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GEOACOUSTIC MODELS FOR SELECTED SHALLOW WATER AREAS

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David L. Bradley
Director

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Geoacoustic models for selected shallow water areas

A. Caiti, F. Ingenito, A. Kristensen, & M.D. Max

Executive Summary: Geoacoustic profiles for 5 bottom types in the Southwest Approaches to the English Channel, the Sicilian Channel and the Balearic shelf west of Palma de Mallorca have been derived using experimental data in conjunction with a best fit approach.

The geoacoustic data have been incorporated into propagation loss and reverberation models for sonar performance prediction.

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Geoacoustic models for selected shallow water areas

Caiti, F. Ingenito, A. Kristensen, & M.D. Max

Abstract: This report summarizes recent work on characterization of shallow-water "reference sites" for well-characterized seafloor types. Geoacoustic models are presented for five sites in three shallow-water areas: the Sicilian Channel, the Balearic Shelf, and the Southwest Approaches to the English Channel. The geoacoustic models have been tested by comparing predicted and measured transmission loss at each site. References to reports on the individual sites are given.

Keywords: Balearic Shelf – bottom properties – Sicilian Channel – Southwest Approaches – SWAP

Contents

1 Introduction

In recent years, a series of measurements has been conducted in representative shallow-water areas with the objectives of testing and evaluating techniques for determining bottom parameters and of acoustically characterizing "reference sites" for model development and evaluation. Three areas have been studied and reported [1-3]. This report summarizes the results; giving, for each area a brief geological description and a geoacoustic model. The acoustic parameters were determined whenever possible from direct measurements. The geoacoustic models are presented in a form suitable for use in acoustic prediction models such as SAFARI [4] and were tested by comparing predictions with acoustic transmission loss measurements.

Geophysical surveys of the areas were conducted, with Uniboom, sparker, and side-scan sonar. Cores and grab samples were also taken and analyzed. Broad-band transmission loss measurements, using explosive sources, were made along at least one track in each of the three areas.

The geoacoustic models consist of compressional and shear velocities, compressional and shear attenuations, and density, all as functions of depth. The compressional and shear velocities were measured by acoustic techniques described in [1–3]. In a few cases one or more of the techniques was unsuccessful. When this happened, the missing acoustic parameter was adjusted, consistent with the known properties of the bottom, until the best agreement was obtained between measured and predicted transmission loss. Compressional and shear velocities or physical properties allowed the bottom layers to be identified, from which attenuation and density could be obtained by the use of empirical relations from the literature [5]. In most cases, predictions made using the geoacoustic model as input to a transmission loss model were in reasonable agreement with measured transmission loss in the frequency band 100-1600 Hz, with lesser agreement at the highest and lowest frequencies.

2
Sicilian Channel

Measurements were made at two sites in the Sicilian Channel: Adventure Bank between SW Sicily and the island of Pantelleria and the area south of Lampedusa.

2.1 Adventure Bank

The Adventure Bank (Fig. 1a, Site A; Fig. 1b) area has a nearly constant water depth of about 75m and a smooth seafloor. A large part of the Bank is underlain by locally exposed eroded calcarenites (calcareous sedimentary rock formed from shelly and algal carbonate detritus) the constituents of which are similar to those in the nearby unconsolidated modern sediments. Adventure Bank is separated from the Sicilian coast by a shallow channel and both the Bank and the channels are swept by strong currents. Virtually no tèrrigenous sediment reaches the Bank, except by aeolian means. The sediment is dominated by calcareous sand formed from shell fragments and coralline algae. Recent sediment along the experimental track is variable in thickness, ranging from virtually no sediment to almost 7 mt. The upper sediments consist of an upper unit of calcareous fragmental sediments overlying a second unit of similar sediment grains that has been cemented together. The top of the second unit is weathered, a process which took place under subareal conditions when sea level was lower during the last glacial maxima about 18,000-10,000 ybp. This relic subareal weathering broke up the carbonate cementation of the older marine sediment to form a seismically transitional unit of low shear strength which increases strongly with depth.

