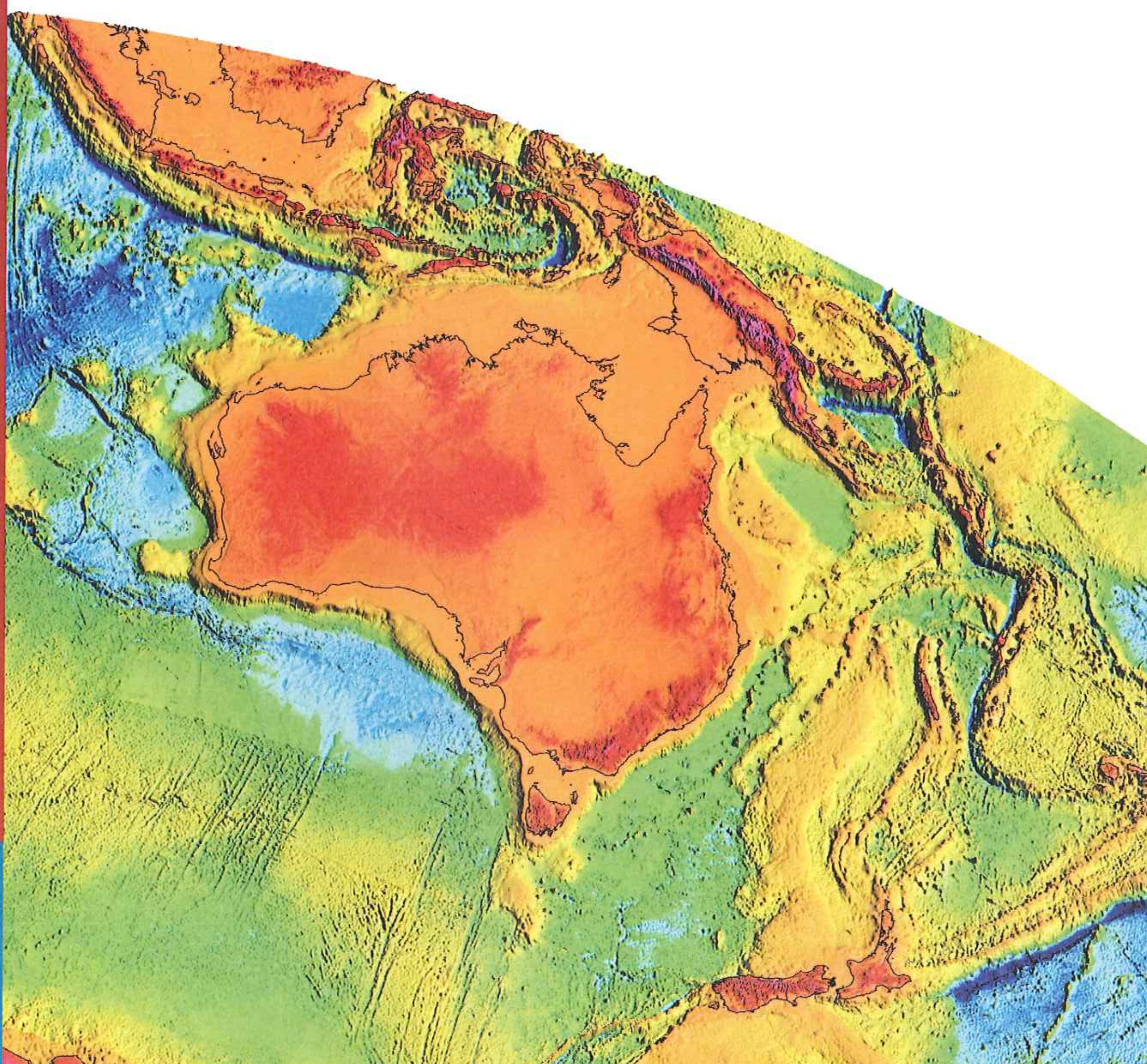
Record 2001/42

Seabed character mapping in the Great Australian Bight

South and Southwest Region Project

Nadège Rollet, Melissa E. Fellows,
Heike I.M. Struckmeyer and Barry E. Bradshaw



GEOSCIENCE Australia

GEOSCIENCE AUSTRALIA

SPATIAL INFORMATION FOR THE NATION

Geoscience Australia Record 2001/42

SEABED CHARACTER MAPPING IN THE GREAT AUSTRALIAN BIGHT

Nadège Rollet, Melissa E. Fellows, Heike I.M. Struckmeyer and Barry E. Bradshaw

South and Southwest Region Project

Geoscience Australia

Chief Executive Officer: Neil Williams

Department of Industry, Tourism & Resources

Minister for Industry, Tourism & Resources: Senator The Hon. Nick Minchin
Parliamentary Secretary: The Hon. Warren Entsch, MP

