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Coastline Shifts and Probable Ship Landing Site Submerged off Ancient Locri-Epizefiri, Southern Italy

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ABSTRACT

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A geophysical survey provides new information on marine features located seaward of Locri-Epizefiri (Locri), an ancient Greek settlement on the Ionian coastal margin in southern Italy. The study supplements previous work by archaeologists who long searched for the site's harbor and recently identified what was once a marine basin that is now on land next to the city walls of Locri. Profiles obtained offshore, between the present coast and outer shelf, made with a high-resolution, seismic subbottom-profiling system, record spatial and temporal variations of buried Holocene deposits. Two of these submerged features are part of a probable now-submerged ship landing facility. The offshore features can be linked to coastline displacements that occurred off Locri: a sea-to-land shift before Greek settlement, followed by a shoreline reversal from the archaeological site back to sea, and more recently, a return landward. The seaward directed coastal shift that occurred after Locri's occupation by Greeks was likely caused by land uplift near the coastal margin and tectonic seaward shift of the coast, as documented along this geologically active sector of the Calabrian Arc.

The seismic survey records an angular, hook-shaped, low rise that extends from the present shore and is now buried on the inner shelf. The rise, enclosing a core lens of poorly stratified to transparent acoustic layers, bounds a broad, low-elevation zone positioned immediately seaward of the shoreline. Close proximity of the raised feature to the low-elevation area suggests it may have been a fabricated structure that functioned as a wave-break for a ship-landing site. The study indicates that the basin extended offshore as a function of the coastline's seaward migration during and/or after Greek occupation of Locri.

ADDITIONAL INDEX WORDS: *Calabria, Calabrian Arc, coastal shift, geoarchaeology, geophysics, Greek, Holocene, Ionian margin, Magna Graecia, marine basin, seismic profiles, ship landing, submergence, uplift, wave-break.*

INTRODUCTION

The ancient Greek colony of Locri-Epizefiri (Locri) is located 3 km SW of the modern town of Locri, on the Ionian coast of Calabria in southern peninsular Italy (Figure 1). The Greeks first colonized Cape Zephyrios (modern Cape Bruzzano) in Magna Graecia at the beginning of the 7th century BC, and 4 or 5 years later moved 20 km to the NE along the coast to settle the town of Locri at its current location between the Portigliola and Gerace rivers (Cerchiai, 2004). The founding of Locri may actually date to as early as the 8th century BC, but this remains uncertain because of discrepancies between the literary and archaeological records (Cerchiai, 2004).

Locri is one of the most intensively studied archaeological sites in southern Italy and for which a large body of literature is now available. The renowned archaeologist Paulo Orsi began excavations at Locri in the late 1800s (Orsi, 1909), and investigations continue actively at present. An extensive list of early publications pertaining to Locri is cited by Costamagna and Sabbione (1990), with more recent relevant works by Barra Bagnasco and Aimar (1992) and Barra Bagnasco (1996, 1999, 2000, 2001). Although much of the ancient Locri area has long been examined, sectors seaward of the town, and especially off its Ionian coastline, have received surprisingly little attention by archaeologists, geologists, and marine scientists.

Locri was a major trade center during Greek occupation, and archaeologists have long sought the location of its port. Some theories about its position have been suggested by Barillaro (1959); de Giorgio (1973); Nucera (1982); Incorpora (1970, 1980); Giudice, Valastro, and Caruso (1989); Costamagna and Sabbione (1990); and Barra Bagnasco (1996). A recent hypothesis presented by Barra Bagnasco (1999) suggests that a port basin (Figures 1D and 2) is positioned on what is now emerged land (Figures 3A and 3B), in the area south of Marasá Sud (Figures 1A and 2) and east of the stoa (covered walkway or portico, generally for public use; Figures 1C and 2). This implies that the ancient coastline was once close to where the city was located (Figure 1E) and landward of the present shoreline (Figure 1F). To date, however, such a marked coastal change has not been investigated.

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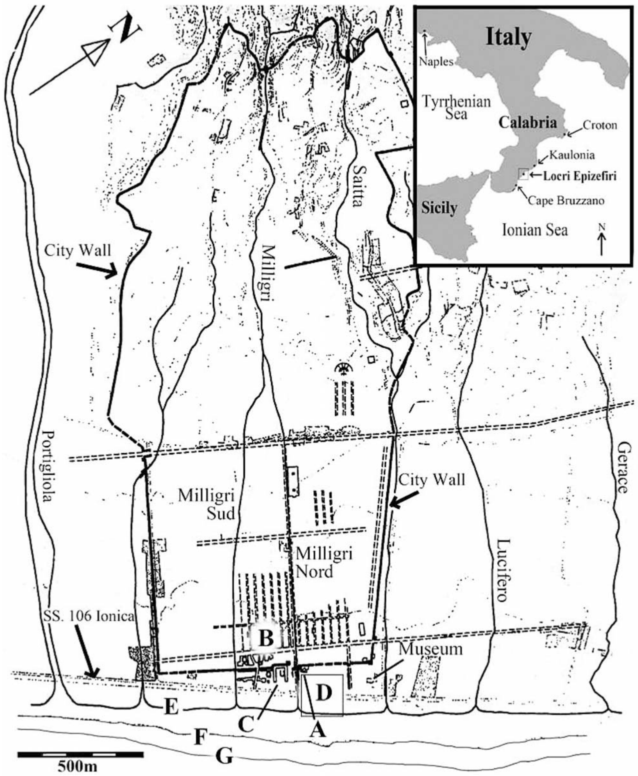

Figure 1. Map of the archaeological site at Locri, Calabria, showing geographic features and archaeological structures, modified from Barra Bagnasco (1996, 1999). (A) Marasá Sud, (B) Centocamera, (C) stoa, (D) port basin location, (E) former coastline position inland of the present shoreline. (F) present coastline position, and (G) postulated earlier coastline, seaward of present shore, as indicated in this study. Shoreline positions are approximate.

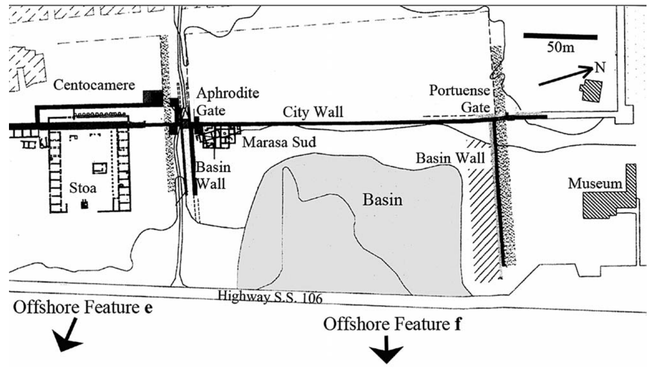

Figure 2. Detailed map of the ship basin (shaded) and adjacent archaeological features excavated on land and discussed by Barra Bagnosco (1996, 1999). Features **e** and **f** discussed in the present study and shown in Figure 8 are positioned just offshore: **e** is seaward of the Centocamera and stoa, and **f** is off Marasá Sud and the basin on land.