The bottom measurements were made at 37° 16.5' N, 12° 05.5' E, where detailed reflection seismic and side-scan sonargraphs confirm the continuity of the seafloor type. The geoacoustic model is given in Table 1

Depth(m)	Cp(m/s)	Cs(m/s)	α_p (dB/λ)	α_s (dB/λ)	ρ (g/cm^3)
0.0	1677	**185**	1.0	2.6	1.9
1.0	1705	**188**	0.8	2.2	1.9
2.0	1718	**206**	0.8	2.0	1.9
3.0	1727	**232**	0.7	1.9	1.9
4.0	1734	**257**	0.7	1.9	1.9
5.0	1739	**278**	0.7	1.8	1.9
6.0	1743	**300**	0.7	1.8	1.9
7.0	1747	**325**	0.7	1.7	1.9
8.0	1750	**351**	0.7	1.7	1.9
9.0	1755	**378**	0.6	1.6	1.9
11.0	1759	**399**	0.6	1.6	1.9
13.0	1763	**417**	0.6	1.6	1.9
15.0	1767	**433**	0.6	1.5	1.9
17.0	1770	**446**	0.6	1.5	1.9
19.0	1773	**459**	0.6	1.5	1.9
21.0	1777	**475**	0.6	1.5	1.9
25.0	1790	**551**	0.5	1.4	1.9
51.0	1809	**677**	0.5	1.2	1.9
100.0	3000	1800	0.8	0.9	2.0

Table 1. *The geoacoustic model for shallow sedimented areas on the Adventure Bank (Site A) in the Sicilian Channel. Depth is in metres from the water-bottom interface. Cp is compressional velocity, C_S is shear velocity, α_p the compressional attenuation, α_s is the shear attenuation, ρ is the density. The values in boldface type were derived from experimental data, the others were obtained using empirical relations. Layer thickness is based on inversion best fit where available and on arbitrary best fit elsewhere. The detailed derivation of the geoacoustic model and the comparison of the measured and predicted transmission loss are given in [1]. α_s appears to be anomalously high at the base of the profile, but provided the best fit of model to experimental data and is consistent with rock, rather than sediment seafloors [5].*

2.2 Lampedusa Bank

The Lampedusa Bank (Fig. 1a, Site B; Fig. 1c) lies at the edge of the shallow water extension of the Tunisian Shelf. Although separated from the Adventure Bank by a channel generally deeper than 500m, the shelly and calcareous biota and the surficial sediments formed from them are similar on both the Lampedusa and Adventure sands as they provide the same depositional environment suitable for generation of calcareous sands. Analyses of samples from the Lampedusa Bank area are almost indistinguishable from those of the Adventure Bank and their seismic response and physical properties can thus be inferred as similar.

The bottom measurements were made at 35° 16.40' N, 12° 45.80' E. The geoacoustic model is given in Table 2.

Depth(m)	Cp(m/s)	Cs(m/s)	α_p (dB/λ)	α_s (dB/λ)	ρ (g/cm^3)
0.0	**1589**	**190**	0.8	2.6	1.8
1.0	**1623**	**193**	0.7	2.6	1.8
3.0	**1640**	**241**	0.6	1.9	1.8
5.0	**1650**	**304**	0.5	1.8	1.8
7.0	**1657**	**364**	0.5	1.8	1.8
9.0	**1662**	**413**	0.5	1.7	1.8
11.0	**1667**	**448**	0.5	1.7	1.8
13.0	**1671**	**471**	0.5	1.6	1.8
15.0	**1674**	**488**	0.5	1.6	1.8
17.0	**1679**	**505**	0.5	1.5	1.8
21.0	**1683**	**524**	0.5	1.5	1.8
25.0	**1687**	**545**	0.4	1.5	1.8
29.0	1691	**567**	0.4	1.4	1.8
33.0	1694	**588**	0.4	1.4	1.8
37.0	1697	**603**	0.4	1.4	1.8
41.0	1700	**627**	0.4	1.3	1.8
51.0	1712	725	0.4	1.3	1.8
100.0	3000	1800	0.8	0.9	2.0

Table 2. *The geoacoustic model for Area B (Lampedusa) of the Sicilian Channel. Depth is in metres from the water-bottom interface. Cp is compressional velocity, Cs is shear velocity,* α_p *the compressional attenuation,* α_s *is the shear attenuation,* ρ *is the density. The values in boldface type were determined from experimental data, the others were obtained using empirical relations. The detailed geoacoustic model [1] derived by both measurement and best-fit modelling show a close match between measured and predicted transmission loss.*

