anatolia added to a synthesis of Fairbridge's curves. This curve represents the school of thought asserting that sea level rose rapidly to above its present level about 6000 B.P. and has since fluctuated above and below present sea level (Fairbridge 1961, 1981). It is probable that all curves shown in Figure 6 are correct for limited regions. Thus, a local relative sea-level curve derived for the Malian embayment must be a composite of tectonic subsidence plus eustatic sea-level rise and fall.

Because Erol's sea-level rise curve (Kraft, Kayan, and Erol 1980) was based on data from the Aegean coastal zone, we use his curve in this paper to calculate ancient sea levels. Using Erol's eustatic sea-level curve we can interpret the complex geological events that occurred around Thermopylae. At the time of the battle in 480 B.C., sea level was slightly above its present level, thus deepening the offshore waters and narrowing the width of the pass at the west, middle, and east gates. Radiocarbon data and stratigraphic interpretations from the cross-section at Thermopylae (FIG. 7) are compatible with Erol's sea-level interpretation. Marine sands extend very close to the subsurface extension of the graben margin and the steep cliffs of Mt. Kallidromon (480 B.C., see dashed line in FIG. 7). Marine waters were close to shore 4500 years B.P. and the marine strata extend to within 1 m of present sea level (see TABLE 1). A date of 2150 or 2300 B.P., as shown in core TP-2, shows the position of a swamp or marsh at that time. These data suggest that the pass at Thermopylae at the time of the battle in 480 B.C. would have been extremely narrow. Yet at the time of the battle with the Gauls several centuries later, the pass was wider, with shallower offshore waters. Fluctuations in width of the pass at Thermopylae over the past five millennia are common, as expected in an unstable structural configuration along the flank of a major graben.

The rates of tectonic subsidence in the Malian Gulf are unknown. The tectonic events probably are short-term, discontinuous, and marked by earthquakes. Many minor earthquakes have been recorded throughout history on the Malian plain including at least one inundation by a *tsunami,* or major sea wave (Pritchett 1965). Figure 8 is a cross-section to the west of the pass of Thermopylae (see line of section B, FIG. 3). These data are based on drill holes made by Stahl, Aust, and Dounas (1974) and by Aust et al. (1980; 1984) in groundwater or hydrologic studies of the subsurface sediments of the Malian plain and Sperchios Valley. They clearly identified up to 300 m of valley-graben sediment infill. Their determination of three gross units (lower mud, middle sand, and upper mud) based on more than 18 drill holes includes a stratigraphic record of transgression and regression of the sea throughout later Quaternary times. The sedimentary record of fluvial and marine deposits in the Gulf of Malia and the Sperchios Valley graben may extend to much greater depths (approximately 800 m). The sedimentary record may possibly include a stratigraphic record of the entire Quaternary and latest Tertiary (Zamani and Maroukian 1980).

Although Aust and Stahl and others clarified artesian relationships in the western Malian Basin, they also showed that single sedimentary environmental lithosomes such as strandlines, paralic sands, distributary sands, alluvial fans, deltaic organic muds, marine prodelta muds, backswamp floodplain deposits, etc. could be precisely delineated given a sufficient number of drill cores, radioisotopic dating, etc. (Sahl, Aust, and Dounas

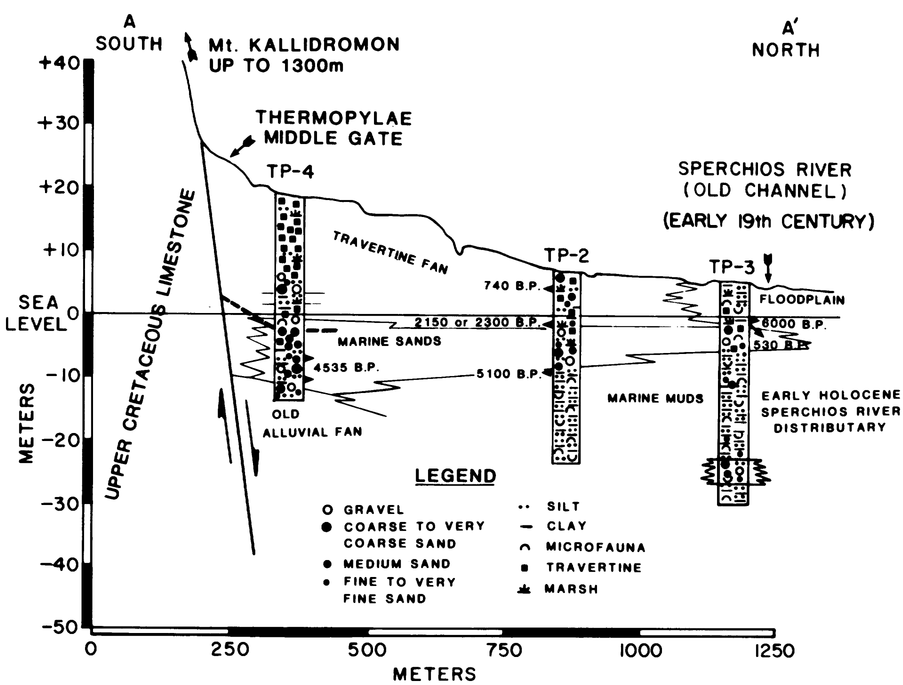

Figure 7. A geological cross-section at the middle gate of the pass at Thermopylae. Drill-core sections provide interpretation of depositional environments for subsurface sediments and radiocarbon dating of materials establishes a time frame for the deposition of these environments. Care must be used, however (i.e., core TP-3 shows a very old date overlying a young date). Spurious dates are common in stream bed sequences as materials can be retransported and deposited. The dashed line indicates land surface and sea bottom, 480 B.C. (See line of section in FIG. 2.)

Table 1. Radiocarbon data from drill-core samples.