A geophysical survey, using a high-resolution, seismic-profiling system, was thus conducted offshore of Locri (Figure 4) to identify seafloor surface features, define the configuration of subbottom strata, and discover features that may have been associated with human activity and are now submerged seaward of the site. Such a study would serve to provide information on natural coastal changes and shoreline migrations during the mid-to-late Holocene, and help to determine whether there once may have been a sheltered coastal or harbor facility landward of the present beach as suggested by our ongoing research.

LOCATION AND HISTORICAL BACKGROUND

The Locri coastal margin is positioned in a highly active tectonic sector of the Calabrian Arc, a major geological contact zone between the African and European plates in the central Mediterranean (Bordoni and Valensise, 1998; Parotto and Praturlon, 2004; Westaway, 1993). The hills immediately behind the site are formed of Pliocene marine and terrestrial deposits (Carta Geologica della Calabria, 1968), and topographic highs within the boundary of the ancient city have elevations to ~150 m above mean sea level (msl) (Barra Bagnasco, 2000). The coast-facing wall of the ancient town is presently about 300 m landward of the shore. The major Ionica highway (S.S. 106) and adjacent railway line parallel the straight, NE to SW–trending coastline and are located ~150 m inland of it. Shoreward of the highway are low, aeolian sand dunes (~3 m or less relief; Figure 3D), and the beach is formed of sand to pebbly sand (Carta Geologica della Calabria, 1968). The Portigliola River, flowing ~400 m south of the city wall, is the closest major fluvial system in the Locri area. In the past, the river transported material up to boulder size from proximal mountains, but today its flow displaces smaller particles, with pebbles averaging ~60 mm in diameter (Ibbeken and Schleyer, 1991). There are also several smaller streams that flow across the site (the Saitta, and the Milligri's north and south branches), some of which were used for cult purposes by the Locrians (Barra Bagnasco, 2001). These streams are mainly seasonal, with strong flow primarily during heavy rain storms that occur mainly in winter months (Barra Bagnasco, 2000).

The occupants in this sector, before arrival of the Greeks, were an indigenous group, the Sicels. They were tricked into moving farther inland when the Locrians arrived from western Lokris in the Euboian region and/or from Ozolian Lokris on the Gulf of Corinth, both in central Greece (Cerchiai, 2004). The ancient town of Locri occupied about 2.3 km^2 (Cerchiai, 2004) in an area that extended from low hills down to the coast. The site was surrounded by a ~7-km-long wall (Randall-MacIver, 1931). In the 6th century BC, Locri expanded its territory by colonizing a sector to the west. There, on the Tyrrhenian side of southern Italy, it comprised the towns of Medma and Hipponion (Randall-MacIver, 1931). The peak in Locri's history was during the 4th century BC, when Dionysius I, a tyrant from Syracuse, came to power. According to the Livius (1905) *History of Rome,* Locri became allied with Carthage instead of Rome during the second Punic war, and shortly after, began to decline. Its influence was reduced after this war, although archaeological evidence in-

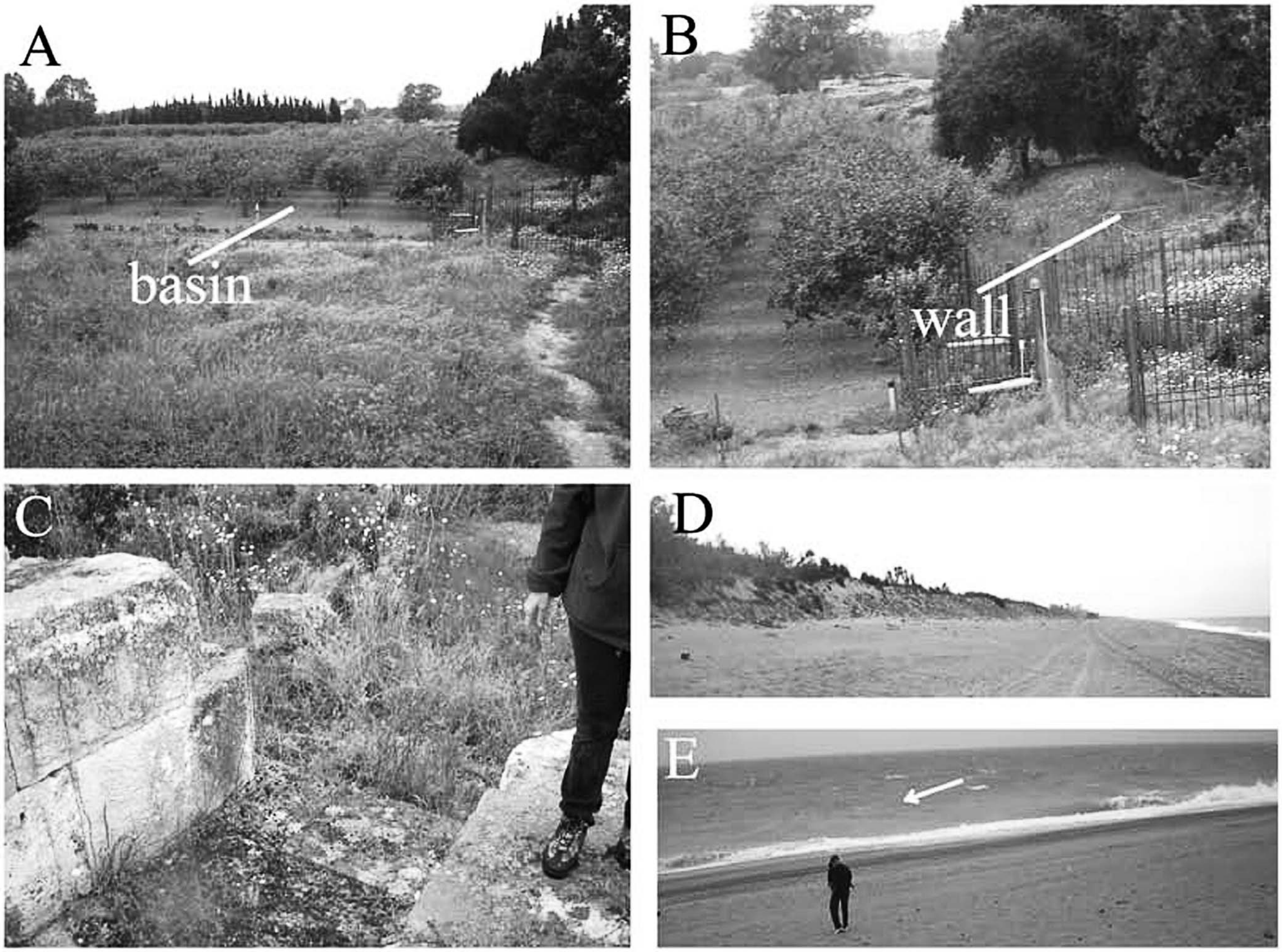

Figure 3. Photographs taken at Locri (17 April 2008). (A) Orchard covering area interpreted as a former basin; view to SW. (B) Close-up of area in A showing contact of basin with site's seaward-facing wall (see Figure 2). (C) Gate opening, near juncture of basin with city wall. (D) View to NE showing low sand dunes backing beach at Locri. (E) Waves from the ESE driven at angle toward Locri shore with displacement of coarse sand and pebbly sand along the coast in a NE direction (arrow).

dicates Locri remained active until the 8th century AD, and then, diminished almost completely following attack by the Saracens in the 9th century AD (Townsend, 1867).