3
Balearic Shelf

The measurements were made in shallow water on the Balearic Shelf west of the island of Mallorca (Fig. 2a). The seafloor in the experimental area above the 200 m slope break is flat to undulating. The acoustic basement is very near to, or at, the seafloor. Recent sediment cover, where it occurs, is present only as a thin veneer less than 4 m thick, except near the shelf edges where it rarely becomes as much as 20 m thick before the slope break itself is reached. The acoustic basement consists of a bedded and an apparently unbedded type, with which well bedded slope sediments merge. This relationship suggests interbedding of off-reef limestones and limy muds and shales and reef knolls. The presence of relic reef knolls immediately beneath recent sediment cover at the margin of the plateau, the overall hardness of the acoustic basement and internal bedding patterns showing draped bluffs and buried platforms, probably of a carbonate nature, strongly suggest that the platform beneath the thin recent sediment is composed of a veneer of carbonate sand.

Information derived from cores and a shallow seismic survey of the area (Fig. 2b) indicates that the bottom is composed of a thin sand layer overlying a consolidated structure which, from historical data, can be identified as limestone. Both the seabed surface and the sand/limestone interface exhibit a rough character. Moreover, a side-scan sonar survey of the area showed the presence of outcropping rocks and scatterers.

The measurement position was 39° 27.35' N, 2° 13.80' S. The geoacoustic model is given in Table 3.

Depth(m)	Cp	Cs(m/s)	α_p (dB/l)	α_s (dB/l)	ρ (g/cm^3)
0.0	**1650**	80	1.2	2.6	1.8
1.0	**2160**	1140	0.06	0.03	1.9
11.0	**2405**	1270	0.06	0.03	2.2
21.0	**2605**	1370	0.07	0.03	2.3
31.0	**2850**	1500	0.07	0.04	2.3
46.0	**3080**	1620	0.07	0.04	2.3
61.0	**3300**	1740	0.08	0.04	2.4
76.0	**3480**	1830	0.08	0.04	2.4
91.0	**3620**	1900	0.08	0.04	2.4
100.0	5500	3000	0.11	0.06	2.6

Table 3. *The geoacoustic model for the Balearic platform. Depth is in metres from the water-bottom interface. Cp is the compressional velocity, Cs is the shear velocity,* α_p *the compressional attenuation,* α_s *is the shear attenuation,* ρ *is the density. The values in boldface type were derived from experimental data, the others were obtained using empirical relations. Layer thickness is based on inversion best fit where available and on arbitrary best fit elsewhere. The detailed derivation of the geoacoustic model and the comparison of the measured and predicted transmission loss are given in [2].*

4
Southwest Approaches to the English Channel

Measurements were made at two shallow-water sites [3] in the southwest approaches to the English Channel (Fig. 3).

4.1 Site 1

This site is on the outer shelf where the prevailing bottom morphology is of long NE-SW asymmetric ridges, with the steeper side toward the NW. These are relic, having been formed when the sea level was lower, over 11,000 years ago. The sediment surface of these large dunes is probably somewhat coarser than when they were originally deposited because of subsequent erosion. Troughs and lower areas will probably have recent, fine-grained sediment, but there may be only shallowly buried more coarse-grained patches. Beneath the sandwaves is upper Tertiary and Plio-Pleistocene sands and gravels, often with thin and limy and limestone partings and beds. Troughs between the ridge crests may directly ground on this unlithified sediment.

The bottom measurements were made at the position 48° 59.06' N, 7° 58.89' W. Because of the failure of the direct measurement methods, the geoacoustic model was constructed by fitting transmission loss predictions to measured loss. The model is given in Table 4. It consists of a single layer of sand over a hard sub-bottom.