ISSN: 1039-0073
ISBN: 0 642 46723 4

Bibliographic reference: Rollet, N., Fellows, M., Struckmeyer, H. and Bradshaw, B., 2001. *Seabed Character Mapping in the Great Australian Bight 2001*. Geoscience Australia Record 2001/42.

CONTENTS

1. EXECUTIVE SUMMARY

This report presents the results of a regional seafloor mapping study carried out during 2000/2001 as part of Geoscience Australia's South and Southwest Regional Project. The aim was to support future Regional Marine Planning in the Great Australian Bight (GAB) by underpinning biological, environmental and economic assessments with basic information on geomorphology and the seabed character.

Four major geomorphological features are present on the margin in the South and Southwest (SSW) region: a continental shelf, marine terraces (including the Eyre and Ceduna Terraces in the GAB), a continental slope and a continental rise. The boundaries of these geomorphological features have been delineated and captured in a Geographical Information System (GIS). The GIS also includes the location of sedimentary basins, plateaus, terraces and canyons previously mapped in the region.

Seabed character mapping was carried out for the GAB area only. Five echo facies have been defined in the GAB area based on the interpretation of available 3.5kHz echo-sounding records and high-resolution seismic profiles in terms of acoustic facies, and their groundtruthing against seafloor samples. The interpretation of these facies has been digitised and captured into a GIS. The GIS includes key attributes for every echo facies. The acoustic facies distribution on the GAB margin and offshore in the South Australian abyssal plain shows the importance of geological inheritance to the geomorphology and sea-bed character of the region. Facies I, which represents undisturbed, layered sediments is mainly localised on the shelf, the Eyre and Ceduna Terraces, and in the greater part of the abyssal plain. Facies II, which may represent more disturbed sediments, is confined to the Ceduna Terrace and along two elongated E-W trending areas on the abyssal plain near the continent-ocean boundary. Facies III, associated with extreme (IIIA), moderate (IIIC) and low (IIID) topography, underlies scarps, canyons, and depressions on the continental slope and the abyssal plain. The distribution of acoustic facies from the upper slope down to the abyssal plain indicates that the major sedimentary process in the deep water GAB is deposition of pelagic sediments. Reworking of sediments by both bottom currents and gravity flows is probably limited to submarine canyons.

2. INTRODUCTION

The Great Australian Bight (GAB) is located offshore central southern Australia, extending across the state boundaries of Western Australia and South Australia (Figure 1). The GAB area overlies five geological sub-basins: the Recherche, Eyre, Ceduna and Duntroon Sub-basins of the Bight Basin, and the Polda Trough (Figure 2). Water depths range from shallow shoreline waters of less than 100 m to the deep ocean greater than 5500 m (Figure 1).

Detailed studies have recently been undertaken on the deep structure in the GAB basins and the seabed character in the GAB Marine Park. The deep structure has been interpreted based on recent work by Geoscience Australia's Southern Margin Frontiers project which conducted a regional study of the Bight and Duntroon basins in 1998-99 (Totterdell et al., 2000; Krassay and Totterdell, in prep.). The seabed character in the GAB Marine Park was studied using swath-mapping (Hill et al., 2000; Rollet, 2000; Hill et al., 2001) and sediment sampling (Rollet and Glenn, 2000; Fellows, in prep.). However, to date there have been no regional studies of the deep water geomorphology and sea-bed character of the GAB. The purpose of this study is to produce a series of regional maps showing the geomorphology across the entire SSW region, and more detailed sea-bed character maps for the GAB.