PROBLEM OF PORT LOCATION

During the past half-century, a number of scholars have alluded to a possible port or harbor facility, but usually in general terms. Some studies suggest the port was positioned within one of the nearby river channels on what is now land. De Giorgio (1973) and Giudice, Valastro, and Caruso (1989) suggested that the harbor may have been located in the lower reaches of the Portigliola River (Figure 1), whereas Nucera (1982) indicated it could be in the Bonamico River, positioned 15 km SW of Locri.

In recent years, a harbor location adjacent to the site has been postulated. Barra Bagnasco (1999) proposed that a ship basin (Figure 1D) was located in the lower part of the city, seaward of the site's Marasá Sud and Centocamera sectors (Figures 1A, 1B, and 2), and adjacent to the stoa (Figure 1C). This latter hypothesis is based on structures found on the seaward side of the Locri city wall, *i.e.,* primarily two walls that extend seaward from the town margin. Landward, these walls are positioned near gates that lead into the city through its surrounding wall (Figures 2 and 3C). An additional, but indirect, argument presented is that the ship basin is located near the town's temples dedicated to Aphrodite and Zeus, divinities worshiped with regard to the sea and navigation (Barra Bagnasco, 1999). Still other approaches have invoked pollen assemblages collected in samples from the Marasá Sud area and dated to the 4th to 3rd century BC. That study, however, provided primarily evidence of freshwater plants (Caramiello *et al.,* 1992), rather than pollen assemblages of salt-tolerant and/or brackish-water plants of the type expected in or near a marine basin.

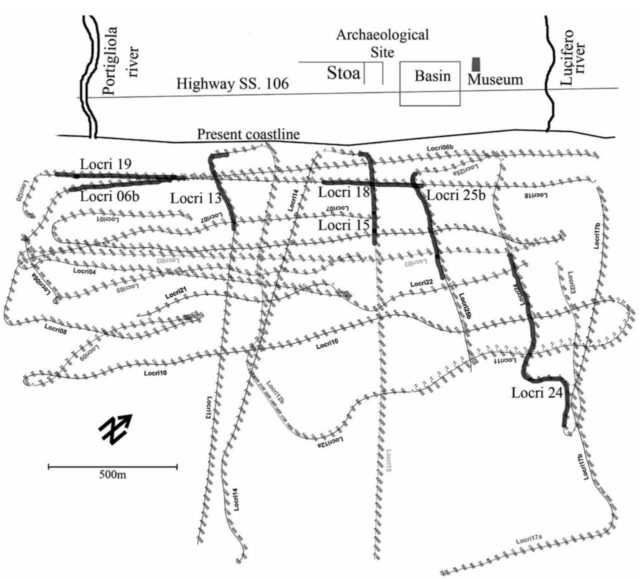

Figure 4. Map showing seismic survey profiles collected off Locri. Shaded line segments are those discussed and illustrated in this study (Figures 5 and 6). Land features simplified from Figures 1 and 2. **For a color version of this figure, see page 401.**

Available marine charts do not reveal any obvious features nearshore on the inner shelf off Locri. A bathymetric survey that included the area seaward of the town was made by Rumohr and Ibbeken (1975), but its focus was primarily the Buonamico Canyon 15 km SW of Locri. In another study, Di Girolamo *et al.* (1994) considered the possible presence of a submerged volcano located just offshore of Locri and suggested that such a feature could be a source for lava fragments used as local building material, but no offshore data in support of this were presented. More recently, a study by D'Alessandro *et al.* (2002) analyzed 20th century Ionian beach evolution along an 80-km-long coastal stretch, including the sector along which Locri is sited. That analysis concluded that the shoreline has retreated landward since the 1950s primarily because of increased erosion that resulted from urban development along the coast and human-influenced reduction of fluvial solid-load discharge into the sea.

METHODS

None of the above-cited investigations record either natural or anthropogenic structures submerged seaward off of Locri. Consequently, a geophysical approach was selected as a means to identify features that might be buried offshore and to provide evidence of shoreline migration patterns near the site (*cf.* Barra Bagnasco, 1999) during and following the time of Greek settlement.

A high-resolution, seismic reflection survey was thus conducted in July 2004 to obtain a series of subbottom profiles seaward of Locri. Equipment used was an IKB-Seismic single-channel seismic-profiling system (Simpkin and Davis, 1993), with a boomer-plate source (Edgerton and Hayward, 1964) and cone-in-line hydrophone array towed on a catamaran float. Water depths in the surveyed area ranged from 3 to 90 m. The survey acquired 25 seismic profiles for a total length of ~30 km within an area of ~2 km² seaward of the coast (Figure 4). Sixteen seismic profiles were obtained parallel to shore, with spacing between profiles ranging from <50 m to 300 m; an additional nine profiles were recorded perpendicular to shore, with line spacings from 50 m to 400 m. Selected sections of seismic profiles discussed in text are shown in Figures 5 and 6. Additional information about equipment and methodology used for this geophysical survey and data processing is provided in a separate study made at the same time off another ancient Greek site, Kaulonia, on the Ionian margin 37 km NE of Locri (Stanley *et al.,* 2007).

A bathymetric map of the modern seafloor surface was compiled (Figure 7A), as was a contour map of a well-defined Holocene subsurface reflector, referred to herein as the *J-horizon* and interpreted to be the former seafloor (Figure 7B; profiles showing J-horizon in Figures 5 and 6). Of special importance in the present study is an isopach map that depicts sediment thickness variations between the present seafloor and underlying J-horizon (Figure 8).

These three maps were prepared using interactive, interpretation software. The seafloor and J-horizon reflection times were picked along the seismic profiles and output to a geographic information system (GIS) mapping program. The x-y-z data set was gridded and contoured using an Inverse Distance Weighted algorithm (Liszka, 1984). Two-way reflection times were converted to depth using a water column velocity of 1500 m/s and a 1600-m/s velocity for the interval between the seafloor and J-horizon. The contour lines were hand-edited to remove spurious single-point features.

