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EVOLUTION AND INHERITANCE OF A ROCK COAST: WESTERN GALICIA, NORTHWESTERN SPAIN

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ABSTRACT

There is increasing evidence that shore platforms and other elements of rock coasts may be inherited, at least in part, from interglacial stages when sea level was similar to today's. Most of this evidence, which includes ancient beaches and datable terrestrial deposits, has been obtained from areas of resistant, slowly eroding rock, where the platforms often appear to be much too wide to have developed since the sea reached its present level. It is much more difficult to demonstrate that inheritance has occurred in areas of weaker rock, which generally lack any datable material. The coast of western Galicia in northwestern Spain has shore platforms in igneous and metamorphic rocks that were deeply weathered during the Tertiary. These platforms are closely associated with ancient beaches from the last interglacial stage, and associated periglacial and fluvio-nival deposits that covered and fossilized most of the Eemian platforms and cliffs during the late middle and late Weichselian glacial stage. The sedimentary processes and the thickness and facies of the sediments were determined by the height, aspect and gradient of the coastal mountains, and their distance from the coast. Radiocarbon dating, sedimentary analysis and platform morphology indicate that the shore platforms of Galicia have been inherited from at least the last interglacial stage. They were fossilized in places beneath thick Weichselian deposits and then exhumed during the Holocene transgression. The abundant evidence for inheritance in Galicia has important implications for other coasts in fairly weak rocks where such evidence is generally lacking. Copyright © 2003 John Wiley & Sons, Ltd.

KEY WORDS: shore platforms; inheritance; periglacial deposits; radiocarbon dating; Late Quaternary; coastal evolution

INTRODUCTION

One of the most important challenges facing rock coast workers is to determine whether, or to what degree, they have been inherited from interglacial stages when sea level was similar to today's (Trenhaile, 2002). Wide shore platforms in resistant, slowly eroding rocks are generally thought to be ancient features, and a variety of dating techniques has demonstrated that in some areas, shore platforms, caves, and other features have been inherited from one or more interglacial stages (Goede *et al*., 1979; Davies, 1983; Bryant *et al*., 1990; Young and Bryant, 1993; Brooke *et al*., 1994; Stone *et al*., 1996). Fairly weak rock coasts generally lack till covers, ancient beach deposits and structural remnants, and the width of their platforms can be more easily reconciled with present rates of erosion than those on resistant rock coasts. These platforms have usually been considered to be entirely postglacial features (Hills, 1971; Gill, 1972; Sunamura, 1973; Takahashi, 1977; Kirk, 1977). Mathematical modelling, however, implies that whether an ancient shore platform is subsequently inherited, modified or completely replaced by a contemporary platform depends upon the complex interaction of a multitude of factors that determine the erosive efficacy of the waves (Trenhaile, 2000, 2001a). The model suggested that most platforms have been, at least in part, inherited from one or more interglacial stages when sea level was similar to today's (Trenhaile, 2001b).

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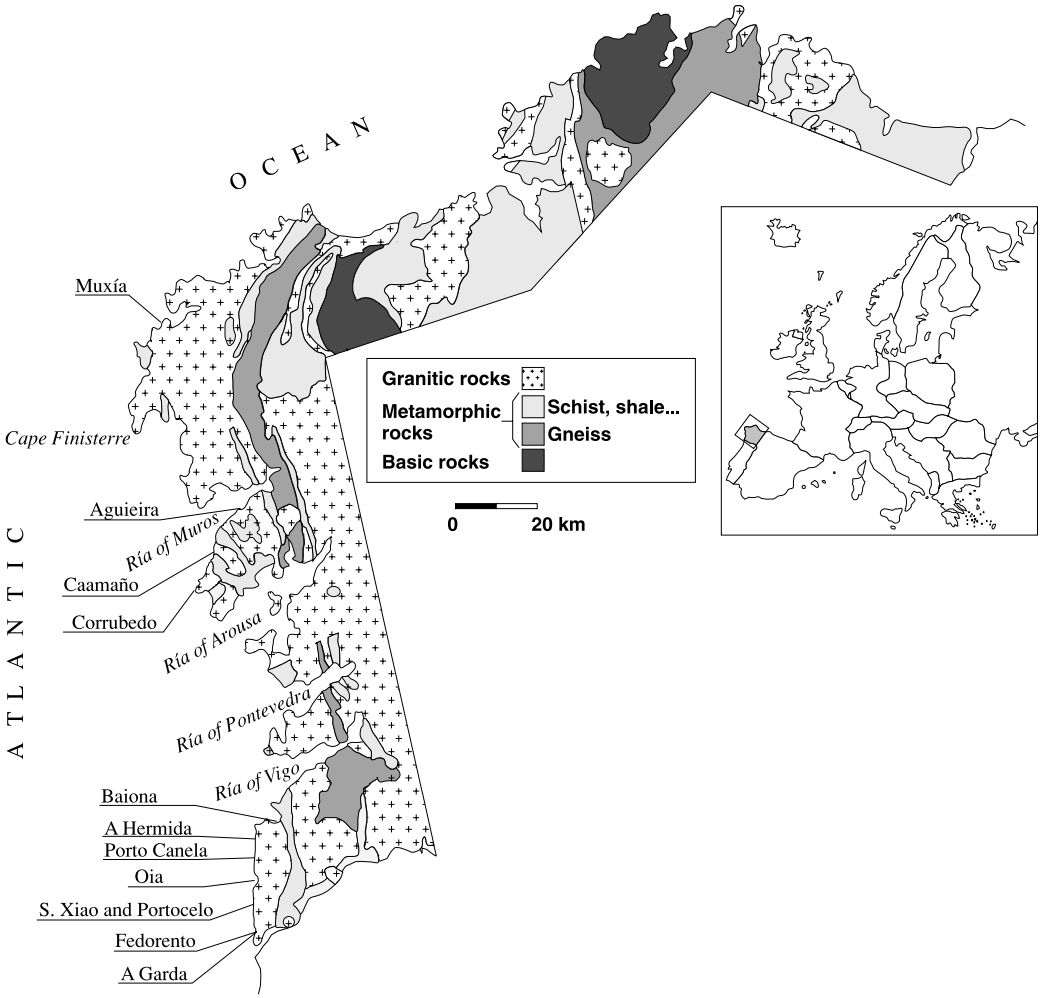

Figure 1. The coast of Galicia, northwestern Spain

THE COAST OF GALICIA

Galicia occupies the northwestern section of the Hercynian Hesperic or Iberian Massif (Figure 1). An extensive network of northwest–southeast and northeast–southwest trending faults was produced in the latter phases of the Hercynian orogeny (Parga Peinador, 1969). A group of north–south running fractures developed later in the early Mesozoic as a result of rifting in the Atlantic. Then, from the Eocene until at least the early Quaternary, intense tectonic movements along the unstable Atlantic margin formed a series of uplifted blocks and basins (Pérez Alberti, 1991); many of these uplifted blocks have created coastal mountains with elevations of between 300 and 600 m. Hercynian or late Hercynian granitic rocks, Precambrian schists and basic rocks dominate in western Galicia, and metamorphic Precambrian and Palaeozoic rocks (shales, gneisses, quartzites) in the north.

The rocks and sediments along the coast were deeply weathered under tropical conditions in the Tertiary (Nonn, 1966; Pérez Alberti, 1991, 1993), and they also experienced periglacial conditions during several well defined cold periods in the Weichselian glacial stage (Pérez Alberti *et al*., 1994; Pérez Alberti and Valcárcel Díaz, 1998; Valcárcel Díaz *et al*., 1998; Valcarcel Díaz, 1999). The first of these periods, from about 38 000

to 31 000 years ago, was very humid, and mean annual air temperature (MAAT) fell to about 6 °C below today's. Glaciers descended to at least 600 m above sea level, and periglacial processes operated down to sea level. The second period, during the glacial maximum, about 18 000 years ago, was more continental in nature. It was colder and drier, with a MAAT about 12 °C below today's. There was widespread deposition of frost-shattered clasts near the coast, and rock glaciers and blockfields developed at higher elevations. There were two later cold periods from 16 000 to 13 000 years ago, when the MAAT was up to 6 to 7 °C below today's, and from 11 000 to 10 000 years ago, when the MAAT was 4 °C below today's.