Lab Sample #	*Elevation of Sample in m**	*Material Dated*	*Inferred Depositional Environment*	$-\delta\,^{14}C$	*Age in Years B.P.* 5568 half-life	*Age in Years B.P.* 5730 half-life	*MASCA Corrected Date†*
TP-2	4.5 to 3.75	Grass root	Coastal swamp-marsh	90 ± 9	755 ± 80	778	A.C. 1220–1200
TP-2	−1.2 to −1.5	Grass root system in gray mud	Coastal swamp-marsh	232 ± 8	2120 ± 80	2184	200 or 350 B.C.
TP-2	−9.25 to −9.6	Pelecypod and gastropod shells	Shallow marine	419 ± 10	4360 ± 140	4491	3150 B.C.
TP-3	−1.3 to −1.8	Total organics in dark gray-black mud	Very shallow marine	478 ± 7	5220 ± 110	5377	4040–4060 B.C.
TP-3	−2.2	Wood-fragment of tree	Very shallow marine	56 ± 9	460 ± 80	474	A.C. 1420
TP-4	−8.0	Marine grasses and/or algae	Very shallow marine	24	3970 ± 330	4089	2585 B.C.
KR-1	+25	Wood	Alluvium	-	240 ± 80	247	A.C. 1703
WG-1	-	Total organics	Pro-delta	-	3760 ± 100	3872	2180 B.C.

*Relative to mean sea level.
†See Ralph, Michael, and Han 1973.

1974). Thus, precise paleogeographies could be reconstructed with a large-scale drilling program. We have shown that the upper 10-20 m of sediment are of mid-Holocene epoch and younger (FIG. 7; TABLE 1) and thus represent Helladic and younger depositional events, all of great import to our hypotheses and interpretations.

Information available to us clearly demonstrates a Holocene-epoch marine incursion to the far west of the Malian embayment. The precise margin of the marine environments along the surrounding cliffs is indefinite, however. We have therefore used our interpretive section at the middle gate (FIG. 7) as a guide to maximum possible strandline positions from Figure 8 and as illustrated in Figures 2 and 4. Figure 8 is of particular interest since it shows clearly that the marine embayment of the Gulf of Malia in Helladic times extended west of the present-day delta-plain towns of Anthili and Moschochorion. Indeed, it is probable that with the initial peak flooding of the graben, approximately 6000 years ago, the entire embayment was flooded to all flanking cliffs.

Erosion of the highlands brought sediment to stream valleys where alluvial systems transported the materials to the low-lying coastal plains. In some of the deltas that were formed, the land protruded far into the sea. In the sheltered Gulf of Malia, at the delta of the Acheloos River to the west of Mesolongi in Acarnania, and at the classic deltas of the Thermaic Gulf where the ancient Macedonian port of Pella has now been abandoned, late-Holocene deltaic deposits have pushed coastlines far seaward. Other important changes have been wrought in areas where the sediments from smaller streams were redistributed by wave action and resultant barrier accretion plains. An example of this type of morphological modification occurred in the area of the "five rivers" and Pamisos River in SW Greece (Kraft, Rapp, and Aschenbrenner 1975). Summaries of some of the processes involved have been published by Kraft, Aschenbrenner, and Rapp (1977); Kraft, Rapp, and Aschenbrenner (1975); Kraft, Kayan, and Erol (1980); and Kraft, Aschenbrenner, and Kayan (1980).

Tziavos (1977, 1978) studied the sediment distribution and micropaleontology of the modern sediments of the Sperchios delta. Zamani and Maroukian (1979) outlined the changes in coastal geography of the various distributaries of the Sperchios River after the great southern extension of the bird's-foot distributary bypassed the southern shoreline at Thermopylae, destroying the geomorphic landform of a "pass" that had existed for the previous four to six millennia. Precise delineation of shoreline positions, coastal and deltaic environments, and general geomorphology of the plains of the Sperchios and tributary valleys prior to A.C. 1810–1830, can only be accomplished by the application of scientific methodologies supported by archaeological evidence and

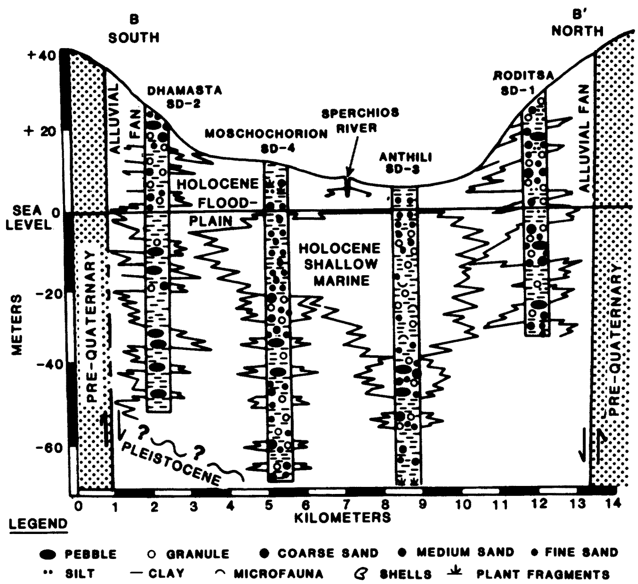

Figure 8. A geological cross-section across the western Malian plain (see FIG. 3 for line of section). Shallow marine sedimentation into the far western part of the Malian plain is proven by the marine sediments in the cores.

historical evidence derived from the examination of narrative historical records.