OBSERVATIONS

Seismic profiles obtained on the narrow-shelf platform off Locri and maps compiled from these data detail the seafloor bathymetry and subbottom sediment configuration to depths of ~10 ms (7 m) beneath the seafloor. Seismic profiles were collected along the entire length of the ancient Locri coastline to within ~10 to 100 m of the shoreline (Figure 4). Both the bathymetric map of the modern seafloor (Figure 7A) and the contour map of the J-horizon surface (Figure 7B) are contoured at a 1-m interval. The J-horizon surface on seismic profiles is detected nearshore to a shallow depth of ~4 ms (3 m) below the seafloor (Figure 4). The isopach map of the sediment sequence between the seafloor and J-horizon surfaces is contoured at a 0.2-m-thickness interval. No major faults that offset the post-J-horizon sediment strata on the shelf platform were observed on these seismic profiles.

The seafloor bathymetry map shows coast-parallel contour lines, with horizontal spacing of 30 to 100 m. Isobaths are traced from depths of ~4 m nearshore to ~19 m, at a distance of ~900 m seaward from shore. The gently seaward dipping modern shelf surface is approximately 600 m wide between the shoreline and ~11 m contour. Contour lines closest to shore, just seaward of the archaeological site, record a gentle seafloor rise (low rise [LR], Figure 7A). This low rise extends toward the ENE, away from the coast, for a distance of ~450 m; the average width of this subtle seafloor feature is ~200

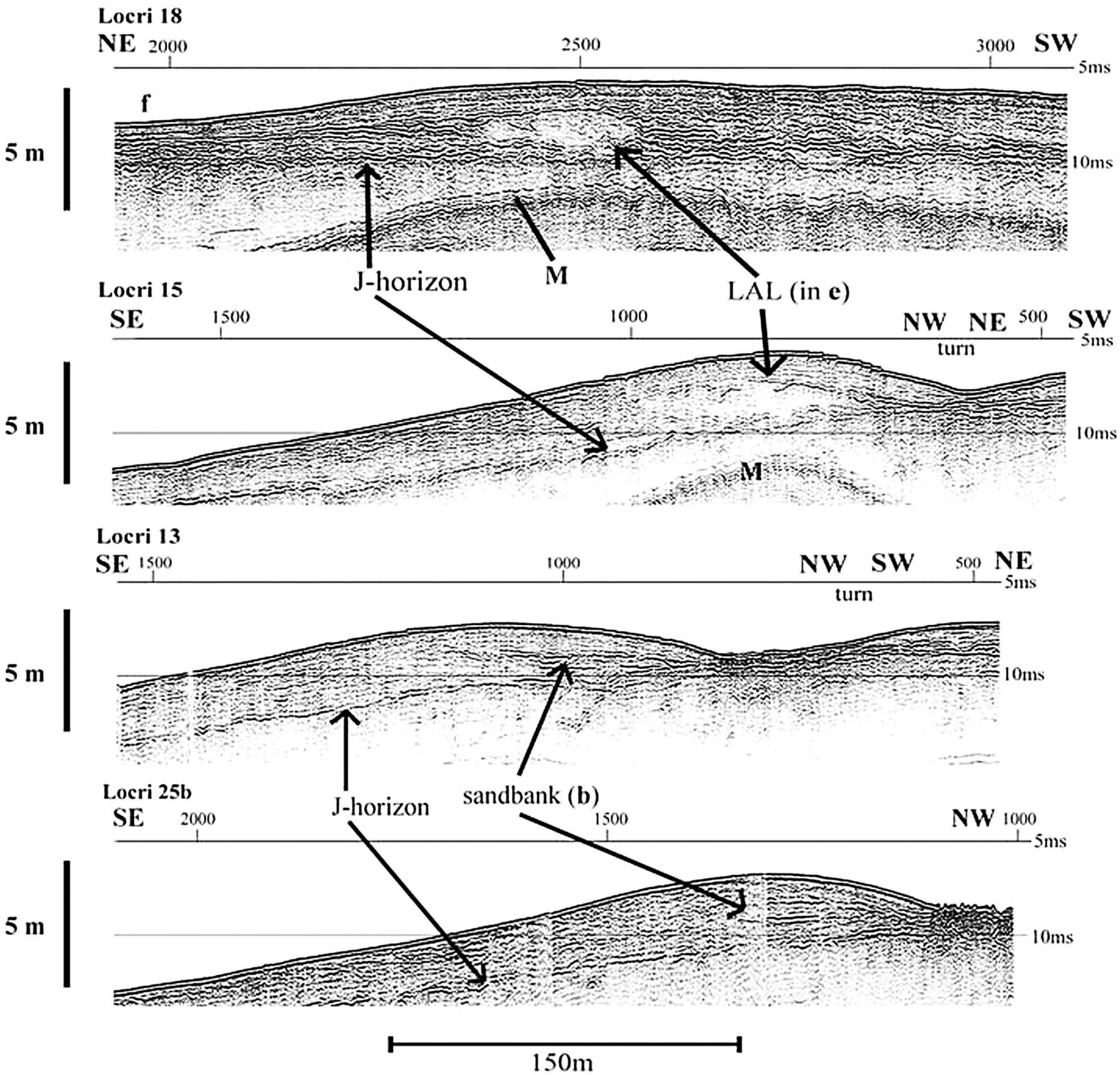

Figure 5. Segments of coast-parallel seismic profile Locri 18 and coast-perpendicular profile Locri 15 provide cross-sections of feature E shown in Figure 8; note low-amplitude lens (LAL) contained in **e.** Low-elevation feature **F** is shown on profile 18. Coast-perpendicular profiles Locri 13 and Locri 25b provide two cross-sections of deposit **b** in Figure 8. These offshore sandbanks record distinct stratification, whereas more poorly defined and acoustically near-transparent strata (LAL) in **e** are shown on Locri 15 and 18. J-horizon, distinct, continuous acoustic reflector is noted, as is M, water-bottom multiple. Small offsets at seafloor are artifacts of filtering algorithm applied to remove swells at sea surface.

m. The rise is apparent on seismic profiles Locri 18 and Locri 15 (Figure 5) and also on Locri 06b (not shown here). The shelf platform is remarkably narrow and deepens abruptly beyond a depth of about 11 m where, within a short distance, it rapidly merges with the upper edge of the slope.

The contoured subbottom J-horizon surface also shows a narrow and rather featureless, gentle seaward-sloping shelf platform (Figure 7B). Contour lines on that older Holocene surface are parallel to the coast and horizontally spaced about 40 to 120 m apart from a depth of ~6 m nearshore to 14 m over a distance of ~700 m from shore. This earlier Holocene platform surface slopes slightly less seaward than does the modern seafloor above it.