3. GEOMORPHOLOGY

3A. OFFSHORE GEOMORPHOLOGY

The SSW Region contains a number of distinct geomorphological and geological features (Figure 3); a broad continental shelf, a wide continental slope including marine terraces, particularly two wide terraces in the GAB (Ceduna and Eyre terraces), and a narrow continental rise. Mapping the offshore geomorphology of the extensive South Australian Margin required modifying the commonly used tripartite shelf margin zones of continental shelf, slope and rise[1]. These modifications were required because the strong geological inheritance on shelf margin morphology in the Great Australian Bight means that the tripartite shelf margin classification system is not always applicable.

The shelf-break identified on seismic profiles occurs at water depths around 200 m ($\pm$ 10 m); therefore, for the purpose of this study the shelf break is taken at the 200 m isobath. In Figure 3, the shelf has been defined as the part of the margin between the coastline and the 200 m isobath. The continental shelf in the GAB is very wide, up to 200 km north of the Ceduna Sub-basin, and up to 100 km north of the Eyre Sub-basin. The shelf narrows to less than 70 km wide at the western end of the GAB. In the GAB, the shelf displays some NW-SE trending features oblique to the coast. These could possibly be interpreted as submarine dunes deposited by eastern flowing currents such as the Leeuwin and South Australian Currents. Submarine canyons incised into the shelf by palaeo river systems are also an important morphological feature of the GAB shelf.

[1] Shelf and slope types are variable and discussed in Vanney and Stanley (1983). The definition used here for the three zones is that of Foucault and Raoult (1988):
(1) The continental shelf is a planar zone, tilted slightly oceanward, 80 km width on average and 200 m deep;
(2) The continental slope is commonly 45 km wide, from 200 m down to 4000 m of water depth, with a 5° slope cut by numerous submarine canyons. A terrace is usually defined as a nearly flat landform with a steep edge formed by a variety of processes. Marine terraces can be used to define palaeo-shorelines that formed under different sea level conditions to the present;
(3) The continental rise has a low angle slope (less than 1°), is between 4000 and 5000 m deep, and grades into the abyssal plain.

Continental terraces are a distinct feature of the GAB shelf margin. The Ceduna Terrace is a particularly well developed feature in the eastern GAB. It is up to 200 km wide and extends from water depths of 200 to 3000 m. The Eyre Terrace is a prominent feature in the western GAB, with a maximum width of 200 km. It occurs in water depths of 200 to 2000 m. Several processes such as eustatic sea level rise, tectonic subsidence, or climatic change could explain the presence of terraces on a continental margin. In this case, the terrace has been described as corresponding to a Late Cretaceous (Albian-Cenomanian) shelf margin that formed during the deposition of deltaic sediments derived from erosion of the uplifted eastern Australian highlands (Totterdell et al., 2000; Norvick and Smith, 2000). Since the beginning of the Tertiary, the GAB has become a sediment-starved continental margin, dominated by cool water carbonates. The Late Cretaceous shelf margin continued to subside throughout the Tertiary at a greater rate than the accumulation of carbonates. This resulted in the Tertiary shelf margin being located considerably inboard of the Late Cretaceous shelf margin. The Ceduna Terrace is thus a relict Late Cretaceous shelf margin (Krassey and Totterdell, in prep.).

The continental slope is quite narrow (20 km) in the western GAB, but widens in the eastern GAB where it reaches a width of 40 km. The continental rise is barely noticeable on the bathymetric map recently compiled by Buchanan (2000), but is observed on seismic lines orthogonal to the margin (e.g. lines AEA1023 between 6.2 and 7.5s TWT, see Figure D12, Hill et al., 2001).

3B. CORRELATION BETWEEN OFFSHORE GEOMORPHOLOGY AND ONSHORE GEOLOGY

The southern Australian continent is composed of rocks varying in age from Archean to Cainozoic. Crystalline shield rocks occur in the southwest of the continent (Yilgarn Craton) and in the southeast of the study area (Gawler Craton), separated by Proterozoic to Palaeozoic rocks of the Albany-Fraser and Officer regions. Cretaceous and Cainozoic sediments of the Eucla Basin (Figure 2) overlie the latter.