Waves off the coast of Galicia are most frequently generated by storms associated with westerly, northwesterly and southwesterly cyclonic activity. They are between 1 and 2·5 m in height for about 80 per cent of the year, although heights of between 2 and 3 m can occur at any time of the year. Most waves higher than 3 m are generated by Atlantic low pressure centres in winter, and they approach the coast from the west and northwest (Dirección General de Puertos del Estado). The tidal environment is semidiurnal with a mean tidal range of 2·5 m, and a spring tidal range of between 3·75 and 4 m (Instituto Oceanográfico de la Marina, Ministerio de Defensa). The offshore zone is generally convex, with higher gradients near the coast. The mean gradient between the shore to a depth of −40 m is normally between about 1 and 2° off the study areas in western and southwestern Galicia, but gradients between 2 and 6° are common from the shore to a depth of −20 m.

Abandoned, sediment-filled caves, elevated cliff–platform junctions, rock ledges and other morphological and sedimentary evidence suggests that sea level during the last interglacial was about 2 to 3 m higher than today's (Trenhaile *et al*., 1999). This elevation is consistent with Eemian coastal features in many places around the world, and it suggests that there has been no significant tectonic or isostatic activity in Galicia since at least the last interglacial stage. No evidence has been found to indicate that sea levels in Galicia have been higher than today in the Holocene.

Because of its lithological diversity and horst and graben structure, the coast, with the exception of the extreme southwestern and northeastern sections, has numerous indentations, including the great rias of the western coast and many smaller inlets and bays. The irregular shape of this coast and the presence of coastal mountains helped to create a morphogenic environment that was dominated by cold processes during the last glacial stage. Consequently, in most of coastal Galicia there are landforms developed during several transgressive episodes that were fossilized by continental deposits in regressive stages. Coastal processes are therefore operating today on a host of inherited and relict landforms, including cliffs, shore platforms and boulder beaches (Pérez Alberti *et al*., 1997).

Coastal deposits

The sedimentary processes, thicknesses and facies of the terrestrial sediments that were deposited over abandoned Eemian coastlines during the middle and late Weichselian, were determined by four main factors: altitude, aspect, gradient and distance from the source (Pérez Alberti *et al*., 1998b):

Attitude. Snow and ice accumulated on mountains close to the present coastline, providing favourable conditions for cold region processes during the last glacial stage. Most of the sediments deposited on the slopes and on the coast are therefore the result of snowmelt, frost action, gelifluction and other periglacial processes.

Aspect. Air masses from the ocean make the sea-facing slopes of the mountains the most humid, and slope orientation played an important role in determining the thickness and extent of the deposits. Along the coast of Galicia, slopes facing the sea were covered by sediments, while those on the opposite side have fewer or thinner deposits with a smaller variety of facies that are restricted to very favourable locations.

Slope gradient influenced the type and efficacy of the erosive and depositional processes. Mountains close to the present coastline have moderate to high gradients, and in many places, including the area between Baiona and A Garda in the southwest (Figure 1), there is an abrupt transition from the mountains to the coast. High gradients generated fast-flowing streams fed by melting snow and cut-and-fill processes, as well as gelifluction and laminar flows that deposited interbedded coarse and fine sediments.

Distance from the source area was also of great importance. In general, coastal deposits are thicker, coarser and more extensive in areas close to the sources than in areas further away, and their finer grained distal ends were in areas that are now under the sea.

Table I. Radiocarbon dated samples obtained by Costa Casais and co-workers* from organic-rich sediment in western Galicia

Location	Age (years BP)	Depth of sample from the cliff top (cm)	Laboratory
Muxía	37 550 ± 690	1020–920	β-130234
	34 700 ± 450	920	β-130233
	35 620 ± 1150	920–850	β-130232
	34 530 ± 470	850	β-130231
	34 380 ± 670	850–690	β-130230
	31 740 ± 360	690	β-130229
	31 050 ± 340	690–530	β-130228
Caamaño	36 050 + 1430 – 1210	750–755	GrN-20506
	32 340 + 2400 – 1800	740–745	GrN-21591
	30 120 + 670 – 620	655–660	GrN-20507
	29 400 + 2200 – 1700	610–615	GrN-21592
	28 750 + 1,100 – 900	37 322	GrN-21593
	20 160 ± 270	500	GrN-20508
	2720 ± 140	160	GrN-22280
	530 ± 80	100	GrN-22279
Mougás	14 100 ± 200	226–172	GrN-20511
	13 720 ± 110	172–130	GrN-20829
	5530 ± 60	130–83	GrN-20828

* Source of data: Muxia, Costa Casais (2001); Caamaño, Costa Casais *et al.* (1994, 1996a); Mougás, Costa Casais *et al.* (1996b).

THE STUDY AREAS

Although the relationships between datable periglacial deposits, Eemian beaches, shore platforms and other elements of rock coasts provide abundant evidence of inheritance in many parts of Galicia, this discussion will be largely concerned with three areas on the western coast where the platforms have been surveyed, and the associated sediments, where present, have been analysed and radiocarbon dated (Tables I and II).

Caamaño

Coastal mountains provided the main source of sediments in many parts of Galicia, but at Caamaño on the southern shore of the Ria de Muros y Noia, there is a coastal plain, or rasa, 3 to 4 km in width, between the 650 m high O Babanza mountains and the coast (Figure 1). The coastal sediments therefore probably originated from the palaeocliff and, being more local in origin than sediments in areas that are closer to the mountains, they are more homogeneous, containing a high coarse sediment content developed under periglacial conditions. The thickest sediments at Caamaño are found in a former valley in the middle portion of the most northern of three small, shallow embayments (Figure 2D). The dominant facies are head, gelifluction lobes, laminar flow deposits and ploughing boulders. The deposit is 8 m thick in the central portion and up to 7 m thick at the sides. Sands and gravels with palaeosoils are dominant in the centre and coarser, more angular rock fragments on the flanks (Figure 3).

The wide intertidal shore platforms at Caamaño are backed by a supratidal rock ledge, or by a steeper and narrower supratidal ramp extending up to several metres above the highest level of the tides. The platforms have mainly developed in vertical to steeply dipping metamorphic strata, although there are also granitic dykes in some places (Figure 2E). The rocks are deeply weathered, and Schmidt rock test hammer values were generally less than 20 (Trenhaile *et al.*, 1999). Although the Schmidt hammer has not been used in the other areas discussed in this paper, the rocks have been weathered in a similar way to those at Caamaño and appear to be of low strength. Trenhaile (1978, 1987, 1999) found that there is a moderately strong correlation between mean regional platform gradient and mean spring tidal range in the North Atlantic. The 0·3° to 0·8° gradient of the intertidal platform at Caamaño, where the mean spring tidal range is 2·2 m, is consistent with this relationship,

Table II. Radiocarbon dated samples from southwestern Galicia obtained by other workers

Location	Age (years BP)	Laboratory sample	Source of data
Mougás	13 600		Nonn (1966)
	18 200 ± 900		Nonn (1966)
	7340 ± 330		Franz (1967)
	>39 000	I-2177	Butzer (1967)
	18 030 ± 160	GrN-8324	Brosche (1982)
	9800 ± 70	CSIC-?	Saa Otero (1986)
	13 790 ± 90	BETA 93270	Cano *et al.* (1997)
San Xiáo	28 400 + 1200 – 1000	I-2261	Butzer (1967)
	28 000 ± 230	BETA 93268	Cano *et al.* (1997)
	38 830 ± 2200	BETA 93269	Cano *et al.* (1997)
Fedorento	18 700 ± 320	I-2176	Butzer (1976)
	28 000 ± 450	GrN-8320	Brosche (1983)
	41 500 + 2200 – 1700	GrN-8321	Brosche (1982)
	43 500 + 2000 – 1600	GrN-8322	Brosche (1982)
	26 450 ± 230	GrN-8323	Brosche (1982)
	32 260 ± 360	BETA 95398	Cano *et al.* (1997)
Oia	32 980 ± 530	BETA 93267	Cano *et al.* (1997)
P. Canela	3410 ± 60	BETA 93271	Cano *et al.* (1997)
	4760 ± 80	BETA 95397	Cano *et al.* (1997)
	4030 ± 80	BETA 95396	Cano *et al.* (1997)
	3330 ± 70	BETA 95395	Cano *et al.* (1997)