New Data: Geological Field Studies

In order to determine the details of the sequence of geological environments and to reconstruct the ancient

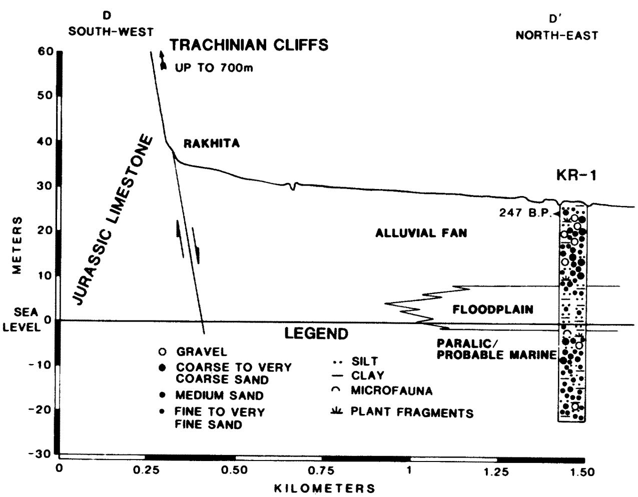

Figure 9. A geological cross-section from the steep Trachinian Cliffs at Rakhita (a Bronze Age site—possibly part of ancient Trachis) at the head of the Malian plain. Core-hole KR-1 suggests that 20 m of sediments in the alluvial fans and floodplains of the Xirias (Melas) and Asopus Rivers coalesce over shallow marine sediments.

topographies at Thermopylae, we drilled and analyzed the materials from seven core holes in the sediments infilling the Gulf of Malia (FIGS. 2, 7, 9).

Surface geomorphic and geological studies and subsurface geological results show the nature of the pass between the mountains and the sea over the past 10,000 years. From the core drilling we were able to identify the depositional environment of the various sediments that form the coastal plain at present day Thermopylae. In the first millennium B.C., the east and west gates were very narrow, faced by steep cliffs. The middle gate was a wider (about 20 m) sandy travertine shoreline (many battles were fought here) between the sea and very high precipitous cliffs (see note 2). Evidence from our drill cores numbered WG-1, TP-1, TP-2, TP-3, and TP-4 (FIG. 2), and from maps by Leake (1836) and Gell (1819), suggests that the narrow pass ceased to exist at the beginning of the 19th century. Massive sedimentation of the Sperchios River delta has bypassed Thermopylae, creating a delta-plain. Nevertheless, transportation along the pass was still poor in the second decade of the 19th century (Gell 1819). Our line of drill cores was made perpendicular to the cliffs of Mt. Kallidromon from the area of the hot springs and Kolonos at the middle gate northward across the southern side of the Malian plain. They show that from 4000 B.C. to approximately Roman times the southern shoreline of the Malian Gulf lay very close (20 to 100 m) to the flank of Mt. Kallidromon at the middle gate (FIGS. 2, 7). Thereafter, the width of the pass fluctuated until the beginning of the 19th century, when a distributary of the Sperchios River infilled the shoreline area at Thermopylae.

Antique maps and sketches can vary from precise to useless and/or misleading sources of data. We were fortunate that Leake published a map of the study area and left good notes regarding rapid changes in landforms at Thermopylae in the early 19th century. His observations are proven, because the recent (19th-century) southerly distributary of the Sperchios River can be directly and favorably compared with its extant dry channel just 1 km NE of the "gates" of Thermopylae (FIG. 10).

Pouqueville (1835) left us with what is potentially a great treasure—a sketch of the landscape along the southern shore of the Gulf of Malia ca. 1800 based on his travels in Greece from 1798 to 1801, which he first published in 1805. Pouqueville's writings regarding topography at Thermopylae are of little use. His sketch "Grèce-Thermopyles" (FIG. 11) published in 1835[3] in a history of Greece, however, includes a perspective diagram of the passes at Thermopylae that shows a land-

3. Although the first initials of Pouqueville are not given in this work, we assume the author to be the same as Pouqueville 1805.