Two main groups of large submarine canyons are observed on the slope off southern Australia. They have been defined previously (Von der Borch, 1968) as the 'Albany Group' from longitude 115°E to 124°E, and the 'Murray Group' from longitude 135°E to 138°E. In addition, there are two areas of small canyons in the western and eastern GAB (Figure 3). The 'Albany group' includes at least 32 canyons on the steep continental slope between Broke Canyon in the west and Malcolm Canyon in the east (Figure 3). The seaward extension of the Darling Fault, a major structural feature that separates Perth Basin sediments from ancient crystalline rocks of the Yilgarn Block, is interpreted to form the western boundary of the ‘Albany Group’ (Von der Borch, 1968). Offshore Albany, the continental shelf is narrow and shows some indentations associated with large gravity slumps observed on the continental terrace and the continental slope (e.g. the Northcliffe Spur, Walpole Spur, Parryville Spur, Albany Spur). These submarine slumps are up to 50 km wide and show a displacement of about 10 km down dip from the shelf break down to the slope.

East of Malcolm Canyon, the trend of the continental slope changes markedly from E-W to NE-SW. This point approximately corresponds with the eastern edge of the Yilgarn Block and the western boundary of the Tertiary Eucla Basin onshore. The point also corresponds to a break between two sedimentary basins, the Eyre and the Bremer basins (Totterdell et al., 2000; Moore et al., 2000; Norvick et al., 2000). These formed in Middle-Late Jurassic and extended offshore of Albany in an E-NE direction, through the Bremer Basin and Recherche Sub-basin to the Eyre Sub-basin (Stagg et al., 1990). Fewer but larger canyons (Eyre and Eucla canyons) occur downslope of the Eyre Terrace (Figure 3). The Eucla canyon is the biggest along this part of the southern margin. An inherited fault zone or an ancient structural boundary may guide this major canyon. The eastern part of the Ceduna Terrace is incised by at least six canyons, including Nullarbor, Yalata, and Ceduna Canyons (Figure 3). The Nullarbor Canyon appears to be the largest and deepest submarine canyon in this area. A series of "deep holes" located along the Nullarbor Canyon have recently been mapped and sampled (Hill et al., 2000; Rollet and Glenn, 2000; Harris et al., 2000; Hill et al., 2001; Fellows et al., 2001). Upper Cretaceous mudstones overlain by a thin veneer of Quaternary sediments have been recovered in the "deep holes" (down to 5250 m). The mechanism for the formation of these "deep holes" is still unclear, but may relate to gravity-driven growth-faults created during recent reactivation of Late Cretaceous faults (Hill et al., 2001). The faults sole out at the base of Turonian shales, which form a décollement for the younger faults. The marine shales are likely to be over-pressured (Totterdell et al., 2000), allowing water to escape along the newly created faults. Escaped water may have prevented deposition of younger sediments in the holes. Deep contour currents in this region may also contribute to shaping the holes and keeping them clear of sediments (Hill et al., 2001). The eastern canyon zone corresponds to the onshore extent of ancient crystalline rocks of the Gawler Craton (Figure 3). It appears to be a correlation between the presence of numerous small to large canyons and onshore geology, i.e. submarine canyons occur preferentially offshore from ancient shield rocks. As submarine canyons form mainly by incision from river systems during periods of low relative sea level, the distribution of the channels may indicate that the palaeo-drainage systems were well developed on the cratons. It could also be related to faults and seismic activity, as the southwestern craton has numerous NW-SE trending faults that are presently seismically active and may have offshore expression that controls the location of canyons (Figure 4).

3C. INFLUENCE OF SEISMIC ACTIVITY

Earthquakes in the offshore SSW region recorded in the last 59 years (Figure 4), have generally been of small magnitude (less than 4) (Geoscience Australia’s Quakes database). Their epicentres are mostly recorded on the shelf, the terrace and on the abyssal plain. Three main active earthquake regions are observed: (1) the offshore Perth Basin, (2) offshore Albany east of the Darling fault, (3) the offshore area between Ceduna and Adelaide. These three offshore earthquake-prone regions are associated with active onshore earthquake zones.

Earthquakes on and near the continental slope may be associated with faulting or slumping. Offshore Albany, earthquakes are quite shallow (around 5 km depth) and have a very small magnitude (below 4). In this region, the continental shelf is very narrow and associated with large gravity slumps extending down to the terrace. Recent earthquakes recorded between 1991 and 1999 (Geoscience Australia's Quakes database) indicate that the shelf and terrace may still be unstable.