but the 4° to 5° gradient of the ramps is much greater than one would expect according to the present tidal range (Figure 4). The platform is backed in places by an abandoned and grass-covered sea cliff, and there are lichen and clumps of salt-tolerant vegetation, mainly *Armeria maritima* and *Crithmum maritimum*, on the supratidal ledges and the ramp, as well as *Eryngium maritimum* in small pockets of fine gravel or aeolian sand. Eight organic-rich samples from the northern bay, ranging from about 36 000 to 530 years in age, were radiocarbon dated. They demonstrated that two caves and the remnants of an ancient beach deposit on the ramp and rock ledges are more than 36 000 years old. There were several sea level maxima during the middle Weichselian, but dates obtained around the world from emerged strandlines and the lack of sufficient climatic amelioration and ice retreat indicate that the sea did not approach its present level at this time. Therefore, the morphological and sedimentological evidence suggests that the supratidal ramp and ledges at Caamaño were probably formed during the last interglacial stage, whereas the much wider intertidal platform developed over one or more earlier interglacial stages when sea level was generally similar to today's (Trenhaile *et al.*, 1999).

Baiona to A Garda

The coast between Baiona and A Garda in southwestern Galicia is essentially straight in plan, except for small re-entrants associated with east–west running fractures (Figures 1 and 5). Granites and granodiorites are dominant, although there are also small intrusions of metamorphic rock. The coastal mountains are dissected on their seaward flanks by east–west and northeast–southwest trending valleys, and in contrast to Caamaño, they extend to within 2 km to only a few tens of metres of the coast. These mountains, which attain elevations of up to 600 m, formed an orographic barrier that created conditions for the fluvio-nival and periglacial slope processes that fossilized the Eemian coast.

There are two main types of cliff deposit in southwestern Galicia.

(a) The deposits are from 8 to 10 m thick in valleys located close to high mountains. The central portions of the ancient valleys are filled with coarse, debris flow material, although there is generally some organic sediment at the base and organic sands deposited by fluvio-nival processes on top. Fluvio-nival sediments occupy the sides of the former channels. These finer deposits contain organic material with charcoal and iron,

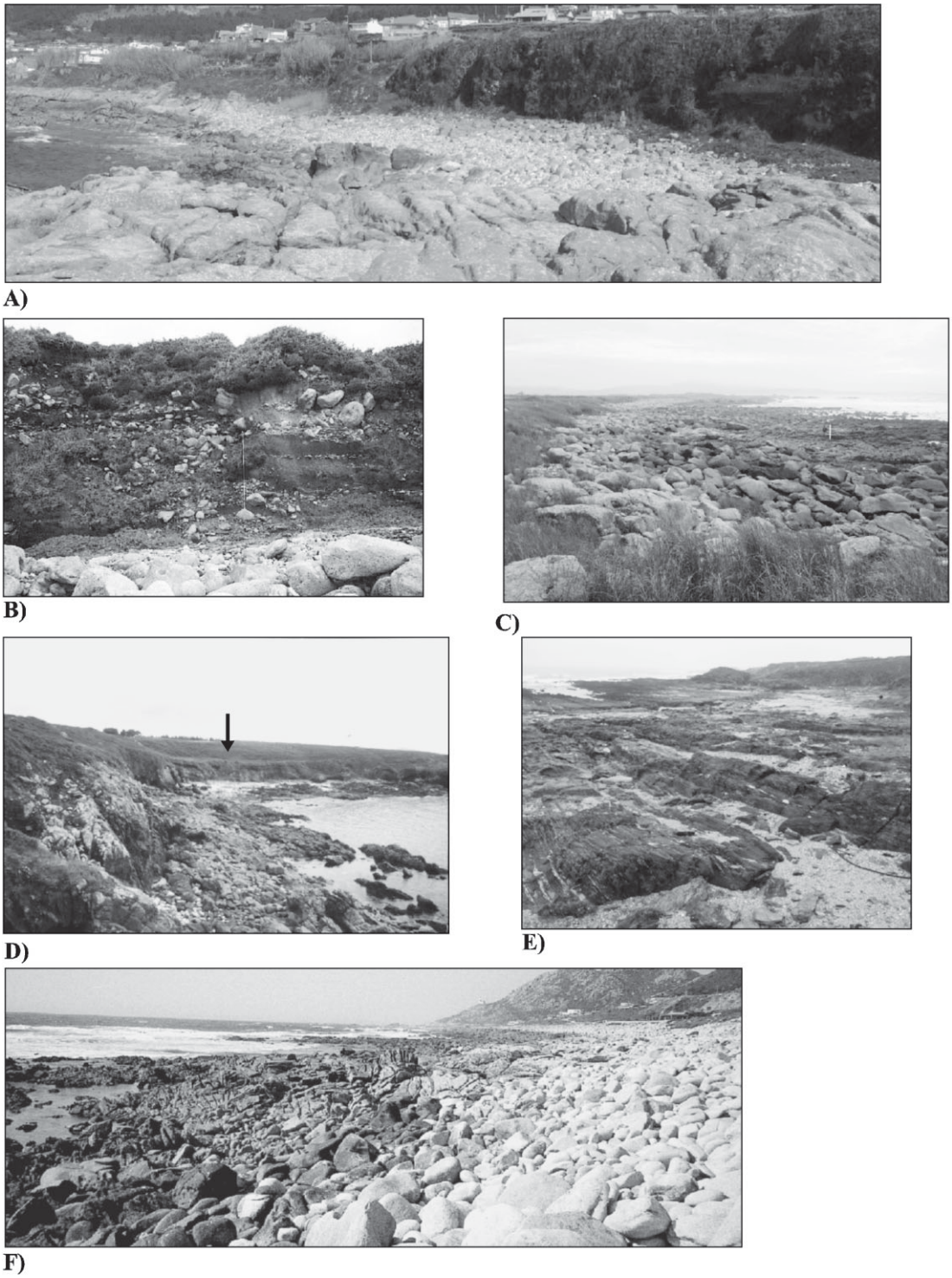

Figure 2. The platforms of western Galicia: (A) Oia near profile 1, with Weichselian sediments in the cliff; (B) the deposit at Oia; (C) platform and boulder beach at Corrubedo; (D) platform in the northern bay at Caamaño; the arrow shows the dated cliff deposit; (E) platform in metamorphic rocks in the southern bay at Caamaño; (F) platform and boulder beach at A Hermida