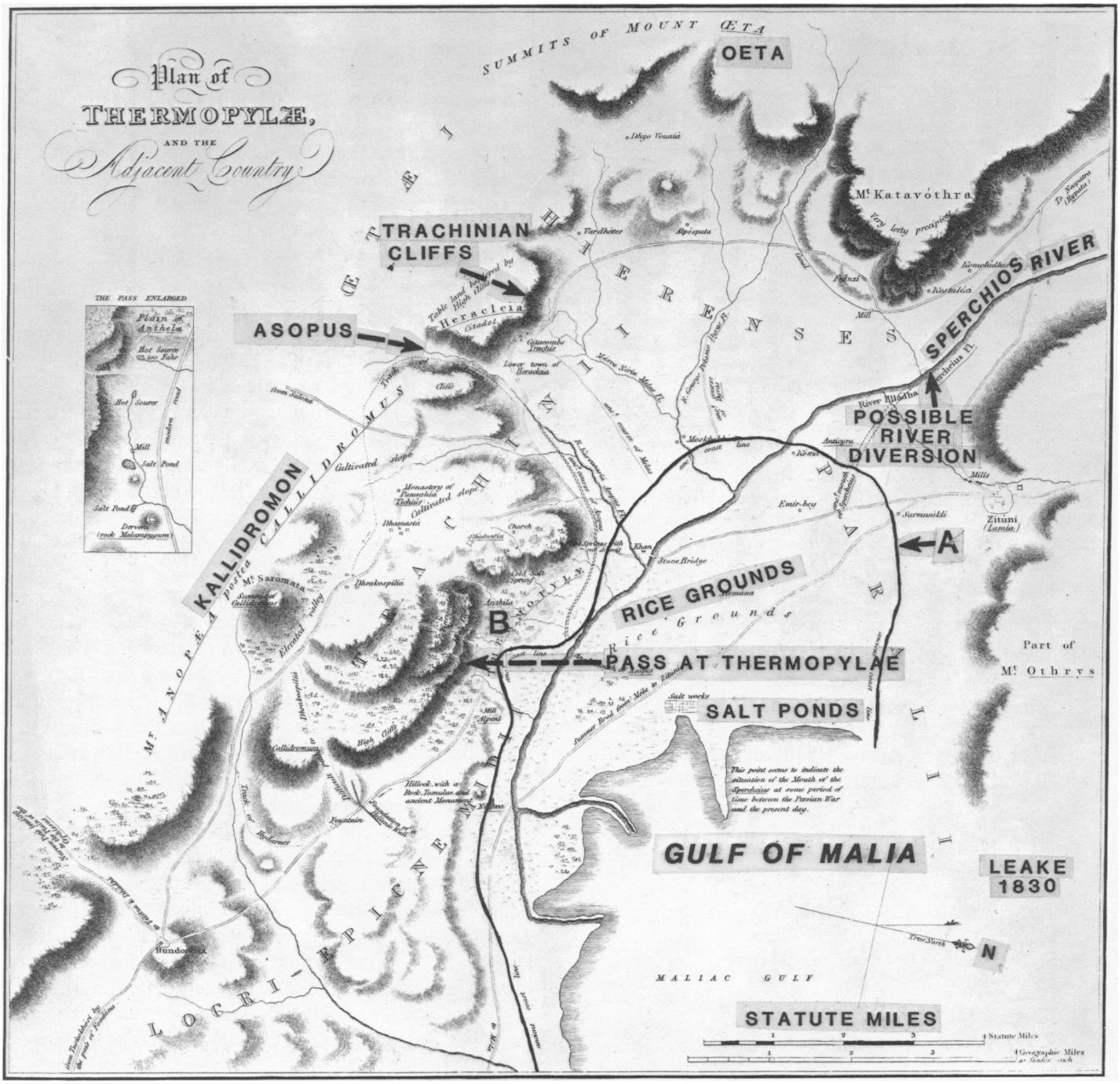

Figure 10. W. M. Leake's "Plan of Thermopylae and the Adjacent Country" (1836). By the time of Leake's travels, the pass at Thermopylae had widened considerably and the delta of the Sperchios River and its tributaries had prograded seaward up to 8 mi. A = ancient coastline as interpreted by Leake; B = middle gate of Thermopylae.

scape sketched near the time of Leake's first travels (ca. 1802).

Figure 11 is a view to the east from the cliffs at Trachis. While the vertical and distance (depth) perspectives are distorted, the view clearly shows the southern Sperchios distributary in the foreground adjacent to the west gate, and in the distant center, the passes at Thermopylae surrounded by a low talus slope and sharp cliffs merging with the sea (Gulf of Malia). From geological and geomorphic evidence, the sketch (FIG. 11) is much as we would predict the passes to have appeared shortly before or at the time of Leake's first visit. Ap-

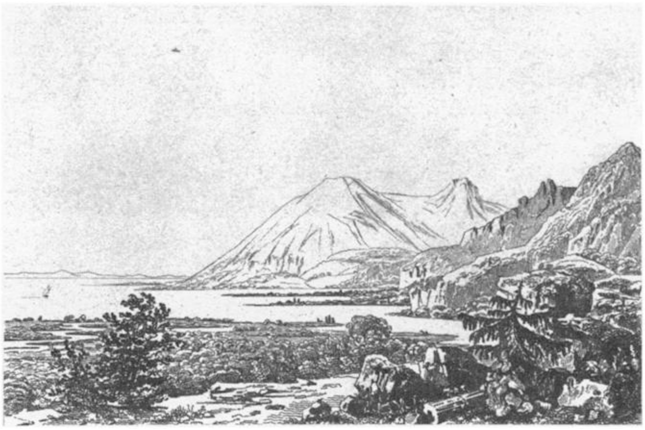

Figure 11. A sketch looking eastward from the cliffs at Trachis/Heracleia to the cliffs at Thermopylae, ca. 1798–1802. Although published by Pouqueville in 1835, the Sperchios River distributary to the lower left and the open waters of the Gulf of Malia (center and left) against the cliffs and alluvial fans of the passes at Thermopylae clearly predate Leake's map (FIG. 10) as published in 1836. Although vertical exaggeration is great, the sketch shows Thermopylae much as it appeared for many millennia. Problems of large-scale traffic through the "passes" are somewhat evident at the first cliff (near the west gate). During an on-site visit, this view was identified by Szemler and Kase as that described in Pausanias 10.22.1.

proximately 20 years later, on his second visit, Leake included his map (FIG. 10), which shows a dramatically different Thermopylae by-passed by the Sperchios River delta. Further, this appearance of Thermopylae (minus the forefront with distributary) is what the passes at Thermopylae would have been like from 1800 back to the Climatic Optimum of 5,000–6,000 B.P. Pouqueville (or his artist) shows what he saw at Thermopylae at the very end of the eighteenth century.

Two excellent geologic-topographic maps of the area have greatly aided us in our study of rates of alluviation in the Gulf of Malia (Maliakos Kolpos) (Marinos et al. 1963; 1967). The present Gulf of Malia is greater than 20 m deep. We have no way of knowing the total thickness of the Quaternary sediments that have partly infilled the gulf. In none of our borings have we encountered the base of the Holocene-age sediment. More than 20 borings by the Greek National Institute for Geological and Mining Research/IGME have penetrated up to 200 m on the lower floodplain of the Sperchios River and the Sperchios delta plain.[4] These sediments include deltaic distributary sands, shallow marine pro-delta muds, levee and backswamp sands and muds, floodplain sediments, and alluvial-fan debris. Correlation of sand and mud sedimentologic units is possible in this artesian system. Precise time-line stratigraphic interpretation and areal delineation of these Quaternary sedimentary environments, however, is not yet possible, although Pleistocene sediments of alluvial fans can be observed along the flanks of the highlands surrounding the graben.

Figure 7 is a cross-section showing the subsurface strata that have accumulated at the middle gate. The location of this cross-section is noted on Figure 2 (A to A′). Our sediment cores were used to determine the environments of deposition by sedimentological and micropaleontological analysis. In those fortunate cases where organic remains were encountered, radiocarbon dates were obtained to place the sequence of environments into a Holocene time frame (TABLE 1).

Figure 8 shows subsurface relationships across the western Malian plain. The location of this section is shown on Figure 3 as B to B′. Figure 9 is a cross-section from the Trachinian Cliffs toward the sea. The location of this section can be seen on Figure 4 as D to D′. Figure 12 illustrates the subsurface section of the eastern tip of the modern delta of the Sperchios River. Its location is shown in Figure 3 as extending from C to C′.