Of note in the SW sector of the survey area close to shore

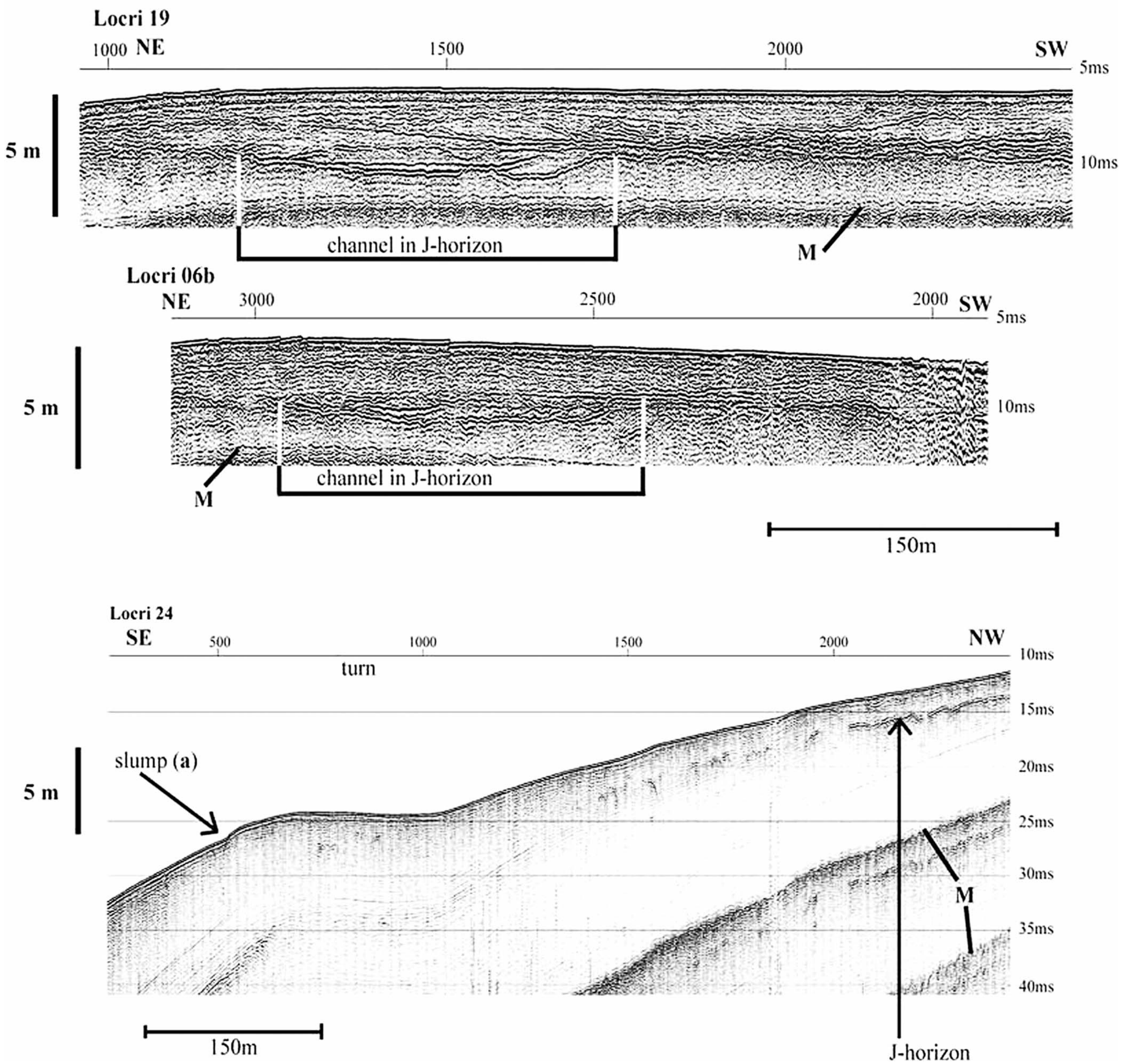

Figure 6. Coast-parallel profiles Locri 19 and 06b show cut-and-fill structures, part of feature **c** in Figure 8 at and above J-horizon; this channel incision appears as a coast-perpendicular depression in the J-horizon map (CI, Figure 7B). Coast-perpendicular profile Locri 24 shows evidence of failure in area of depositional feature **a** (Figure 8) as denoted by slump scar at shelf platform-slope margin; also the J-horizon becomes discontinuous and progressively more poorly defined in a seaward direction. The apparent flat bench upslope from slump scar is an artifact caused by a coast-parallel turn during data acquisition (Figure 4). M, water-bottom multiple. Small offsets at seafloor are artifacts of filtering algorithm applied to remove swells at sea surface.

is a distinct coast-perpendicular depression that is well defined by the 8-m-depth contour line [coastal incision (CI), Figure 7B]. This narrow channel-like incision, positioned >100 m from the present shoreline, and 250 m NE of the modern Portigliola River outlet, occurs at the subbottom J-horizon on seismic profiles Locri 19 and Locri 06b (Figure 6). Both profiles parallel the shore, with Locri 19 at a distance of ~120 m and Locri 06b at ~150 m (Figure 4) from the coast.