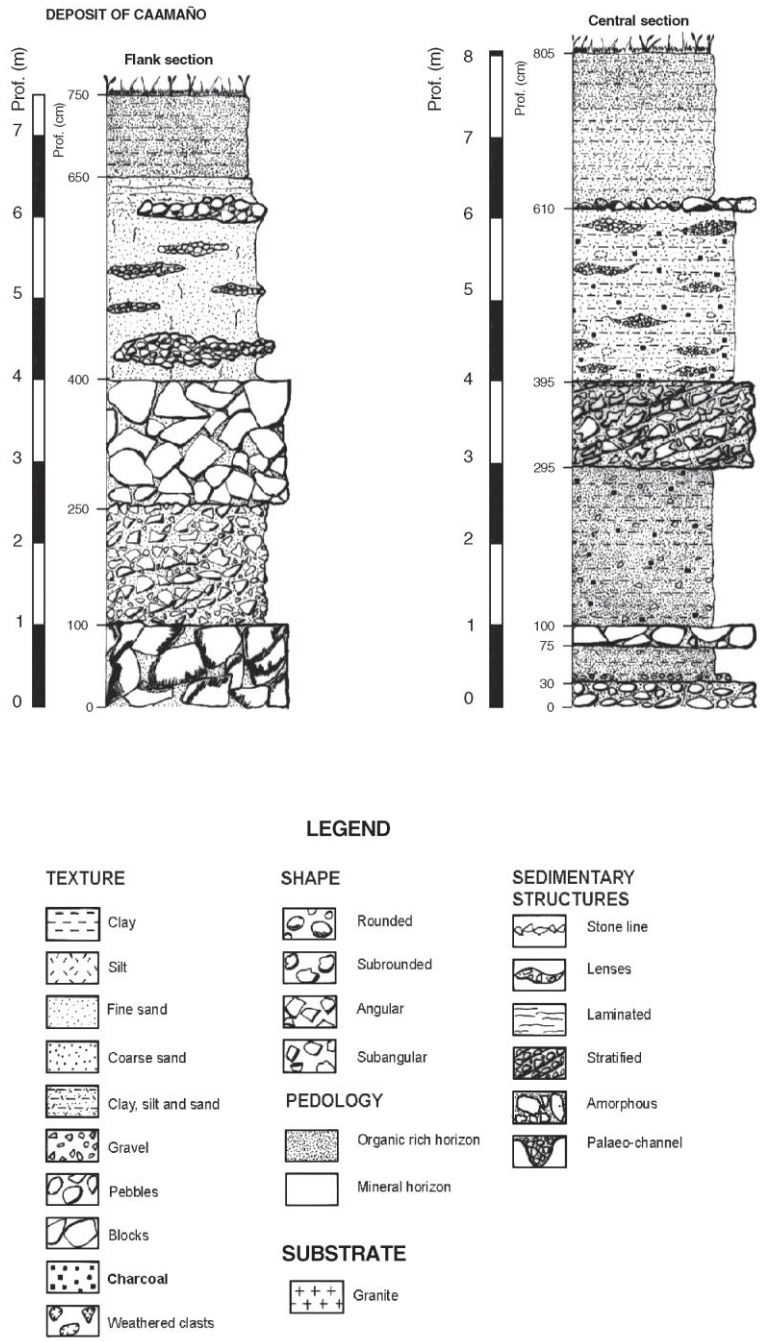

Figure 3. Typical sediment profiles in the northern bay at Caamaño

and bands of colluvial sand and silt mixed with angular gravel. Radiocarbon dating indicates that the debris flow materials were deposited between 35 000 and 30 000 years ago, during the first of the cold stages in the middle and late Weichselian.

(b) Deposits that are some distance from their source in the coastal uplands, and not in former channels, are dominantly fine-grained and generally less than 2 m in thickness. They consist of sand and silt mixed with fine, angular colluvium and gravel lenses. Radiocarbon dating suggests that these periglacial slope deposits developed

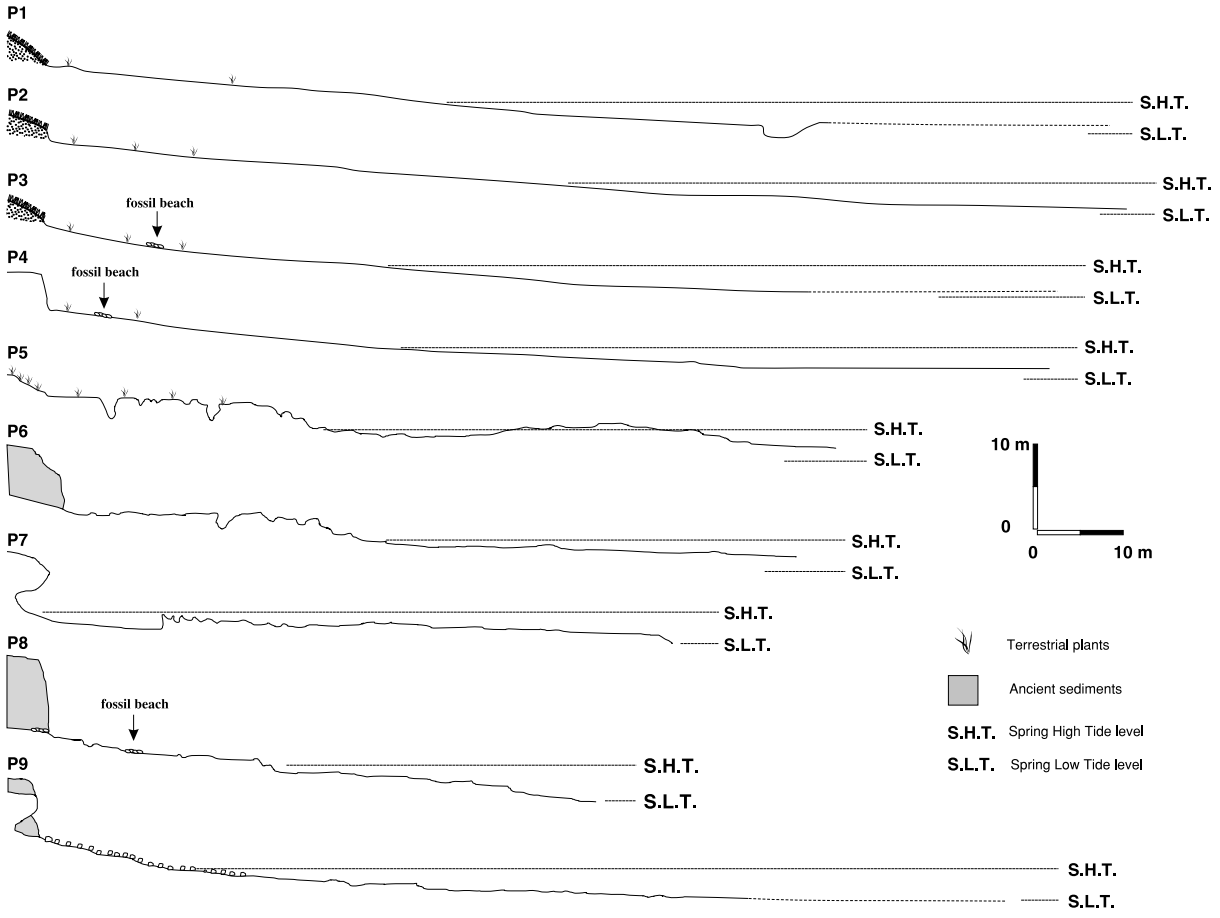

Figure 4. Surveyed platform profiles at Caamaño. Note the inherited cave filled by Weichselian sediments at the back of profile 9 (P9) and ancient beach deposits on the steeply sloping ramp, well above the level of the spring high tides (from Trenhaile *et al*., 1999)

in the period extending from the drier and colder period about 18 000 years ago up to the beginning of the Holocene.

Detailed investigations have been made of the coastal sediments in two areas along this coast. The polycyclic deposit at Oia is fronted by a boulder beach (Figures 2A and 5). It is 8 m thick in the central portion and 5 to 6 m thick at the flanks, and it contains facies that vary vertically, and laterally with distance from a small river (Figures 2B and 6). There are well rounded to subrounded clasts and laminated sand and rounded pebble structures close to the mouth of the river, and an increase in the proportion of fine sediment relative to the flanks. Fine sediment interbedded with sand and pebbles was deposited in complex channel systems. Flows from snowmelt and periglacial slope processes were most important in the deposition of these sediments. Snowmelt was responsible for the channels that cut the basal, rich organic matter level, forming cut-and-fill sequences with well rounded, oriented, and imbricated sediments. Interbedded sand and gravel lenses are more abundant in the upper portions of the deposit. The periglacial facies are gelifluidal, with clasts and sand in a silt–clay matrix, oriented parallel to the slope. Although only one sample has been radiocarbon dated at Oia (Table II), the similarity between this deposit and other dated coastal deposits in adjacent areas along this coast (Cano *et al*., 1997; Costa Casais *et al*., 1994, 1996a,b), as well as at Caamaño and elsewhere in Galicia, suggests that sedimentation took place between 40 000 and 10 000 years BP.