Figure 2 is a map of the pass at Thermopylae showing the steep cliffs of Mt. Kallidromon near the middle gate. The alluvial fans of several valleys that emerge to the east and west of Kolonos and from the deep ravine near Anthela are also shown. It is important to note, however, that these fans were much smaller at the time of the battle of Thermopylae in 480 B.C. The merging contours shown on Figure 2 indicate that the slopes at the east gate and the west gate are extremely high and cliff-like.

During the drilling of core-hole KR-1 at the western end of the Malian plain near the Trachinian Cliffs, we

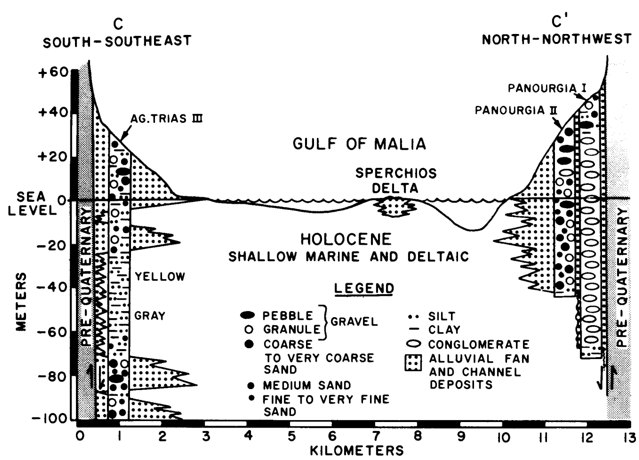

Figure 12. A geological cross-section of the extreme eastern tip of the modern delta of the Sperchios River across the Gulf of Malia in the vicinity of Agios Trias. The Sperchios River is still rapidly advancing eastward, infilling the relatively deep Gulf of Malia. (See FIG. 3 for line of section.)

4. The Holocene infill of the Malian Gulf is at least 70 m thick, south of Lamia.

encountered a thick section of probable paralic marine sands underlying floodplain and alluvial-fan sediments. A small number of red, coarse sand-size grains were observed among the gray sand grains dominant in the entire section. Out of curiosity, one sand grain was collected and sent to Dr. Diana Kamilli for analysis. This showed the specimen to be a medium-fired, oxidized *ceramic* fragment containing biotite-quartz-feldspar with a hematite-stained matrix. Although this occurrence of ceramic material in the marine section is without a precise date, it does indicate that people were using pottery when the waters of the Malian Gulf were at the westernmost end of the Malian plain. This is compatible with our geological interpretations of the western end of the Malian Gulf in the Early Bronze Age.

Cross-section Figure 9 shows the relationship of the Bronze Age site at Rakhita at the foot of the Trachinian Cliffs of ancient Trachis to the low floodplain between the Xirias (ancient Melas) and Asopus Rivers. Core-hole KR-1 was drilled in the low-lying area between the two rivers along a new drainage ditch to which the old term "Melas River" has now been applied. Figure 9 shows that 3 m of sedimentation occurred over the last 247 years. More than 20 m of floodplain and stream deposits have formed in this area overlying a probable coastal/marine sand unit. Presence of the paralic sand unit in core-hole KR-1 shows that the ancestral marine Malian embayment extended close to the Trachinian Cliffs (FIGS. 4, 13), possibly precisely to the foot of the cliffs.

The varied depositional environments identified from our surface studies include alluvial fans, river-channel deposits, the natural levees and channels of bird's-foot deltaic extensions, floodplain or overbank alluvial deposits, salt-marsh swamp deposits, and shallow-marine sandy silts and muds. In addition, in the pass at Thermopylae, particularly at the middle gate, a large travertine fan is building upward and seaward.

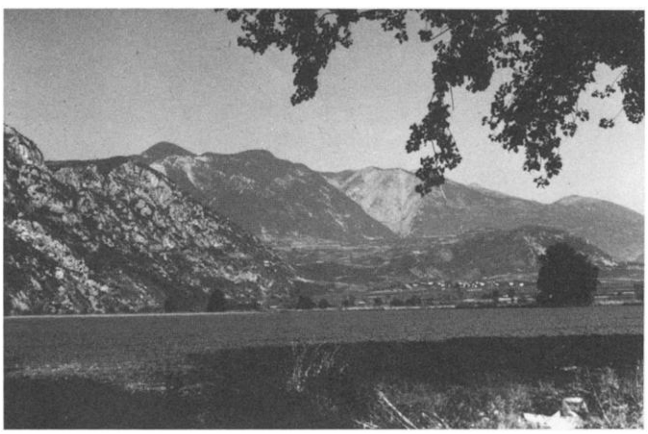

Figure 13. The western end of the floodplain of the Gulf of Malia. The Trachinian Cliffs are to the left, with the pass of Vardhates (near the Dhema Gap) in the center and Mt. Oeta to the right. Photograph taken from the low floodplain between the alluvial fans of the Asopus River and the Xirias (Melas) River, looking west.

Discussion: Reconstruction of the Ancient Landscape

The physiography at Thermopylae has varied considerably through time. Most of this variation is the result of changes in local relative sea level and sediment depositional infill of the west end of the Malian graben, including major alluvial fan, travertine fan, and deltaic progradation.

A reconstructed shoreline for approximately 480 B.C., the time of the battle of Thermopylae, is shown in Figures 2, 4, and 14. Equally important, the reconstructed Bronze Age shoreline for approximately 4500 years before present is shown in Figures 4 and 14. Any Bronze Age sites along the western end of the Malian embayment probably were coastal sites. Particularly, any of these sites that might be associated with the passes of the Gorgopotamos (Dyras) River or the Xirias (Melas) River might be considered to have been port sites for transshipment of materials inland via passes to the Valley of Doris and thence into southern Greece. When the sea extended to the westernmost limits of the Malian embayment, the pass at Thermopylae would have been a cliff into the sea at the west, middle, and east gates and, therefore, impassable to large-volume vehicular traffic. From 5000 to 3000 years B.P. many small towns may have lain along the foot of Mt. Oeta along the ancient shoreline, but these would now be buried under as much as 20 to 30 m of sediment and are thus essentially undiscoverable by archaeologists (Simpson 1981: 81).[5] Those few sites that were higher up on the flanks of the hills or buried in the earlier portions of alluvial fans take on a new importance in terms of the traffic from northern to southern Greece (see Rakhita, FIG. 9).