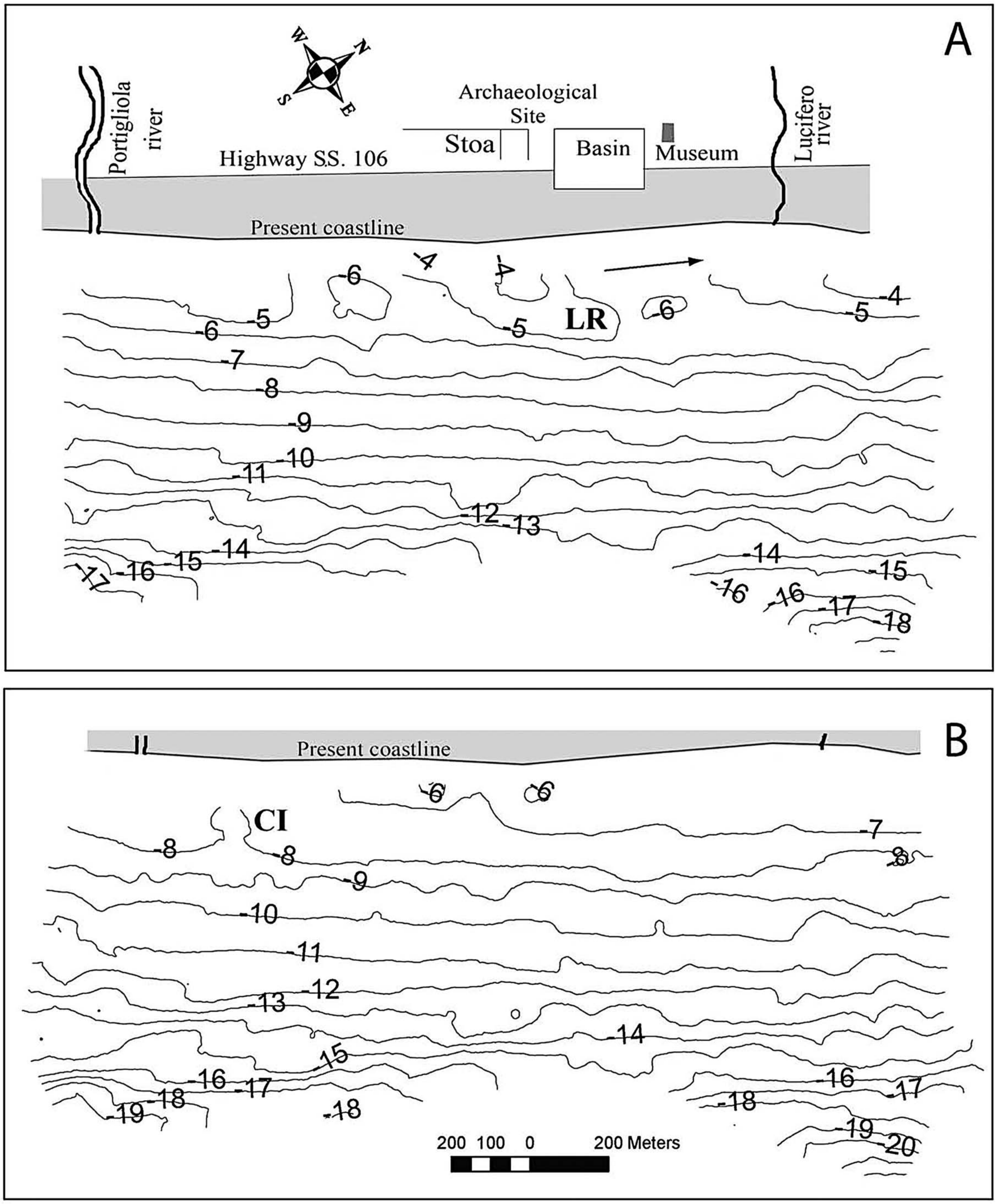

Figure 7. Maps generated from seismic data collected seaward of Locri. (A) Bathymetry of modern seafloor. LR, low-rise (upper part of feature **e** in Figure 8). Arrow denotes dominant NE coastal current direction. (B) Contour map of depth to J-horizon, a distinct acoustic subbottom horizon recorded on most profiles in survey (Figures 5, 6). CI, channel incision beneath feature **c** in Figure 8; 1-m contour intervals shown on both maps.

The isopach map reveals marked Holocene sediment thickness variations between the seafloor and J-horizon. In particular, six distinct features denoted as **a** to **f** on Figure 8 are described below:

(a) Depositional build-ups **a,** the most distant features from the shoreline considered here, are ~700 m offshore in the NE part of the surveyed area near and just below the shelf-slope break. One of the irregular to oval deposits is

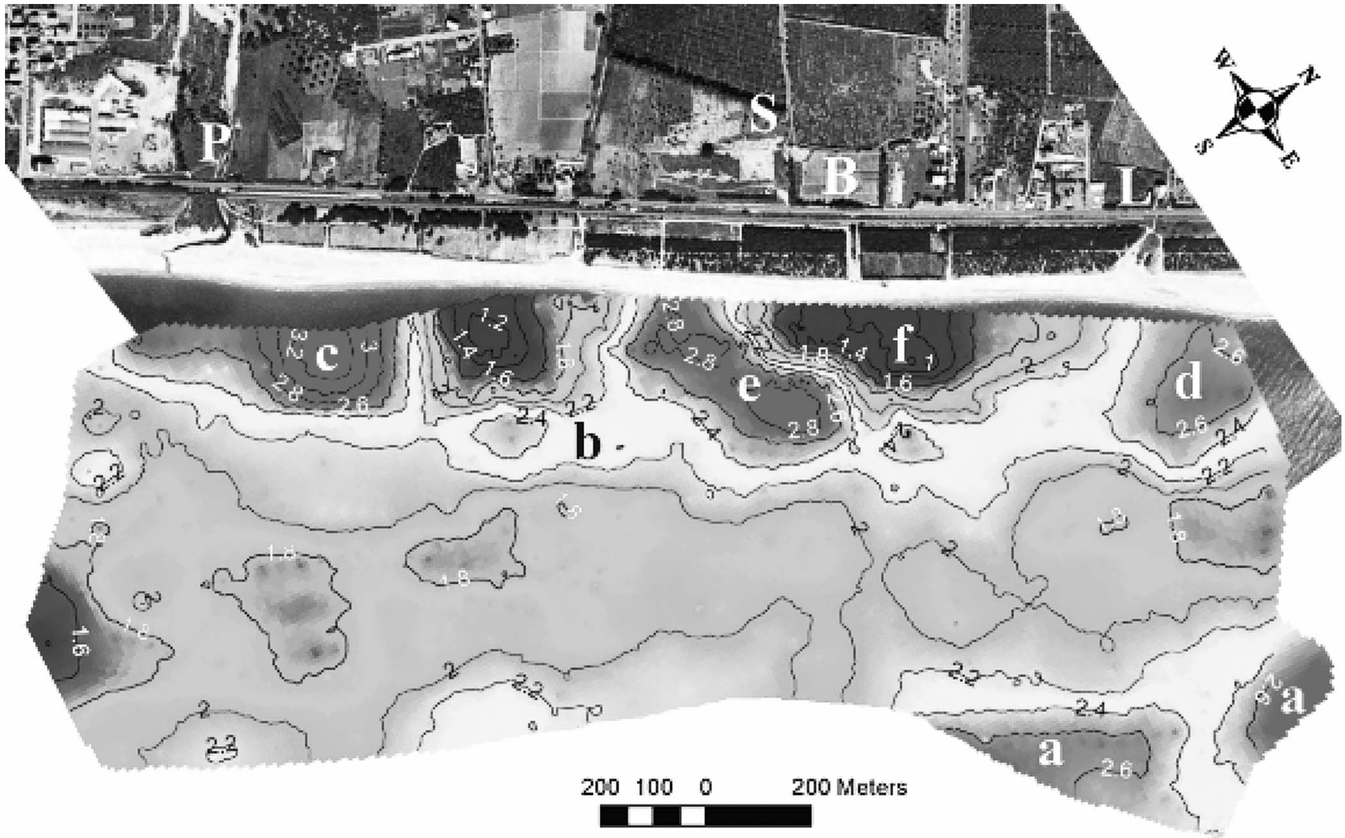

Figure 8. Isopach map shows Holocene thickness variations and six features (**a** to **f** discussed in text) in sediment sections between the seafloor and J-horizon (Figures 7A and 7B). Contour interval is 0.2 m. P, Portigliola River; S, stoa; B, basin; L, Lucifero River. **For a color version of this figure, see page 401.**

~700 m long and oriented N to S, and the other is ~500 m long and extends from NNW to SSE. Their thickness ranges from 2.2 to 2.6 m. The J-horizon reflector on seismic profiles in this outermost shelf-upper slope sector (Locri 24; Figure 6) is not as well defined as on profiles closer to shore (Figure 5).

(b) Low, elongate, continuous, coast-parallel ridge **b** is at least 1500 m long and ~150 m wide. The ridge is 2.2 to 2.4 m thick and appears on the isopach at about 250 m seaward from the coast. The ridge is shown in profiles Locri 13 and Locri 25b (Figure 5).