4. SEABED CHARACTER

4A. BACKGROUND

In the absence of extensive swath data sets in the GAB area, the character of sea-floor can be mapped effectively using variations in acoustic response of echo sounders. Echo sounders are used primarily to measure water depth. They measure the time it takes for a sound signal to propagate though the water column, reflect off the seafloor and return to the ship. The velocity of sound through water is a function of temperature, salinity and water pressure. These must be measured or approximated to translate the transit time into depth (Turekian, 1968). In addition to depth soundings, echograms provide useful data on changes in seafloor reflectivity and microtopography. Hollister (1967) introduced the use of echo-character maps based on changes in acoustic reflectivity observed on 12 kHz echograms. However, the 12 kHz echograms showed little or no penetration of acoustic energy below the seafloor (0-10 m) due to the use of high frequency waves. The low frequency waves used for the 3.5 kHz echo sounder can attain seafloor penetration of 100 m or greater (Kennett 1982; Damuth 1980). Damuth (1973, 1975) developed a classification system for 3.5 kHz echograms based on Holister's 12 kHz-classification system. He classified the echo-character of the seafloor into three main categories based on parameters including clarity and continuity of echoes and seafloor morphology:

I. Distinct echoes,
II. Indistinct echoes – prolonged,
III. Indistinct echoes – hyperbola.

These categories were further sub-divided into several types based on presence/absence of a sub-bottom reflector, and prolonged extent and relationship of hyperbolae to the seafloor. Different echo-character types form through the interaction between ocean bottom and echo-pulse. Sediments affect the echo return by their grain size, mineralogy, layering, structure and topography (Flood, 1980). However, additional information such as sediment samples, seafloor photographs, hydrographic temperature data, and/or multi-beam sonar and current meter data are needed to define the echo-types in terms of regional sedimentary processes.

To construct an echo-character map, all available echograms across a region need to be examined to develop a classification system that is suitable and specific for the study area. Meaningful regional maps may not be possible if the data spacing is too wide or if echo-types are too complex in areal extent (Damuth, 1980).

4B. DATA AND METHODOLOGY

The data set used for this study (Figure 5) includes about 86 000 km of 3.5 kHz records from Geoscience Australia surveys S65, S199, S222 (AUSTREA-1, Hill et al., 2000, 2001). About 110 000 km of seismic data have been used from surveys S222, S215 and S216. Swath images from AUSTREA-1 cruise in the GAB Marine Park have also been used. Sediment sample information used to groundtruth the facies interpretation was derived from the Geoscience Australia marine sediment database (MARS) and include gravity cores and dredges from surveys S66 and S102, and new samples from cruises SS01/00 (Rollet and Glenn, 2000) and S231 (Fellows, 2001).

A representative set of data based primarily on echo-type character observed in the GAB is shown in Figure 6. This data set was used to map acoustic response of surface sediments in the GAB (Figure 7). The 3.5 kHz acoustic response of surface sediments was used to predict sedimentary facies (e.g. Damuth, 1980; Whitmore and Belton, 1997). Echo-types were identified and interpreted using all available along-track 3.5 kHz data in the Great Australian Bight. Echo-types were then mapped along-track using Petrosys software. Although the line spacing varies widely across the study area, interpolation between tracks was possible by using the Geoscience Australia bathymetry grid (Petkovic et al., 1999) as a supporting data set and by verifying interpretations at line intersections. The confidence levels that can be placed on the interpretation vary depending on the line spacing and frequency of line intersections (Figure 8). Where no 3.5 kHz data were available, the upper 50 milliseconds (ms) of acoustic facies observed on seismic data were used by applying the echo-type/seismic facies correlation (Figure 9a, b, c, d) recognised in the GAB Marine Park by Hill et al. (2001). The resolution on seismic lines is considerably less than on 3.5 kHz, but it still allows a meaningful interpretation of echo facies for the whole of the GAB. This interpretation indicates clear changes in seabed character from the shelf to the abyssal plain (up to 650 km from the coast), which can then be used as an aid to assess geological processes at the seabed.