In the first decades of the 19th century, Leake (1836) studied the area of the head of the Malian Gulf and the pass at Thermopylae. He produced a map (FIG. 10) that is extremely revealing in terms of the fluvial and marine processes that had continued from the time of the ancient Greeks to his time. Leake's map shows his estimate of the location of classical Greece's ancient coastline. His interpretation is obviously schematic, although he at-

5. R. H. Simpson (1981: 81) reported "three Mycenean sherds on the lowest terraces of the site of ancient Heraclea" (see FIG. 4) but no signs on the citadel above. This raises the possibility that Helladic shorelines extended further westward, as proposed in this paper. Unless verified by additional evidence, however, the sherds could as well have been introduced during a later occupancy or become emplaced as pebble-size clasts in transit across lower prehistoric Trachis.

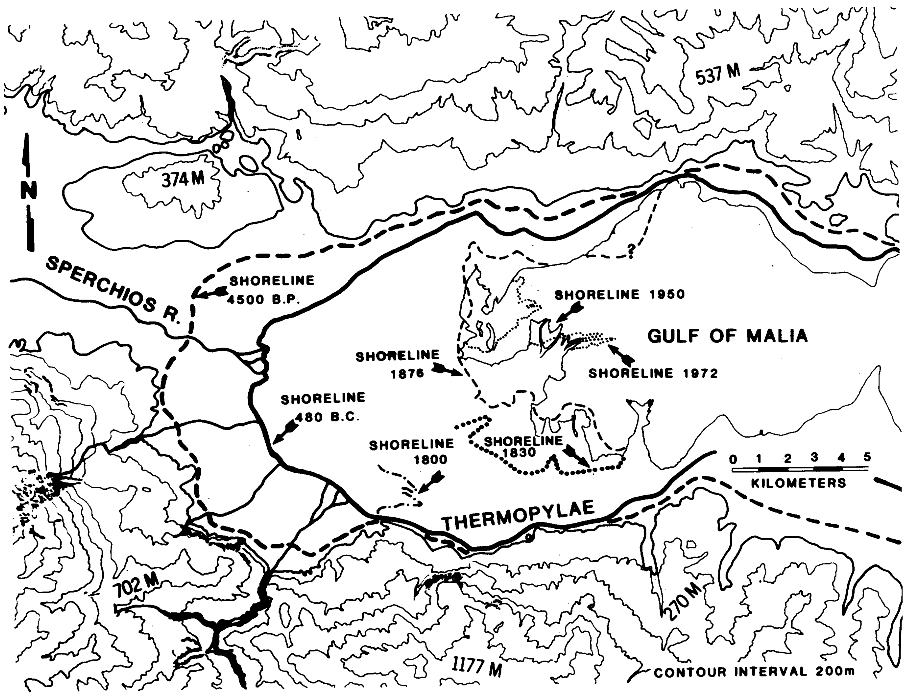

Figure 14. Variations in modern and ancient shorelines of the Gulf of Malia-Sperchios River delta-floodplain. From various maps and as reconstructed in this paper (Tziavos 1977, 1978; Bittner et al. 1880).

tempts to become more specific at the middle gate where he shows a deep indentation of the coastline toward the cliffs of Kallidromon, east of Anthela and just west of the hill of Kolonos. Clearly, the Sperchios River was the major stream carrying the greatest amount of sediment into the head of the Malian embayment. Its tributaries were, in decreasing order of importance of volume of sediment, the Asopus River, the Dyras River (Gorgopotamos), and the Melas River (Xirias). It is interesting to note that the path of the Sperchios River diverges southeasterly immediately upon emerging onto the Malian plain and then flows almost directly toward the west gate, thence parallel to the cliffs of Thermopylae, to its distributaries east of Thermopylae. (This abandoned channel is still precisely identifiable in surface morphology.) This is a most unlikely path for a major sediment-bearing river flowing into an embayment, however. One would expect the river to flow into the center of the embayment although, as its levees rose, it would break through and flow to other paths. To have such a long extension of the river flowing along the flanks of the embayment as opposed to the middle suggests the possibility of human intervention. Leake labels a major area in the center of his map as "rice grounds" and notes a salt works near the shoreline. The possibility must be considered that humans altered the course of the Sperchios River to its maximum southerly position in the later 18th or very early 19th century in order to create a large, flat, well-irrigated area for the growing of rice. Natural phenomena could have created a similar situation, but it is not as likely. Leake also notes the great changes in delta morphology between his first (1802) and, some 20 years later, second visits.

The dynamics of geological change in the mountain ranges probably have been fairly slow to effect change in the hard mountain rock. On the other hand, in the fluvial systems of the Sperchios River, its floodplain, and its tributaries (the Asopus, the Melas, and the Dyras) and deposition of sediments into the Gulf of Malia, quite the opposite is true. Precision contour maps of the Asopus River, the Xirias (Melas) River, and the Gorgopotamos (Dyras) River clearly show large alluvial fans. These deltoid intrusions into the ancient Gulf of Malia varied greatly in geographic extent over the past 5,000–10,000 years (FIG. 8). At times the alluvial fans were low-lying and small, at other times large and expanded, as at present. The Asopus River has a 130° fan spread to the NW of its present position (FIG. 4). On the average, the river flowed 30° to the north of its present position. Thus it is possible, as noted by Green (1970: 126), that a large portion of the Persian army "pitched camp near Trachis between the Sperchios and the Asopus Rivers," although it is questionable whether they occupied Anthela (on the other side of the Asopus River) and a low ridge of Mt. Kallidromon at the same time. We must also remember that the flanking movement of the Persians in 480 B.C. refers only to a regiment of 5,000 men (the Immortals) as opposed to approximately 300,000 men and women in the Persian army, if we can believe Herodotus' numbers (How and Wells 1928). But it is quite clear that 10,000 to 20,000 Persians could have been camped on the right bank of the Asopus River fan and plain between the river and Mt. Kallidromon even if the Asopus River of 480 B.C. flowed along the extreme southeasterly-possible channel on the fan closest to Mt. Kallidromon. The Persian encampment surface probably lies under the present Malian plain, buried at least 15 to 20 m beneath part of the present Asopus alluvial fan by alluvium of the tributary rivers and floodplains of the Sperchios River.