The thickness of the deposit at San Xiáo (S. Xiáo), south of Oia, varies between 6 and 8 m in thickness (Figure 5). It has a variety of facies. The basal, organic-rich layer of this deposit has provided radiocarbon dated ages of 38 830 ± 2200 and 28 000 ± 230 years BP (Cano *et al*., 1997) (Figure 6). There are greater amounts of

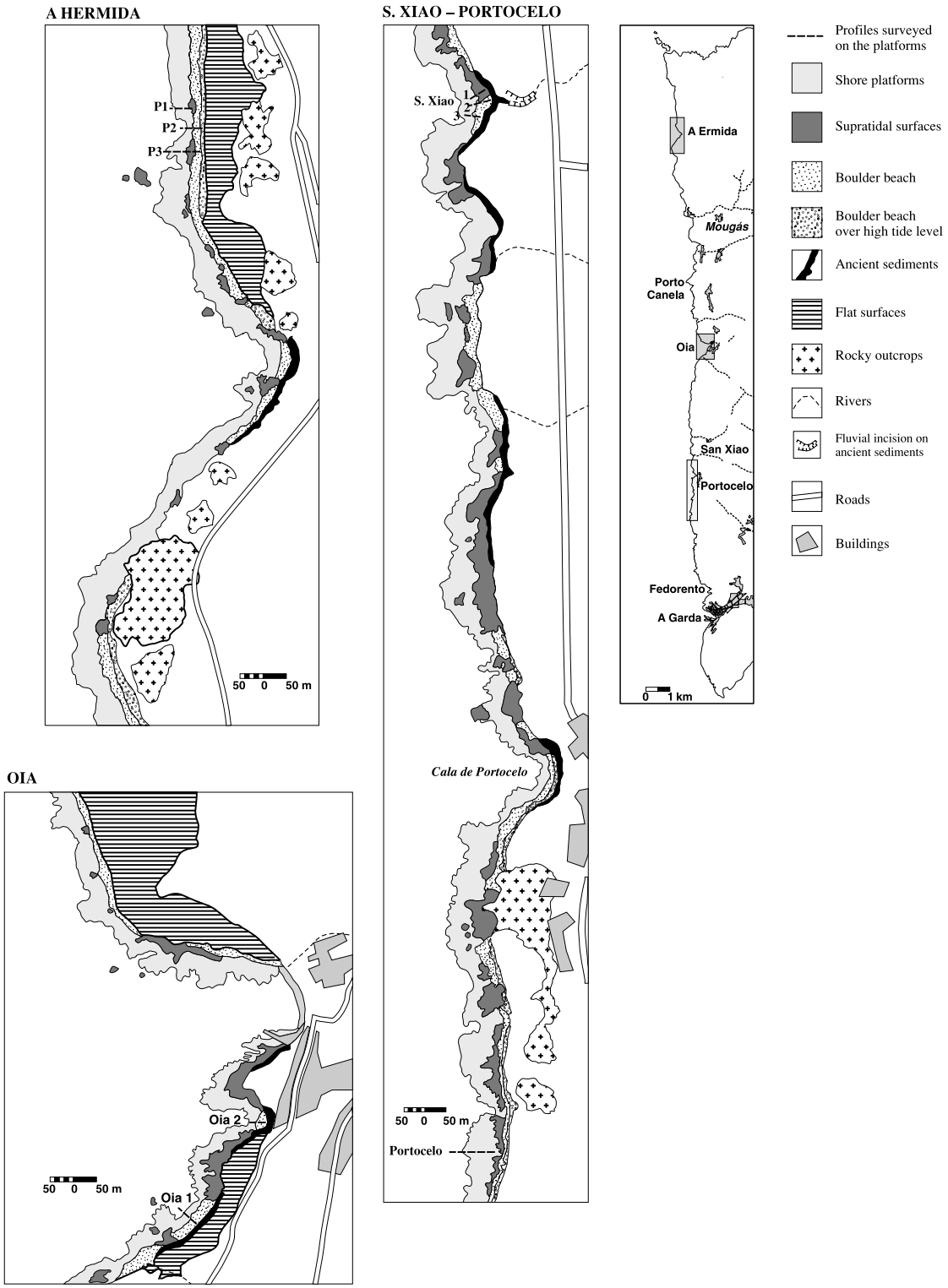

Figure 5. Coastal characteristics and profile location in the study areas between Baiona and A Garda in southwestern Galicia

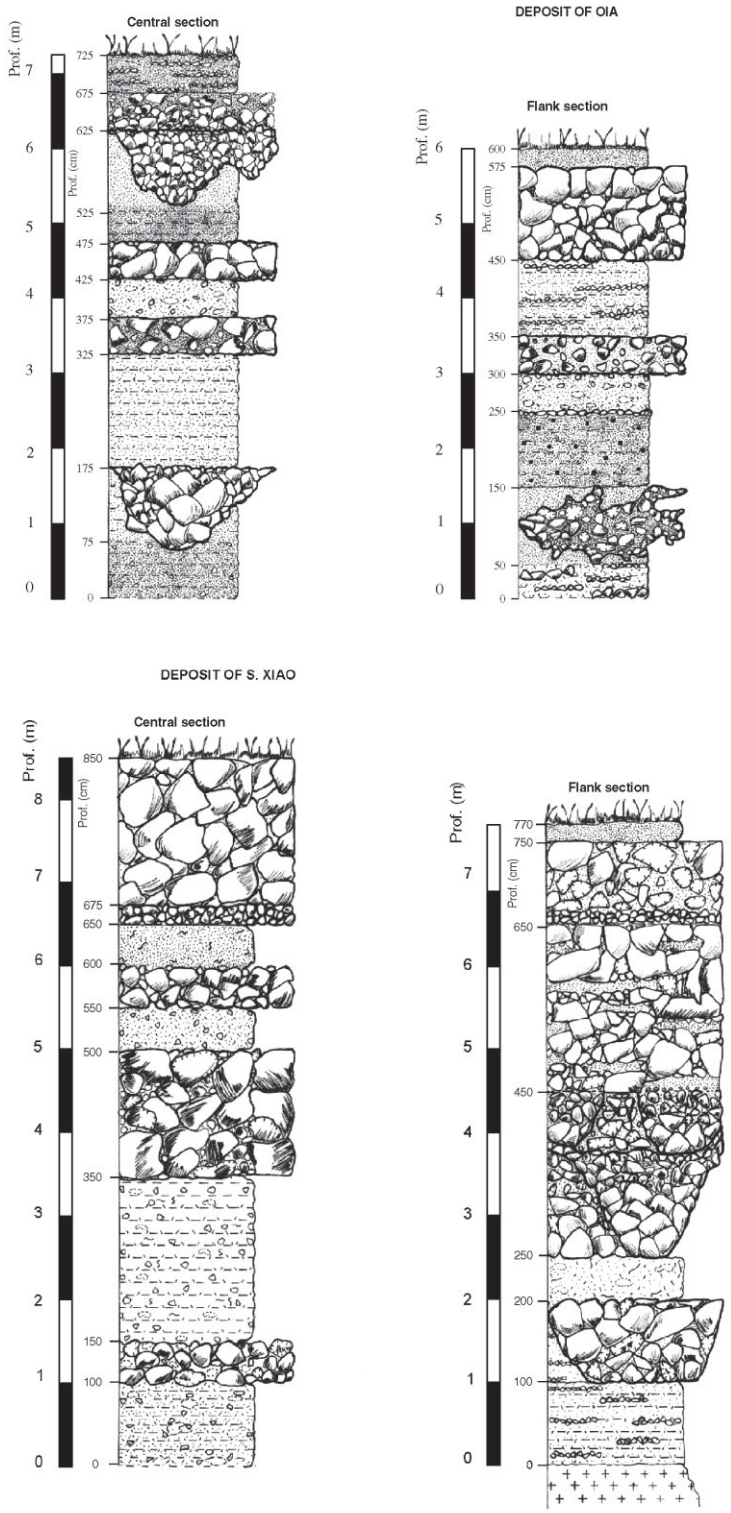

Figure 6. Typical sediment profiles at Oia and San Xiáo between Baiona and A Garda (see Figure 3 for sediment legend)

coarse debris (gravel, pebbles and rock fragments) to the south of the inlet, close to the mouth of a small river. These sediments are rounded or subrounded, well sorted and oriented. The percentage of fine, organic-rich sediments increases towards the central part of the inlet, where they are interbedded with palaeochannels of gravel and pebbles, as well as laminated structures and alternating layers of sand and rounded or subrounded gravels. There are well sorted, stratified and imbricated gelifluction structures further from the mouth of the river. In the northern section of the deposit, far from the river mouth, the main facies are gelifluidal and gelifluction (head), consisting of stratified sands and pebbles in a silt–clay matrix.