Depth(m)	Cp(m/s)	Cs(m/s)	α_p (dB/λ)	α_s (dB/λ)	ρ (g/cc)
0.0	1800	700	0.40	1.0	2.0
2.0	3000	1700	0.11	0.1	2.6

Table 4. *The geoacoustic model for Site 1 in the southwest approaches to the English Channel. Depth is in metres from the water-bottom interface, Cp is the compressional velocity, Cs is the shear velocity, α_p the compressional attenuation, α_s is the shear attenuation, ρ is the density. All values were obtained by fitting to transmission loss data. Layer thickness is based on arbitrary best fit. The detailed derivation of the geoacoustic model and the comparison of the measured and predicted transmission loss are given in [3].*

4.2 Site 2.

This site has a chalk bottom formed from Cretaceous marls which were buried, lithified, and exhumed during weak tectonic activity. The upper surface of the chalk bottom has relief of less than one metre, with some upstanding chalk bedding often not completely covered by sediment. Resting immediately on the chalk is an older, somewhat rippled sediment, formed from coarse sand and gravel, which is locally buried by an infilling sand disposed in long streaks and irregular shaped patches. The younger sands also lie directly on chalk. On the reflection seismic record the rippled sediment shows high internal scattering and the infilling sand, low internal scattering.

The bottom measurement position was 50° 11.8' 1N, 7° 22.56' W. The geoacoustic model for this area is given in Table 5.

Depth(m)	Cp(m/s)	Cs(m/s)	α_p (dB/λ)	α_s (dB/λ)	ρ (g/cc)
0.0	**1720**	700	0.8	1.4	1.8
3.0	**1768**	785	0.6	1.1	1.9
10.0	**1815**	873	0.5	1.1	1.9
20.0	**1862**	939	0.5	1.1	1.9
30.0	**1910**	997	0.5	1.1	1.0
44.0	**1957**	1030	0.4	1.1	2.0
58.0	**2004**	1055	0.4	1.0	2.1
100.0	5500	3000	0.1	0.1	2.6

Table 5. *The geoacoustic model for Site 2 in the southwest approaches to the English Channel. Depth is in metres from the water-bottom interface, Cp is the compressional velocity, Cs is the shear velocity, α_p the compressional attenuation, α_s is the shear attenuation, ρ is the density. The values in boldface type were derived from experimental data, the others were obtained using empirical relations. Layer thickness is based on inversion best fit where available and an arbitrary best fit elsewhere. The detailed derivation of the geoacoustic model and the comparison of the measured and predicted transmission loss are given in [3].*

5 Discussion

Previous SACLANTCEN acoustic propagation modelling in the Sicilian Channel used estimated average bottom properties based on two short cores from the Adventure Bank, three short cores from around Lampedusa [6] and a general bottom classification chart of the region [7]. Acoustic velocities were not estimated independently for the higher acoustic velocity calcareous rock which floors a large part of both Banks and underlies the thin sediment areas as a detailed site investigation was not carried out and the high-resolution geological character of the underlying seafloor had not been determined. In addition, the acoustic experiments were carried out over more than one type of seafloor which may require a range-dependent acoustic model. Reasonably good modelling of the transmission-loss experiments was achieved using an average physical property model [6].

New geophysical measurements from the Sicilian Channel sites have been modelled using detailed geological and geophysical, layered characterization derived from analysis of side-scan sonar, reflection seismics, core data and measurements and estimates of the subjacent geoacoustic structure. The improved geoacoustic modelling technique refines the seismo-acoustic description of the immediate sub-bottom and produces a better fit with experimental propagation data than previous work. The geoacoustic model provides a better estimate of the seismo-acoustic properties of geologically similar sites, because it is based on a detailed and more realistic sub-seafloor description.

Modelling of two acoustic experiments based on estimated average geoacoustic properties of outer southwest approaches to the English Channel seafloor [8] of a region with seafloor similar to Site 1, showed reasonably good frequency *versus* range comparisons. Detailed geological and geophysical characterization derived from analysis of side-scan sonar, reflection seismics, additional core data and measurements and estimates of the geoacoustic structure have been used in the new modelling [9]. A thin layer of sand and gravel sediment overlies a hard and much higher acoustic velocity seafloor. The average geoacoustic velocities previously used [8] are estimates which are now known to be lower than those in the newer two-layer model [3]. The chalk seafloor in the southwest approaches [10] has very different seismo-acoustic properties to the bedded sandy and silty sedimentary succession seafloor on the outer shelf [3]. It is therefore characterized by a different geoacoustic profile that is necessary to model the dramatically different transmission-loss bottom-interaction experimental data.