More accurate mapping of acoustic facies was possible in the GAB Marine Park using information from along-track 3.5 kHz profiles, confirmed with full swath-bathymetry, acoustic backscatter data (Hill et all., 2000) and groundtruthing by bottom samples (Rollet and Glenn, 2000). The GAB Marine Park area is considered as a reference area for the interpretation of sediment facies in the GAB because of the presence of complementary data sets. In the western part of the GAB, seismic reflection profiles and/or 3.5 kHz data are available (Surveys S065, S199, S215, S216) from the upper shelf (50 m) down to the abyssal plain (more than 5000 m deep). Most of the data from the eastern part of the GAB (surveys S215, S216, AUSTREA-1) are available for the upper part of the margin between 50 m and 3000 m water depth. The data here are mainly reflection seismic profiles, except along the transit of the AUSTREA-1 cruise between the isobaths 2000 and 3000 m, where 3.5 kHz and swath data are available. As a consequence of the variable distribution of data across the GAB, the degree of confidence in the interpretation of sediment characteristics varies from 90% in the GAB Marine Park, to 70% in the western GAB, and 60% in the eastern GAB.

It is important to groundthruth sediment facies to obtain more confidence in the echo results as the echo-character of different sediments can be similar. The lack of sediment samples in the GAB from the continental shelf down to depths of >5000 m (see samples location on Figure 6) does not allow complete identification of each echo-type. Therefore, the map on Figure 8 should only be used as a broad indication of the distribution of sediment families in the GAB.

4C. ACOUSTIC FACIES IN THE GREAT AUSTRALIAN BIGHT

4C1. Echo-type description

Five major echo facies types were defined for the Great Australian Bight region using the methods described above. They largely correspond to the echo facies described by Hill et al. (2001), although some have been regrouped into broader facies groups without or with fewer subdivisions (e.g. IA and IB are combined in facies I, and IIA and IIB are combined in facies II). This is because the quality of the 3.5 kHz data acquired during cruises S065, S199, S215 and S216 does not allow differentiation of echo-type within the major facies groups I and II. In the third group, distiction into sub-types is easier because their definition is based more on roughness rather than penetration of acoustic response. In some areas, especially in the Marine Park where the data are of better quality, more detailed mapping was possible and facies I (IA, IB) and II (IIA, IIB) were subdivided. Examples of echo types from two data sets of different quality are given in Figure 6a (the Austrea-1 survey in the Marine Park) and Figure 6b (survey 199).

Facies I: This facies incorporates sharp, continuous echo with no (IA), 1-2 sharp (IC), or up to 20 (IB) continuous, parallel sub-bottom reflectors. The sub-division has only been made in the Marine Park where the data set was of better quality.

Facies II: This facies incorporates semi-prolonged echo with discontinuous, parallel sub-bottom reflectors (IIA), with no sub-bottoms reflectors (IIB), with many sharp discontinuous non-parallel wedging sub-bottom reflectors (IIC) (Damuth, 1978). The sub-division has only been made in the Marine Park where the data set was of better quality.

Facies III: This facies incorporates large, irregular, overlapping prolonged hyperbolic echoes associated with extreme topography (IIIA), moderate topography (IIIC), or small, regular overlapping hyperbolic echoes associated with low topography (IIID). Echo-types IIIA, IIIC and IIID are similar to those defined previously in on the South Tasman Rise by Whitmore and Belton (1997). The echo-type IIIB, defined by Damuth (1980) as regular, single hyperbolae with varying vertices and conformable sub-bottoms, has not been recognised in the GAB area.

4C2. Echo-type distribution

The spatial distribution of the interpreted echo facies in the GAB (Figure 7) clearly reflects changes in morphology of the margin and the abyssal plain.

Facies I probably represents undisturbed, layered sediments and occurs mainly in four areas of the Bight: on the shelf, on the Eyre Terrace, in the central part of the Ceduna Terrace and in the greater part of the South Australian Abyssal Plain.

Facies II may represent more disturbed sediments and is mostly confined to the Ceduna Terrace. It also occurs locally in the central part of the Eyre Terrace and in two elongate E-W trending areas on the abyssal plain, near the continent-ocean boundary (location shown on Figure 7) as defined previously by Sayers et al. (2001).

Facies III, associated with extreme (IIIA), moderate (IIIC) and low (IIID) topography, is interpreted mainly on the continental slope, along scarps, canyons, depressions, and on the abyssal plain along E-W trending ridges. An abrupt lateral facies change occurs on the eastern continental slope between the Ceduna Terrace (covered mainly by facies II and IIIC) and the Duntroon Sub-basin (covered mainly by Facies IIIA). This rapid facies change reflects a rapid change in the gradient of the slope. The Duntroon Sub-basin slope is narrower, steeper and more extensively incised by canyons, compared to the wider Ceduna Terrace, which has only five main canyons (Nullarbor, Yalata, Adieu, Ceduna and Fowlers Canyons).