The extensive shore platform between Baiona and A Garda , which is up to 100 m in width, has an irregular surface, and almost everywhere the highest part is covered by ancient continental deposits, cliff debris and blocks of loose rock (frequently 30 to 50 cm in diameter) (Figure 2A and F). In front, extending down to the mid-tidal level, the platform is covered by large accumulations of variably rounded blocks, ranging up to a metre in size, with some angular blocks with major axes of up to 2 m. Gastropods (*Patella* sp., *Littorinas*) extend over the entire intertidal area, and between mid-tide and low tide the platform is covered by crustaceans (*Balanus perforatus*, *Chthamalus stellatus*), molluscs (*Mytilus edulis*) and algae (*Lithophyllum lichenoides*). Waves transport coarse material landwards, and there is almost no loose abrasive material in the lower portion of the platform (Blanco Chao, 1999) (Figures 7 and 8).

The supratidal portion of the platform generally has steeper gradients, often about 3°, than in the lower intertidal zone, where the gradients are typically between 1 and 2°. The morphology of the supratidal zone, including its high elevation, steep gradient and narrow width, suggests that it is in disequilibrium with the prevailing conditions. This is consistent with the occurrence of similar supratidal ramps at Caamaño and in other parts of Galicia (Trenhaile *et al*., 1999), and it provides further evidence that sea level during the last interglacial stage was from 2 to 3 m higher than today's. Whereas the ramp was formed during the Eemian, however, the lower, more gently sloping portions of the platform were probably exposed to wave action during many interglacial stages in the Pleistocene, which would account for their greater width and degree of planation.

The associated sediments provide support for the conclusion, based on morphological evidence, that the platforms of southwestern Galicia are ancient, inherited features. Organic middle and late Weichselian and Holocene cliff material, ranging from about 43 500 to 3300 years BP, has been radiocarbon dated by a number of workers in several places along this coast (Brosche, 1982, 1983; Costa Casais *et al*., 1996b; Cano *et al*., 1997). Patches of the lowest organic layer occur on the back of the platform, along with some older cemented beach deposits which are thought to be Eemian because of their elevation above present sea level and sedimentary position beneath the organic layer.

Periglacial conditions and low sea level during the middle and late Weichselian caused the platforms and cliffs to be covered by fluvio-nival and geliflucted slope deposits derived from the coastal mountains. Erosion of these deposits during the latter stages of the Holocene transgression gradually exhumed the Eemian littoral forms and released enormous amounts of coarse abrasive material, which produced numerous potholes. Cliff erosion was greatly reduced as the sea approached its present level, and the deposits are covered in vegetation and are only eroded during storms today. Exhaustion and non-replacement of the abrasive material through cliff erosion has caused the potholes to become inactive, and they have been colonized by algae (*Lithophyllum incrustans*) and colonies of molluscs, sea anemones (*Actinia equina* and *Anemona sulcata*) and especially by sea urchins (mainly *Paracentrotus lividus*). The occurrence of lichen and terrestrial vegetation on the boulders at the cliff foot above the high spring tidal level, the lack of loose material and intense biological colonization of the rock surface in the intertidal zone provide further support for the contention that abrasion and other processes of mechanical wave erosion are not effective today.

It is more difficult to determine whether platforms that are located further from the mountains, and are therefore not backed by sedimentary cliffs (Figures 7 and 8, A Hermida and Portocelo profiles, respectively), were covered and later exhumed from beneath terrestrial deposits. The presence of fine, organic-rich matter in all the cliff deposits along this coast suggests that even though they were not fossilized under thick, coarse sediments, areas some distance from the mountains would have been covered by 1 to 2 m of fine-grained sediment representing the distal end of the deposits. Most of these deposits would have been removed very quickly during the Holocene transgression, although the organic, black material, which always forms the base of the middle and late Weichselian sediments in Galicia, occurs in several places on top of buried rounded

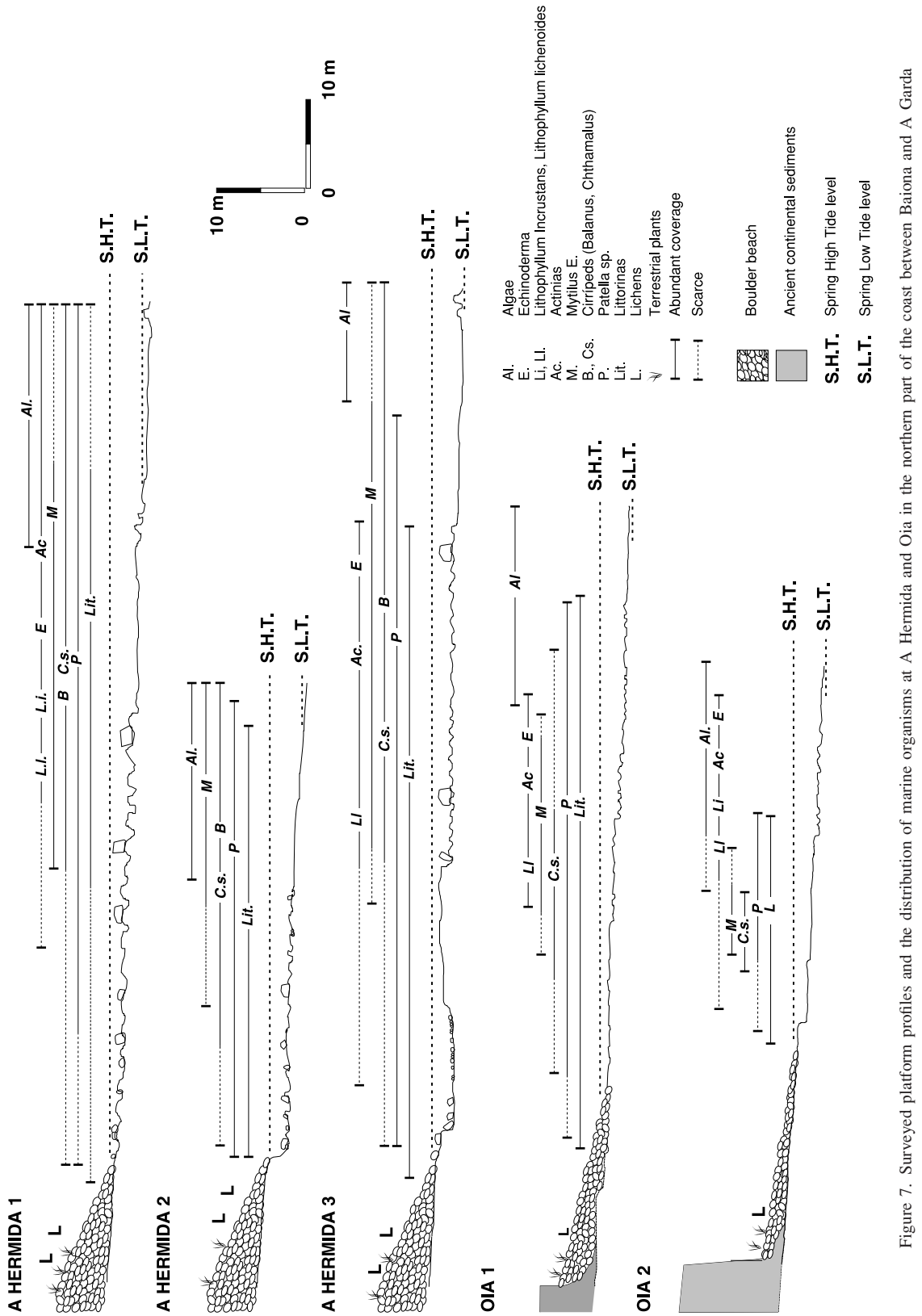

Figure 7. Surveyed platform profiles and the distribution of marine organisms at A Hermida and Oia in the northern part of the coast between Baiona and A Garda

Figure 8. Surveyed platform profiles and the distribution of marine organisms at San Xiáo and Portocelo in the southern part of the coast between Baiona and A Garda

boulders; this deposit has been dated and found to be about 36 000 years old in this area. The boulder beaches at A. Hermida and Portocelo also extend well above the present level of wave action, and may therefore be of Eemian age (Blanco Chao, 1999).