(c) Oval-shaped lobe deposit **c** extends seaward nearly 250 m from the coast, and its seaward margin parallels the shore for ~600 m. The thickest section is 3.2 m and positioned directly above the coast-perpendicular channel incision recorded by the 8-m contour line on the map of the J-horizon (CI, Figure 7B).

(d) Deposit **d** has a more angular-shaped configuration than feature **c** and extends ~300 m from land and parallels the shore for ~250 m. Its thickness ranges from 2.2 to 2.6 m.

(e) Angular, hook-shaped feature **e** is ~450 m long and has an average width of ~200 m. It extends ENE, and is positioned directly beneath the ENE-trending low rise noted on the shelf surface bathymetric map cited earlier (LR, Figure 7A). The thickness is 2.8 m. Feature **e** merges with coast-parallel ridge deposit **b** about 200 m seaward from the coast. Seismic profile Locri 15, oriented perpendicular to the shore, and Locri 18, parallel to the shore, record in **e** a large lens of sediment characterized by poorly defined stratification. This low-amplitude lens is indicated as LAL in Figure 5 and positioned ~150 m seaward of the coast (Figure 4). Two seismic profiles cross the area where feature **e** is recorded on the isopach map (Figures 4 and 8). The LAL lens is contained completely within thickened feature **e** and located just landward of where deposits **e** and **b** merge. The LAL is located above the stratigraphic J-horizon, is ~65 m long as recorded on seismic profile Locri 18, and is <60 m wide as measured on Locri 15. The LAL is ~2 ms (>1.5 m) thick and is buried by ~1.5 ms (>1 m) section of stratified sediment. Feature **e** lies SE of the stoa at the archaeological site. No feature comparable to **e** is observed elsewhere in the offshore survey area.

(f) The length of elongate-oval feature **f** is 640 m parallel to shore and 200 m wide, perpendicular to shore. This low-elevation zone is 1.0 to 2.0 m thick and partially surrounded by raised hook-like feature **e.** Area **f** is transected by profile Locri 18 (Figure 5) and lies just seaward of the depressed area on land interpreted by archaeologists as a former basin (Figure 2).

OFFSHORE FEATURES OF DEPOSITIONAL ORIGIN

Four of the six features (**a**–**d**) recorded on the isopach map (Figure 8) are interpreted as Holocene sediment sequences essentially of natural depositional origin, whereas features **e** and **f** may be partly associated with human activity and are discussed separately in the following section.

Deposit **a** is linked to sediment buildup, instability, and failure of strata accumulating at the shelf edge and upper-slope margin, some of which has occurred since the time of the J-horizon. An example of a slump scar in this sector is observed on profile Locri 24 (arrow, Figure 6).

Linear ridge-like feature **b,** oriented near-parallel to the shore and recorded on seismic profiles Locri 13 and Locri 25b (Figure 5), is interpreted as a coastal current-formed offshore sediment bank. Its geometry is similar to low-rise, coast-parallel sandbanks observed in the seismic survey conducted offshore ancient Kaulonia, the other Greek site where the same equipment and methodology were used (Stanley *et al.,* 2007).

Deposit **c** in the SW sector of the study area, positioned mostly landward of the offshore sandbar discussed above, was deposited in post-J-horizon time from sediment discharged by the Portigliola River. Its location is seaward of this river that previously carried a much larger fluvial sediment load before construction of protective embankments, dykes, quarries, reservoirs, and the effects of reduced flow, resulting from water diversion from the channel for irrigation. The rivers in Calabria, at least in recent time, have experienced episodic flooding and increased discharge at about 25-year intervals (Bartholoma, Ibbeken, and Schleyer, 1998). The mouth of the modern Portigliola is now positioned on the coast ~50 to 100 m SW of the thickest section of deposit offshore. This records a southward displacement of the lower river channel and mouth since the time of accumulation of the older Holocene fluvial sediments that were once released farther seaward.

Deposit **d** in the NE sector of the isopach map (Figure 8) is similar in form and origin to deposit **c.** It is a fluvial sediment build-out positioned NE and seaward of the Lucifero River outlet. This deposit covers a smaller area and is less thick than deposit **c** formed off the Portigliola River.

LANDING SITE SUBMERGED OFFSHORE

Feature **e** on the isopach map extends just offshore from the archaeological site and to the south of where previous studies (Barra Bagnasco, 1999) indicated a port basin may have been located. A stream-related origin for this feature is unlikely based on three factors: its angular hook-like shape, acoustic characteristics, and orientation offshore in a direction that is neither perpendicular nor parallel with the coast. Although fluvial sediment from the branches of the Milligri stream reached the coast in the area near feature **e,** both flow and discharge were considerably smaller than those of the Portigliola and Lucifero rivers that gave rise to deposits **c** and **d.**

Processes that produced feature **e** are not clearly defined at this time. Winds in the region are variable, with those in winter predominantly from the N and/or S, and prevailing ones in summer mainly from the NW (Clarke, 1989). Surface currents are dependent on seasonal and regional winds, with a general trend to the S or SE at sea at a distance from Locri's coastal sector (U.S. Naval Oceanographic Office, 1991). Measured dominant long-term longshore transport directions shed more pertinent light on sedimentation off the coast. Net longshore transport direction at Bianco Beach, 15 km SW of Locri, is predominately to the NE, especially at times of high to medium energy storm systems (Bartholoma, Ibbeken, and Schleyer, 1998; CNR and MURST, 1996). The same coastal current pattern is observed along the Locri shore (Figures 3E and 7A). The orientation and shape of feature **e** may be associated with this NE longshore drift pattern.

The poorly defined LAL acoustic lens observed on seismic profiles appears as a core-like feature entirely within feature **e** (Figure 5). In contrast, the linear bank **b** in the survey area (Locri 13 and Locri 25b; Figure 5) shows well-defined internal stratification that is unlike the thickened sediment sequence that encloses the poorly stratified LAL (Figure 5). It should be pointed out that no lens-like feature similar to the LAL in deposit **e** is recorded at any other location in the surveyed Locri area nor, for that matter, at the seismically detailed sector seaward off the Kaulonia site to the NE (Stanley *et al.,* 2007). The LAL may be associated with attributes of soil compaction, particle size, organic matter content, moisture retention and/or possibly the presence of underlying anthropogenic material. Core drilling will help determine whether one or a combination of several of these factors produced the lens-like feature on seismic profiles (Marriner and Morhange, 2007; *cf.* Neal, 2004).

Depositional sector **f** of low elevation is positioned just seaward of the gentle sloping zone next to Locri walls interpreted by archaeologists as a shallow basin (Figures 2, 3A, and 3B). There is currently no available evidence that this area offshore had been excavated artificially. It is possible, however, that the low area may have been partially shielded from coastal current transported sediment by higher feature **e** positioned adjacent to it.