A similar situation exists at the "pass" at Thermopylae. MacKay (1963) noted that Marinatos dug a trench 8 m deep at the middle gate and was still in sediments of Byzantine age. Our geological analysis of the middle gate area clearly shows that up to 20 m of travertine and other forms of sediment overlie the actual battle site at the middle gate (FIG. 7).

Figure 4 is a topographic map showing Mt. Oeta and the Trachinian Cliffs. At the Trachinian Cliffs, a precipitous cliff drops off sharply to the Malian plain. Nearby and to the NW, the hills and cliffs of Mt. Oeta are still high but not precipitous. The Xirias River (Melas River) and the Gorgopotamos River (Dyras River) carried sediments into the head of the ancestral Gulf of Malia.

It is, therefore, reasonable to identify a large area of the Malian plain at the foot of Mt. Kallidromon with part of the Persian camp between the Asopus River and Mt. Kallidromon. Thus Herodotus' statement that the Immortals first crossed the Asopus River and then entered a pass with the Trachinian Cliffs on the left and Mt. Oeta on the right is a reasonable account and accurate geomorphic description of the situation in 480 B.C. This would lend support to the hypothesis (Wallace 1980) that the pass at Vardhates was that used by the Immortals. The argument regarding the path of the Immortals will continue into the future as it has raged for the past 250 years. It is absolutely critical, however, that any further discussion of this matter consider the paleotopography of the western end of the Malian plain, including the various positions of the Asopus and Xirias (Melas) Rivers, and the fact that the plain was much lower (ca. 20 m), with its river channels constantly changing.

Neither currently-visible nor abandoned channels of the Asopus River observed by anyone within the past 500 years have any known relationship to loci of Asopus River channels of more than 2000 years ago. The "modern" alluvial fan-floodplain lies many m above sediments deposited 2500 years ago as the Asopus River fan expanded upward, north, and east across the Malian plain. The Asopus River channel of 480 B.C. could have flowed in any direction and azimuth over a 130° arc into the Malian plain. The river of that time would have flowed across a much lower slope alluvial fan-river plain than that of today. Precise geological determination of the location of the river channel (or indeed multiple channels) is impractical for two reasons. First, a very large number of drill holes is required for accurate study of the third dimension (subsurface) morphology of any time-depositional surface. Second, one is unlikely to encounter organic materials suitable for radiocarbon dating for each channel and stratum of fluvial sediments related to each of the many paleo-channels of the ancestral Asopus River. The Asopus River channel of 480 B.C. could have been anywhere between the Trachinian Cliffs and the northern flank of Kallidromon, more likely in the middle three-fifths of the river fan.

There has been an extremely sharp, "cliff-like" drop into the sea at the west gate for at least the last 6000 years. Passage to southern Greece was possible via either the very narrow "wagon-track" path along the sea or by climbing over the relatively low-lying (between 100 and 250 m in elevation) ridge-like extension of Mt. Kallidromon in the vicinity of Anthela, thence downward to the seashore by the middle gate, which is bordered by very high cliffs, thence by the east gate which again was "cliff-like" into deeper waters with a very narrow pass. The topography south of the east gate or along the flank of Mt. Kallidromon at the east gate was of relatively low slope and could be bypassed (FIG. 2). Thus, in studying possibilities of passage from northern to southern Greece via the pass at Thermopylae, one must focus on the middle gate along the ancient strandline.

Exceptions of lower sea level, with accompanied widening of the pass at Thermopylae, possibly occurred ca. 300 B.C. to A.C. 1100 and 1700 B.C. to 1300 B.C. (Livy 36. 16.5).[6] Thus geological evidence shows that the pass at Thermopylae should be eliminated as a major access route to southern Greece throughout the greater part of pre-Roman historic and prehistoric times back to Late Neolithic-Early Bronze Age time.

6. The impact on historical events of sea-level fluctuation along a precipitous cliff, narrow strandline, and adjacent sea must have been profound. At the time of the 480 B.C. battle, sea level was relatively high and the middle gate narrow. On the other hand, during the invasion of the Gauls in 279 B.C., relative sea level was lower, and historians record the problems of the Athenian fleet in evacuating the surrounded Greek army due to the offshore muddy shoals. By 191 B.C. the middle gate had become wide enough to serve as the Roman army staging area while Antiochus opted to defend the higher ridge at the east gate. At times of peak sea levels we should anticipate waves against rocky cliffs with no significant passage possible; i.e., the pass at Thermopylae would be "closed." Analysis of sea-level fluctuation as used herein is based on a curve derived from the eastern Aegean, locally-derived geological evidence from a subsiding graben, and compatible historical statements. With this caveat one can reconstruct coastal paleogeography.

The slope of the topography *above* the west and east gates is not cliff-like and might have been flanked. The Spartan leader, Leonidas, may have chosen the middle gate for his defensive position based on the vicinity of the low hill, Kolonos, and a wall supposedly built by the Phokians. In effect, he adopted a position from which his troops could attract the Persians into a slightly wider portion of the pass and then retreat behind protective positions flanked by the precipitous cliffs of Mt. Kallidromon, Kolonos, and the sea (Gulf of Malia of 480 B.C.).