Corrubedo

The granitic platform at Corrubedo, on the southwestern end of the Barbanza Peninsula about 10 km south of Caamaño, is generally between about 100 and 150 m in width and 1 and 2° in slope (Figures 1 and 2C). The platform surface is very irregular, and channels have been cut along the joints (Figure 3). Most platform profiles are essentially linear or concave-linear, with a steeper ramp with gradients of between 4 and 5° at their landward end (Figure 9), but others, possibly reflecting local structural influences, are concave–linear–convex, with a steeper seaward terminus (Figure 9, profiles P3 and P4). Several profiles contain segments that are noticeably flatter than the rest of the profile, although they occur at a variety of elevations ranging from the low (Figure 9, profiles P7 and P8) to the mid- (Figure 9, profiles P3 and P4) tidal levels.

Large, mainly rounded blocks, with long axes of between 0·5 and 2 m, have accumulated in the upper portions of the platform. The blocks are covered in algae, crustaceans and other organisms, many are weathered along the joints, and there is no evidence of abrasion or impact quarrying under them; it therefore appears that waves are unable to move these rocks today. Conversely, because of deeper water at high tide, storm waves are able to move the blocks in the lower portion of the boulder beach, where the rocks are free of biological organisms and exhibit evidence of abrasion.

In contrast to much of the area between Baiona and A Garda to the south, there is a low hinterland at Corrubedo and the mountains are far away from the coast. Therefore the platforms in this area could not have been buried under periglacial slope deposits and fossilized when sea level fell during the last glacial stage. Datable organic material and ancient beach deposits are absent at Corrubedo, but although the back of the platform lies beneath the boulder beach and is inaccessible, extrapolation of the platform surface with the low hinterland suggests that it extends up to a few metres above the highest level of the tide; this would be consistent with the elevation of the sea in Galicia during the last interglacial. Furthermore, as in southwestern Galicia, the top of the boulder beach at Corrubedo extends well above the level of contemporary wave action, even during storms, and it has been colonized by terrestrial vegetation. If the Corrubedo platforms are inherited (Pérez Alberti *et al*., 1998a), which is a reasonable assumption given the abundant evidence in other places along this coast, they would have been largely exposed during the coldest phases of the last glacial stage. Although global circulation models suggest that permanent pack ice extended almost this far south about 18 000 years ago, sea level was much lower than today at this time, and the main effect of cold, glacial stage climates on the contemporary shoreline would have been frost action. It is tempting to suggest that the numerous large loose blocks on the platform at Corrubedo and the much greater irregularity of its surface, relative to platforms that were protected under thick deposits, are evidence of the erosive efficacy of frost action during the Weichselian. Morphological evidence can be ambiguous, however, and one cannot rule out the possibility that wave quarrying has been more effective in the past.

Other areas

There is abundant evidence of coastal inheritance in other parts of western Galicia. On the Ria de Muros y Noia, between Aguieira and Caamaño (Figure 1), for example, the back of the platform is covered by several metres of undated organic material, coarse periglacial slope deposits and dune sands, at the base of which is an ancient, presumably Eemian, beach deposit. There are also patches of cemented dune sand on the platform surface, along with several ancient, sediment-filled potholes. Five radiocarbon dates, ranging from 37 550 to 34 380 years BP, have been obtained from the cliff deposits at the head of a small bay at Muxia, in northwestern Galicia (Table I, Figure 1). A large patch of the lower organic layer, with two C^{14} dates of 31 740 years BP and 31 050 years BP, outcrops in the middle of a sand, pebble and boulder beach (Costa Casais, 2001). Although this particular deposit has not been excavated to determine whether it is on a shore platform, it frequently overlies platforms, or Eemian beach deposits on platforms, in other parts of Galicia, and there is an undated section at Muxia on the back of the platform a few hundred metres to the east. The presence of the submerged portion of a shore platform in front of the beach further suggests that inheritance has also occurred in this area.

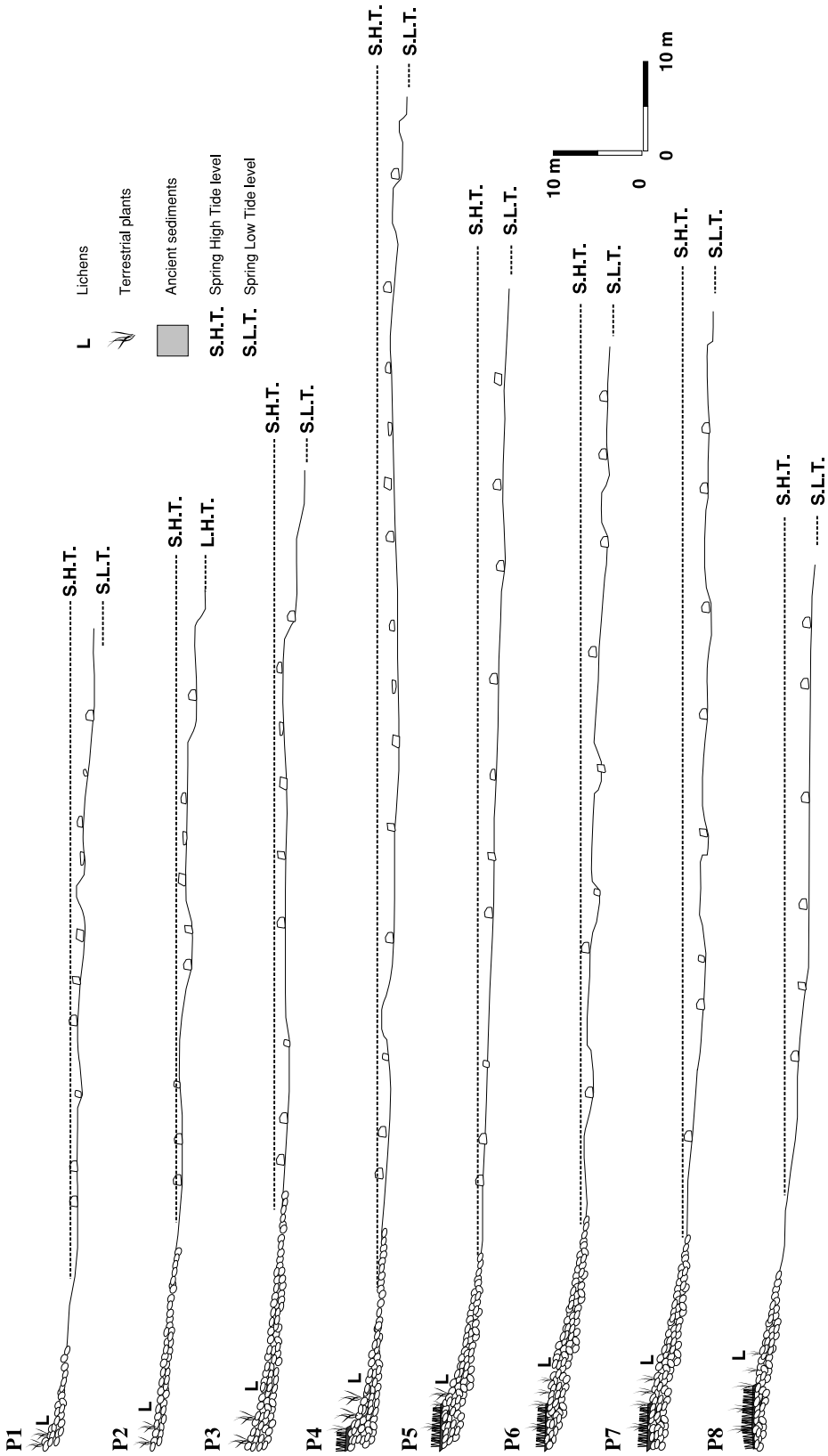

Figure 9. Surveyed platform profiles at Corrubedo

DISCUSSION

The base of most of the cliff deposits in Galicia consists of an organic-rich layer ranging from about 30 000 years old at the top of the deposit to more than 40 000 years at the bottom. The oldest coastal sediments that have been radiocarbon dated are near A Garda in the southwest, where two samples provided ages of 43 500 and 41 500 years BP (Brosche, 1982). It is possible that because these ages are very close to the limit of radiocarbon dating, the sediments could be older than is indicated, although many workers question the reliability of these older dates. Therefore, at present, there is no evidence that cold process deposition occurred in western Galicia during the early and much of the middle Weichselian glacial stage. This is in contrast to northwestern Europe, where there is evidence of periglacial activity about 80 000 years BP (Van Vliet-Lanöe, 1989; Van Vliet-Lanöe *et al*., 1992). The later onset of cold conditions in Galicia, relative to northwestern Europe, must reflect latitudinal gradients in temperature and humidity during the last glacial stage. In Belgium and Normandy, cold conditions were dominant in the early Weichselian, and the environment was favourable for periglacial activity and deposition at the coast. The warmer and more humid climate in Galicia at this time was conducive to slope runoff and the deposition of sediment in the sea, and periglacial processes only began to operate when the climate became colder, about 40 000 years ago (Cano *et al*., 1977; Costa Casais *et al*., 1996a; Trenhaile *et al*., 1999).