Although there is insufficient information at this time to reliably interpret the origin of features **e** and **f,** their configuration and position in close proximity to, and just seaward of, the archaeological site suggest that they could relate in some manner to effects of human activity. It is recalled that the thin-sediment section zone **f** is positioned immediately seaward of the interpreted ship basin and/or landing site protected by two SE-trending walls (Figure 2; Barra Bagnasco, 1996, 1999). This postulate is reinforced by the presence of the higher feature **e,** adjacent to low-elevation area **f.** The raised, angular, hook-shaped feature **e** that bounds the SW, S, and E parts of area **f** (Figure 8) conceivably served as a protective structure, such as a seawall, against the brunt of NE-driven waves and coastal currents.

HOLOCENE COASTLINE CHANGES

The geophysical survey provides evidence of geologically recent (late Holocene) seafloor changes just off Locri. Although offshore subbottom units have not as yet been dated, a reflector acoustically similar to the J-horizon at Locri was dated as early to mid-Holocene in the survey at Kaulonia farther up the coast, and attributed to pre-Greek occupation time (Stanley *et al.,* 2007).

Several observations are warranted. For example, the low nearshore rise observed on the present seafloor does not appear on the J-horizon surface at depth, indicating that sediment in this particular sector accumulated since the time of reflector J-horizon. Additionally, the coast-perpendicular depression noted on the J-horizon is not observed on the present seafloor. Moreover, the present coast-parallel contour isobaths on the seafloor map (Figure 7A) shows a somewhat increased shelf slope that occurred since J-horizon time (Figure 7B). These changes could be explained by an upward lift of the inner Ionian shelf that, in turn, may have caused the shoreline to migrate seaward after J-horizon time. Such a recent geological displacement is not unexpected in this region, which is subject to frequent active land motion (Antonioli *et al.,* 2006; Bordoni and Valensise, 1998; Westaway, 1993). Evidence for recent marked uplift of land behind Locri are Quaternary marine terraces, some dated to >110 ka and presently elevated to 92 m above msl (Dumas *et al.,* 1995). A regional uplift in the late Holocene in this coastal margin of the Calabrian arc caused an offshore coastline displacement such as the one that occurred at ancient Kaulonia NE of Locri (Stanley, 2007; Stanley *et al.,* 2007).

Evidence of such a seaward shift of the shoreline is the coast-perpendicular depression noted on the contour map (Figure 7B), and detailed on seismic profiles Locri 19 and Locri 06b (Figure 6). This record of fluvial channel erosion and thick Portigliola deposit c located ENE of the present river outlet (Figure 8) denotes the seaward extent of the ancient river channel before, or contemporaneous with, reflector J-horizon. Feature **c** indicates that the Portigliola channel during the late Holocene was positioned at depths that are now to ~13 m below present msl (Figure 7B).

Observations show that before J-horizon (pre-Greek) time, a channel of the ancient Portigliola was cut and positioned seaward ~200 m NE from where it is currently located. Following this time of lowered sea level and channel incision, eustatic sea level rose, leading to a landward advance of about 330 m by the time of Greek settlement, *i.e.,* from shoreline position G to position E adjacent to the site as shown in Figure 1. The Greeks settled and developed Locri following this landward shoreline migration, and it was during this period that a ship-landing facility partially confined by two protective walls was formed next to the town as suggested by archaeologists (Figure 2). Tectonic uplift occurred at some as-yet-unspecified time during or after the site was occupied by the Greeks and/or subsequent settlers, *i.e.,* between the 8th century BC and 9th century AD. This is the probable cause of the observed increase in slope of the inner Ionian shelf, as well as the coastline shift seaward by about 150 to 200 m from position E to a position seaward of F in Figure 1. Finally, shoreline migration once again reversed direction and advanced landward to present coastal position F as a result of sea-level rise and coastal erosion processes. It appears that the rate of landward shoreline advance has increased in recent years in part because of reduction of sediment discharged to the coast and consequent increase in shore erosion (D'Alessandro *et al.,* 2002).

The back-and-forth shoreline shifts, involving a sea-to-land movement, then a reversal, from land to sea, and finally a return-to-land migration at Locri recalls the pattern that occurred at ancient Kaulonia since the mid-Holocene (*cf.* Stanley, 2007). The main difference is that, at Locri, Greek settlement occurred before land uplift and seaward coastline advance, whereas Greek occupation at Kaulonia took place after major land uplift and offshore coastal shift. This time-wise difference of shoreline migration at the two closely spaced (37 km) sites in the southern Calabria region is not unexpected. The Ionian margin experiences strong episodic land motion, with shifts occurring at somewhat different times along various coastal sectors. One explanation for these spatial and temporal differences along the short Ionian coastal stretch is differential motion along two major active strike-slip faults and other tectonic structures positioned between Locri and Kaulonia (Carta Geologica della Calabria, 1968).

FURTHER EXPLORATION BECKONS

Recent archaeological studies at Locri indicate that a ship basin was located on what is now land and that the coastline during Greek occupation was situated adjacent to the site's position. The present geophysical survey suggests two features offshore associated with this facility, one that may have served as a wave-break structure, the other a low, more protected area associated with the postulated ship basin adjacent to the site that is now subaerially exposed. To test this scenario will require hard data of the type best derived by obtaining a series of sediment borings recovered by drilling along land-to-sea transects as well as archaeological excavation efforts offshore. Analyses of sediment petrology and faunal assemblages in core sections to be collected between area D on land (Figure 1) and sectors **e** and **f** offshore (Figure 8) are needed to substantiate whether a semiprotected ship landing site next to Locri was displaced seaward as the coastline shifted offshore. It is now necessary to date well-defined subbottom offshore horizons to reliably correlate stratigraphically submerged features observed in this study with dated archaeological features on land.

Finally, several observations made seaward of ancient Kaulonia could be of possible application for further study at Locri. For example, underwater exploration by archaeologists at Kaulonia in the 1980s resulted in a detailed map showing the position of numerous large Greek artifacts, such as column sections, lying above a well-defined substrate (Iannelli, Lena, and Mariottini, 1993; Lena and Medaglia, 2002). The geophysical survey offshore Kaulonia in 2004 was made a few years after the dated horizon covered by the Greek material had been buried on the seafloor by a 1- to 4-m-thick layer of storm-driven sand-rich sediment. None of the seismic profiles revealed the presence of large archaeological artifacts that had been observed only a few years before and that were now buried beneath a new veneer of sandy sediment (Stanley *et al.,* 2007). It is thus possible that off Locri, Greek and/or other artifacts are perhaps also present above the J-horizon. However, if present, they are covered by a veneer of storm-displaced sediment and are not apparent on seismic profiles made in the present survey.

Excavation by divers on features **e** and **f** seaward of the site and in area **c** offshore the Portigliola River will help determine the timing of the proposed coastal migration to land, then to offshore, and finally back toward land in the mid- to late-Holocene. This would supplement information obtained from drill cores to be taken between features **e** and **f** and on land at the port basin locale indicated by archaeologists. Expanded geoarchaeological exploration serving to further correlate the newly discovered features offshore with those mapped on land promises to provide new information on Locri's navigational and sea trade activities.

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