The distribution of these facies suggests that modern sedimentation is linked to seafloor topography in the GAB. To understand better the sedimentary processes in the GAB, it is necessary to verify or "groundtruth" these different facies using surface and sub-surface sediment samples.

5. Geological interpretation of acoustic facies

The nature of acoustic facies within a study area can vary significantly with location and geomorphological/bathymetric position. In order to achieve a meaningful interpretation of sediment type and sedimentary processes reflected by the different echo facies types, it is essential to groundtruth each echo type at various positions in the study area. Geological interpretation of acoustic facies requires many seabed samples for each facies encountered at different locations and water depths. The quality of such groundtruthing is also limited by the penetration of sediment cores. In the GAB, only 95 samples are available within the map limits (Figure 5), including some dredge samples from the continental slope and abyssal plain. Despite the lack of data, each of the acoustic facies described above has been groundtruthed, but only with one or two samples.

Sediment samples available in the GAB region (Table 1) were mainly collected as part of petroleum exploration programs (1975-1993) and five scientific surveys: BMR survey 66 (Willcox et al., 1988), Rig Seismic Survey 102 (Feary et al., 1993), ODP sites sampled during Leg 182 (Feary and James, 1998), Southern Surveyor cruise SS01/00 (Rollet and Glenn, 2000) and the Franklin Cruise FR 1/01 (Fellows, in prep.; Radke, 2001).

Table 1: Number of samples collected in the GAB

Survey	Cores	Dredges	Grabs
BMR Survey 66	20	0	0
Rig Seismic Survey 102	12	3	0
Southern Surveyor S224	9	3	0
Franklin S231	23	0	5

5A. FACIES I

5A1. Upper Slope and Eyre Terrace

The acoustic facies comprising echo type I on the outer shelf is only groundtruthed in the Eyre Terrace area by vibrocore samples acquired during survey 102 (Feary et al., 1993), and gravity cores collected during Franklin survey 231 (Fellows, in prep.). Core data show a Tertiary/Pleistocene carbonate cover with a thin Holocene mollusc and lithoclast lag on the inner shelf, and a 9,000-13,000 year old rhodolith pavement on the deeper outer shelf (Feary et al., 1993). Quaternary age foraminifer-nannofossil oozes occur on the upper slope and Eyre Terrace. Cores from shallow water depths have ubiquitous bioturbation, which becomes progressively less intense in cores from deeper water (Feary et al., 1993).

5A2. Ceduna Terrace

Cores recovered during survey 66 (Willcox et al., 1988*)* along a NE-SW profile in the central part of the Ceduna Terrace consiste predominantly of pelagic calcareous ooze. In the western part of the Ceduna Terrace, gravity cores recovered Quaternary age foraminifer-nannofossil ooze along a NE-SW transect (survey 102; Feary et al., 1993). These samples show an increasingly well-preserved colour banding in the deeper cores, coinciding with decreasing bioturbation, that probably reflects climate-controlled cyclic oxygenation variations caused either by Antarctic bottom water fluctuations or by distal Leeuwin Current effects (Feary et al., 1993). The cores recovered in the GAB Marine Park (Rollet, 2000; Rollet and Glenn, 2000) all comprise mainly fine-grained hemipelagic, calcareous foram/nannofossil ooze. Most cores obtained from the upper slope contain unconsolidated and reworked calcareous sand and mud. The top of core 224GC01 comprised light olive gray foram-nanno ooze, 33% sand and 66% mud, and has a low magnetic susceptibility value close to zero, which is characteristic of non-terrigenous, biogenic sediments (Harris et al., 2000).

5A3. Abyssal Plain

Foraminifer-nannofossil ooze was recovered from gravity cores collected on the abyssal plain during survey 102 (Feary et al., 1993), east of the Ceduna Terrace.

5B. FACIES II

5B1. Eyre Terrace

Facies II on the Eyre Terrace is only constrained by 2 samples (102GC06-07; Feary et al., 1993) that recovered nannofossil-foraminiferal ooze with abundant bioturbation and a few sandy turbidite layers.