The morphology of the middle gate varies from periods when waves lapped against the cliffs of Kallidromon, as at 6000 to 4000 years B.P. and much of the third millennium B.P., to the current plain of 5-km width. In all probability, the pass was not more than 20–30 m wide during the 480 B.C. battle. During the battle of Thermopylae in 191 B.C., it is possible that relative sea level had begun to drop and the pass at the middle gate would have been wider. This may have been the reason that Antiochus decided to base his defense at the east gate, forcing the Romans to a disadvantage as they attacked out of the narrow middle gate toward the east gate. It is further possible that Antiochus, wishing to avoid the many flanking possibilities (e.g., the actual disaster that befell him when Cato attacked his flank and destroyed his army), feared entrapment if he positioned his army at the middle gate.

In addition to the slow but steady changes due to erosion and deposition, catastrophic tectonic events have and will continue to affect the graben embayment of the Malian Gulf. Pritchett (1965) noted a reference to a tsunami engulfing the head of the Malian Gulf in the 6th century A.C. Pritchett quotes Finlay (1877: 255): "The waters of the Maliae Gulf retired suddenly, and left the shores of Thermopylae dry; but the sea, suddenly returning with violence, swept up the valley of the Sperchios, and carried away the inhabitants."

Conclusions

We have shown that the Gulf of Malia, particularly the western part including the Malian plain, is highly dynamic and ever-changing in geomorphic form due to tectonic, catastrophic, and erosional-depositional-sedimentological processes. We have further shown that very high rates of deposition occurred at the head of the Malian plain and that up to 20 m of sediment overlie the site of the battlefield at Thermopylae at the middle gate. Similar volumes of sediment overlie the land surface of the Malian plain upon which the Persians encamped. Therefore, any conclusions based on present geomorphology are suspect unless one takes into account all of the physical processes occurring during the past 2500 years. The argument as to how the Persian Immortals and others made a flanking movement via the Anopoea path must consider the probability that the morphologies of the areas of the Persian encampment at the head of the Malian Gulf and the east gate at Thermopylae were much different than those at present. The differences may have been so great as to place at least part of the Persian encampment on the opposite side of the Asopus River from that assumed at present. If so, then the requirements that Herodotus' path of the Immortals started with their crossing the Asopus River, with the mountains of the Oetaeans on the right and the Trachinian mountains on the left, might easily be met by the simple explanation that the Asopus River built its alluvial fan and flowed in channels over a 130° spread of river flow.

Similarly, the reason for Anthela's location in an indentation between a deeper ravine and the west gate must be reexamined. The present morphology has little to do with the original siting of Anthela. This important site of the Amphictyonic League of the third millennium B.P. was located in a highly defensible position, with deep waters against cliffs at the west gate and the pass at Thermopylae probably closed, with waters lapping at the very foot of Kallidromon's rocky cliffs.

Finally, we should raise the issue of the relative importance of the pass at Thermopylae. When the pass was open to traffic it was an easy route into southern Greece (Szemler 1981). Geological and geomorphic evidence, however, suggests that the pass was closed for great portions of the last 5000 years and even when open was frequently very narrow and marshy. Recent research by the Phokis-Doris Expedition of Loyola University of Chicago (Edward Kase, Director) has shown a more favored route into southern Greece to the west of the Asopus Gorge, at Dhema Gap near Vardhates. Here an easily accessible and wide pathway led to the Valley of Doris and thence south to Attica or to the Gulf of Corinth via the pass at Gravia and Amphissa. This route was always open, in the geomorphological sense, for the past 5000 years. It was fortified in the Gap and at Kastro Orias. It is noteworthy that the armies of both Xerxes and Brennus the Gaul fought major battles in the pass at Thermopylae and then, having attained victory, they turned west (backwards) and entered southern Greece via the Dhema Gap. Perhaps their fear of a Greek army on their rear flank outweighed their desire for access to the south via Thermopylae. Certainly from the Greek point of view this makes more strategic sense for repeatedly forcing battle at Thermopylae.

The geological interpretations we have presented should be major factors when considering those historic and prehistoric events that occurred at the head of the

Malian Gulf over the past 5000 years. Both catastrophic and slower geological processes occurred leading to massive changes in morphology at the "passes" of Thermopylae and at the head of the Malian plain. The shoreline has prograded eastward into the Gulf of Malia at least 15 km within the last 4500 years (FIG. 14). Because the alluvium that formed the Malian plain is so extensive and so thick, we cannot hope to know the specifics of any ancient human works under the plain. We can only state that changes in morphology and in flow directions of the tributary streams and the Sperchios River were probably the norm rather than the exception throughout the last five millennia.

We will end with a brief comment on the nature of evidence and the philosophy of our approach to the solution of interdisciplinary problems. Historians and some archaeologists approach problems of ancient landscapes from a narrative historical line of reasoning. Classicists constantly challenge the interpretations of others and attempt to make a "best fit," sometimes with antipodal answers. Scientists, geologists in particular, and some archaeologists primarily use empirical data. Scientific methodology combines the interpretation of factual information, hypothesis building, and deduction in order to reach a conclusion (sometimes multiple working hypotheses). In this paper we promote the integration of a multiplicity of disciplines into a common approach to the solution of problems that address interpretation of ancient landforms and historical events.

Acknowledgments

We wish to acknowledge the Institute of Oceanographic and Fisheries Research (I.O.K.A.E.) Athens, Dr. Constantine Vamvakas, then General Director; the Phokis-Doris Expedition of the Loyola University of Chicago;[7] the Archaeometry Laboratory of the University of Minnesota at Duluth; and staff of the Department of Geology, University of Delaware, for their participation in this research.

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7. An expanded version of this study, including geomorphic analysis of the "Great Isthmus Corridor," will be published as a part of the final publications of the Phokis-Doris Expedition by the Loyola University of Chicago.

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