The occurrence of molluscs, including *Patella* spp., *Mytilus edulis* and *Littorina* spp., and the crustacean *Balanus perforatus*, over much of the intertidal surface, and echinoderms and *Lithophyllum incristans* and other algae on the inner walls of potholes, suggests that the inherited shore platforms of Galicia are experiencing very slow rates of mechanical wave erosion today. This may be attributed to wave attenuation over the wide, gently sloping platforms, wide surf and swash zones, the dominance of spilling breakers and bores, and wave saturation in the inner, bore-like surf zone. Conversely, there is some evidence of continuing, or at least recent, exhumation of the Eemian coast through erosion and retreat of the sedimentary cliffs. At Caamaño, for example, an organic sample taken from 1 m below the top of a vertical cliff, provided a radiocarbon age of 530 years BP. This demonstrates that continental sedimentation has continued in this area during the last few hundred years, and that exhumation of the landward portion of the platform has therefore been recent. Other radiocarbon dated samples, 2720 years in age at Caamaño (Costa Casais *et al*., 1994, 1996a), and from about 3000 to 5000 years in age at Porto Canela in the southwest (Cano *et al*., 1997), have provided further evidence of historical cliff retreat and platform exhumation in Galicia. Although similar dates are lacking at present elsewhere, many of the ancient deposits on the coast of Galicia have similar sedimentary structures that imply that these areas have a comparable late glacial and postglacial history.

CONCLUSIONS

The coast of western Galicia consists of a series of tilted surfaces composed of strongly fractured and deeply weathered rocks that have facilitated marine erosion, and slopes that are covered by periglacial deposits. In some places, Eemian shore platforms and other elements of the rock coast of Galicia were exposed to frost action during the Weichselian. Frost may have been responsible for the large loose blocks and irregular surface of the platform at Corrubedo, and possibly for similar features at A Ermida and Portocelo in the southwest, which were covered under thin distal deposits. In contrast, there are fewer loose blocks and the platform surfaces are more regular at Camaaño, San Xiao and Oia, which, being closer to the coastal mountains, were covered and protected by thick fluvio-nival and geliflucted slope deposits. These ancient coasts were then exhumed and inherited as sea level rose to its present position during the Holocene (Figure 10). The distinction has been made between Caamaño on the southern margin of the Ria of Muros, where sedimentation during the middle and late Weichselian had local sources and was controlled by the ancient coastal cliffs, and the southwestern coast between Baiona and A Garda, where the mountains formed an orographic obstacle to humid oceanic air masses. The low hinterland is another important factor that must be considered at Corrubedo, in addition to distance from the mountains.

Galicia provides a rare example of a coast formed in fairly weak, weathered rocks that has associated deposits that can be radiocarbon dated. This area is therefore providing some of the most convincing evidence gathered

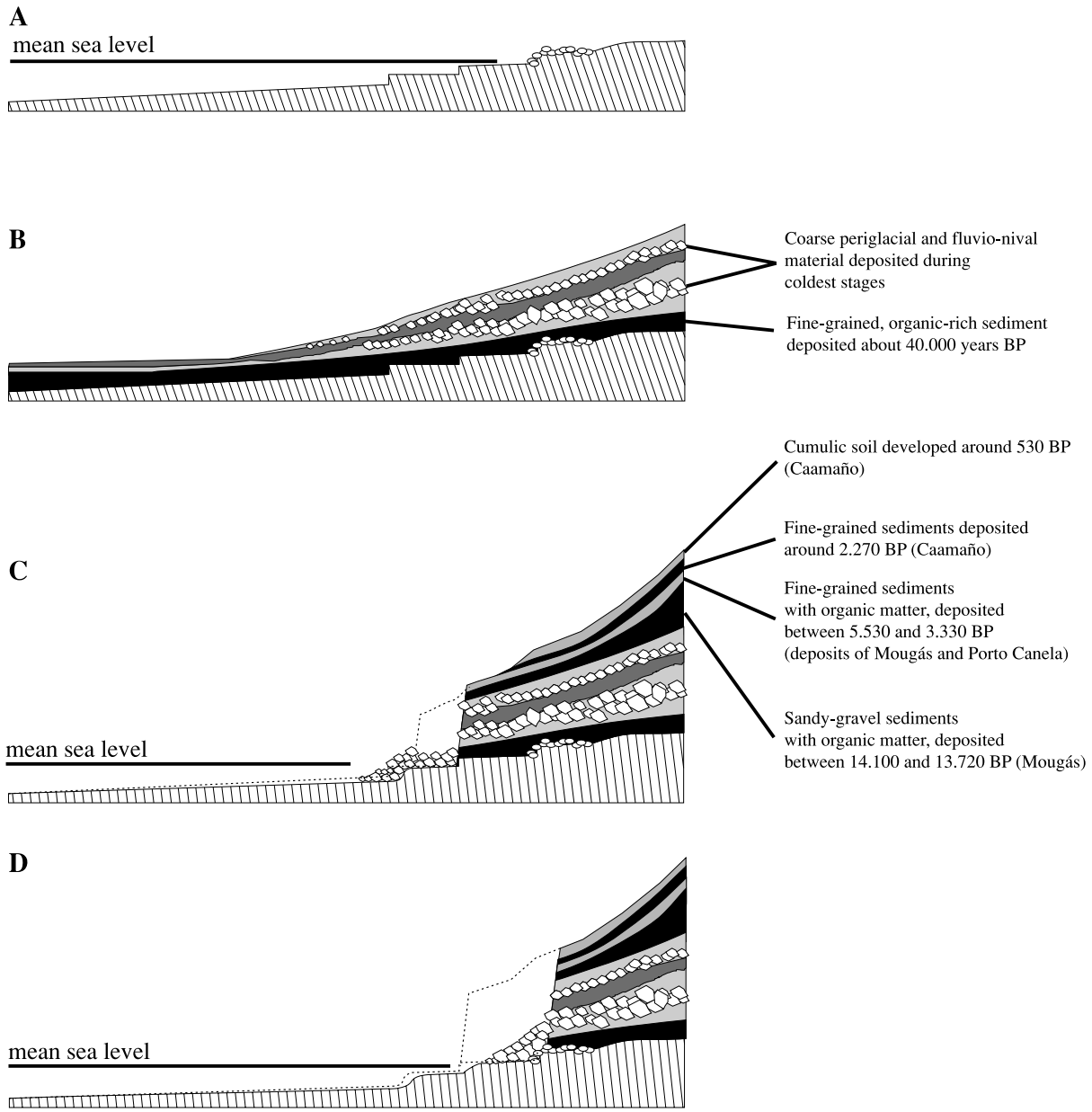

Figure 10. Stages in the fossilization and exhumation of Eemian coasts in western Galicia: (A) the Eemian coast; (B) fossilization under Weichselian terrestrial deposits; (C) Holocene continental deposition during retreat of the cliff; (D) present conditions. The occurrence of ancient raised beaches on the platforms suggests that there has been little downcutting by waves or weathering in Galicia during the Holocene, although steep scarps are retreating as a result of wave quarrying

to date that shore platforms, caves and other elements of rock coasts may be inherited, at least in part, from one or more interglacial stages when sea level was similar to today's. This conclusion has important implications for coasts in fairly weak sedimentary and metamorphic rocks elsewhere, where fairly rapid erosion may have removed ancient beach deposits, glacial, periglacial or other terrestrial deposits over the rear of shore platforms, ledges and other evidence of platform inheritance which might once have existed.

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