The site assessment and geoacoustic profiles reported here for the Balearic shelf comprise the first generally available information of this type from this area. Although the profile can be regarded as valid for the west Mallorca platform, it is not known whether this can be applied to the whole of the shallow water shelf of the platform because a complete geological analysis has not been carried out.

The geoacoustic model takes into account the actual seismo-acoustic structure in the seafloor in an attempt to model the real world using the acoustic experiment/model method as opposed to an arbitrarily selected synthetic geoacoustic model, which may merely approximate the experimental results at that point. If the seafloor geoacoustic structure is not understood and modelled reasonably accurately, then the degree to which the experiment and the model can be used to predict acoustic transmission-loss elsewhere, is called into question.

6
Conclusions

The newer layered models better approximate the seafloor geoacoustic structures important for acoustic transmission-loss, and replace the previous estimated average bottom parameters. The new geoacoustic models generally have higher acoustic velocities for both the Lampedusa and Adventure Banks and the outer shelf of the Southwest Approaches. The new geoacoustic model for the west Mallorca platform of the Balearic ridge is quite simple because hard, high acoustic velocity carbonate rocks or carbonate cemented sediments are only partially covered by discontinuous sands.

Areas in which acoustic experiments are to take place should first be geologically and geophysically characterized to provide optimal interpretation of the acoustic properties through the use of models that require detailed physical parameters of the medium.

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a)

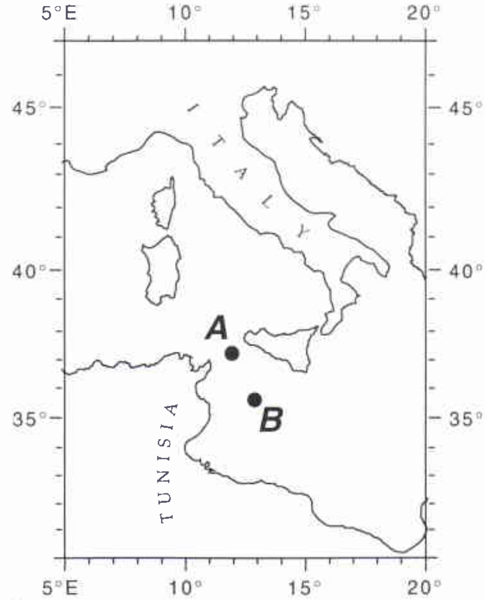
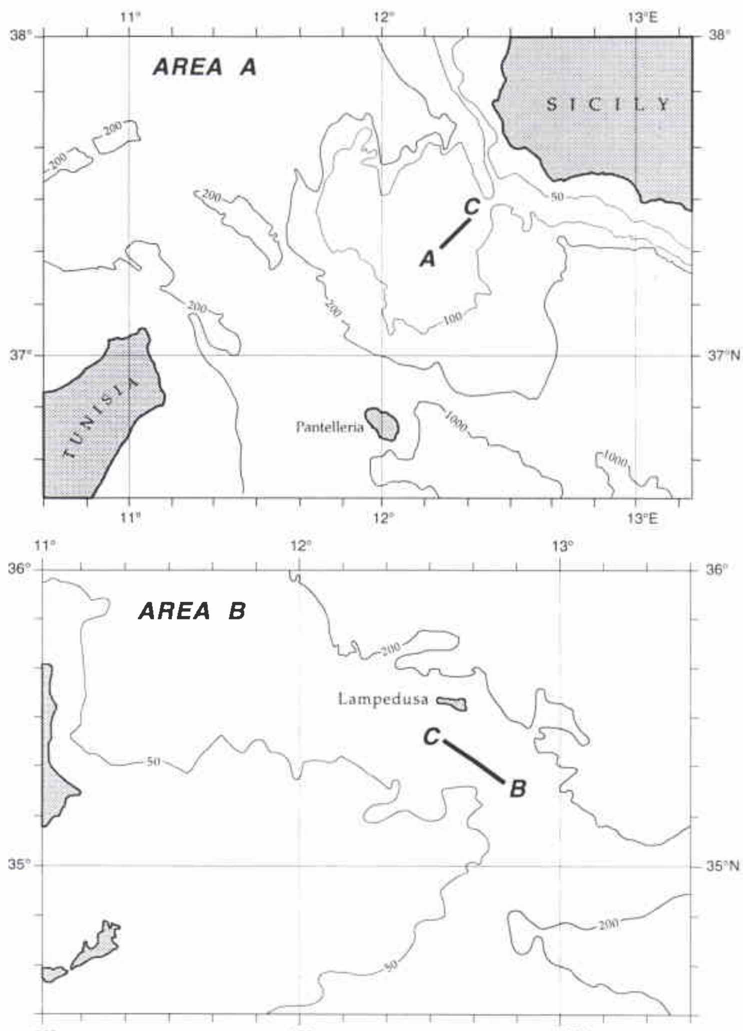


Figure 1. *a. General position of the measurement sites in the Sicilian Channel. Site A is on Adventure Bank and Site B is on Lampedusa Bank. b. A-C, Line along which model fit to experimental data was made on the Adventure Bank. c. B-C, Line along which model fit to experimental data was made on the Lampedusa Bank.*

b)

c)



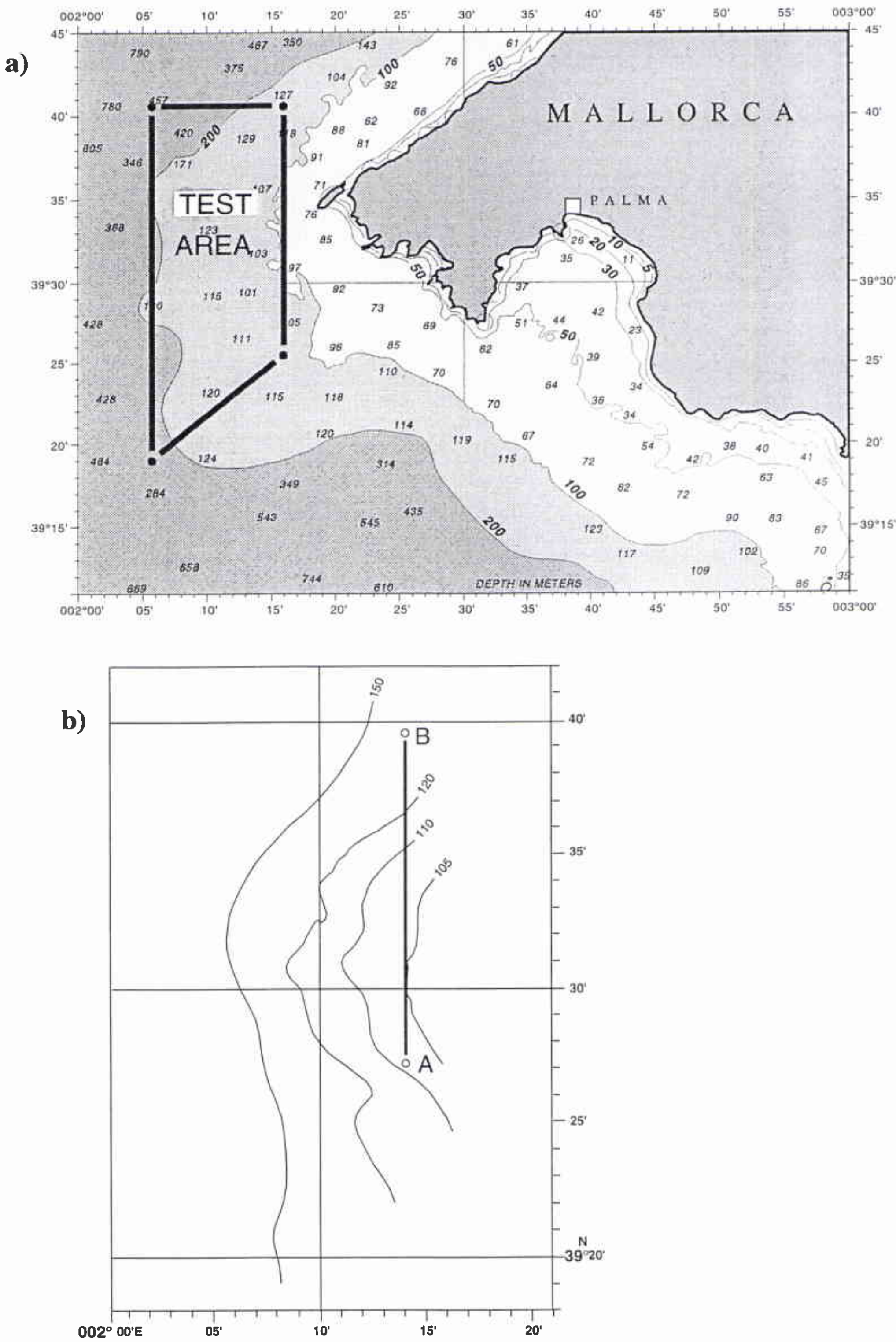


Figure 2. a. *General location of the measurement site on the Balearic Shelf immediately to the west of Palma de Mallorca. b. A-B, Line along which model fit to experimental data was made.*

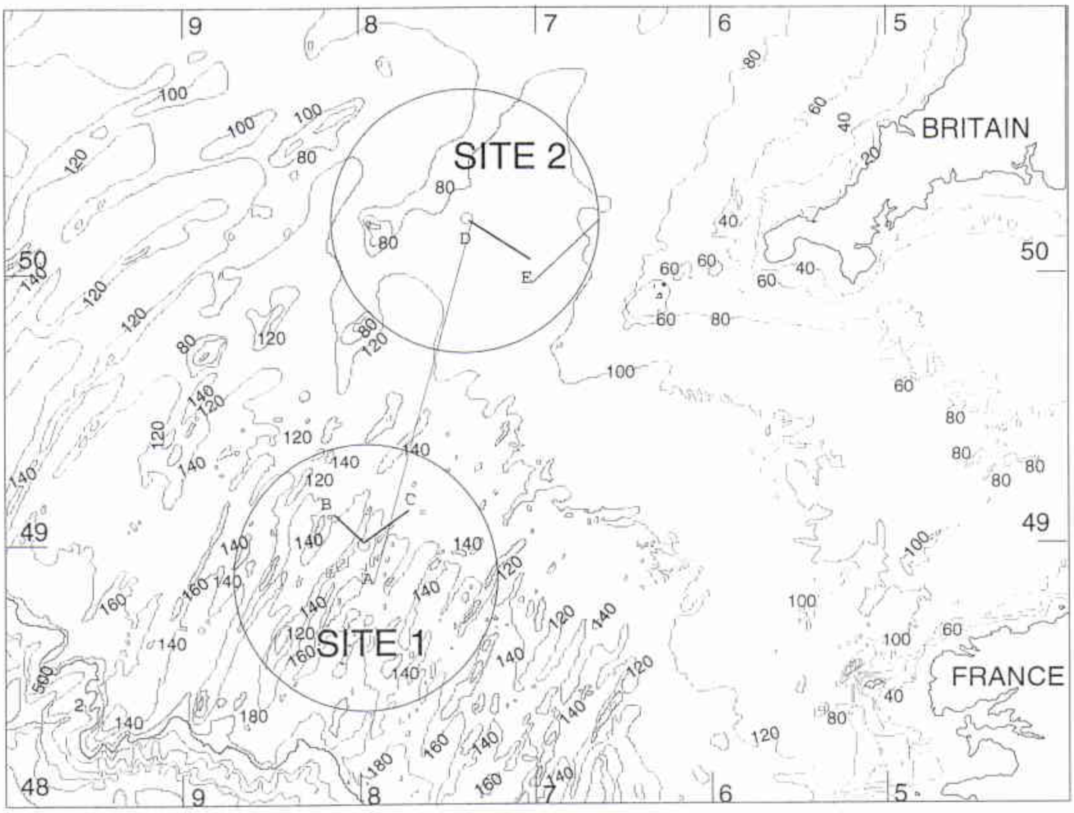


Figure 3. *The measurement sites in the Southwest Approaches to the English Channel. A-B, A-C, lines along which model fit to experimental data was made at Site 1. D-E, Line along which model fit to experimental data was made at Site 2.*

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