5B2. Ceduna Terrace

Reworked pelagic sands were encountered in two cores recovered from the upper slope of the Ceduna Terrace during survey 66, (GC01 and GC07; Willcox et al., 1988). They are probably contourites or locally sourced grainflows (Willcox et al., 1988). The lack of grading, poor sorting and abundant matrix suggest debris flow deposits. Similar deposits on other continental slopes (MacIlreath and James, 1984) are attributed to grainflow (possibly storm generated), turbidites, and contour-parallel currents (geostrophic currents).

5B3. Abyssal Plain

Facies II observed on the abyssal plain has only been sampled by one dredge (102DR09). This dredge recovered some manganese nodules, manganese-rich mudstone and large boulders of laminated pelloidal grainstone/packstone (Feary et al., 1993). Ten percent of recovered material comprised tholeiitic basalts that give indications of the nature of the ocean floor. The calcareous-poor composition of the sediments is probably a function of depth, being deposited below the Calcium Compensation Depth (CCD) (Feary et al., 1993). It is difficult to groundtruth this facies with one sample, so this information should be taken as only an indication of the possible nature of this facies on the abyssal plain.

5C. FACIES IIIA

5C1. Ceduna Terrace

Dredge sampling during survey 102 successfully recovered an extensive suite of terrigenous siliciclastic rocks and, in one dredge east of Ceduna Terrace (102DR07 in the Topgallant Canyon), a range of calcareous and dolomitic rocks. Nannofossil data show that the calcareous rocks are of Middle Eocene to Mid-Late

Oligocene age, while palynological studies show that the terrigenous siliciclastic rocks are of Late Cretaceous (Campanian to latest Maastrichtian) age.

Magnetic susceptibility curves for cores 224GC03, 224GC04 and 224GC05 from the GAB Marine Park continental slope exhibit significant "down-core variability related to variations in sediment composition. These cores may contain palaeo-environmental records associated with changes in the rate of terrigenous sediment (aeolian dust?) influx to the core sites during Quaternary climatic variations" (Harris et al., 2000, p.38).

"Core GC07 recovered only 13 cm of Quaternary age pinkish white mud overlying compact dark green grey sediments which blocked the core catcher. These sediments are sandy mud and muddy sand that include considerable plant and coal fragments. The combined bioclasts, plant material, and poorly sorted sediments are compatible with a marginal marine estuarine or deltaic environment. The observation of fractures perpendicular to bedding laminae in some dredged material, as well as the cellular appearance of associated oxide fragments, would suggest the probability of tectonically-induced fracture porosity" (Radke, 2000, appendix 4).

Black mud and mudstone were found at the base of the four cores (224GC06,07,08,09) taken from the deep holes in the Nullarbor Canyon, and in three dredges. Palynomorph assemblages recovered from the samples have been assessed to determine the ages of the sediments (Young et al., 2001). The results indicate that these muds are generally Late Cretaceous in age, and particularly of Late Campanian to Early Maastrichtian age on the continental slope, at the bottom of cores (GC) 06-09. The identification of different associations within samples suggests that reworked material is incorporated in the assemblage. The reworked material included sedimentary rocks of the following ages :

(1) Albian to Cenomanian (GC06, 08, 09, DR01 and 02);
(2) lowermost Santonian to lower-middle Campanian (GC06, 09 and DR03);
(3) Early Campanian (GC09).

The multiple reworking of deep water sediments from the large holes in the Nullarbor Canyon suggest either a tectonically active and/or an extensively eroded high energy shelf margin. However, the time period over which such events have transpired is poorly constrained. Only a thin veneer of recent ooze (about 2 cm) was recovered at the surface, indicating that recent sediments have been eroded or were not deposited in the holes. Expulsion of fluids along fault lines, or the actions of deep contour currents have been proposed as possible causes for keeping the holes clear of infilling sediment (Rollet, 2000).

5C2. Duntroon Sub-basin

The samples recovered from the Duntroon Sub-basin area were mainly collected from canyons. They consist mostly of Late Eocene and Early Oligocene wackestones, with minor Late Paleocene and Mid-Eocene organic-rich mudstone (66DR12; 66DR15; 66DR16) and Late Cretaceous sandstone (66DR11).

5C3. Abyssal Plain

This facies has not been sampled on the abyssal plain and cannot be groundtruthed.

5D. FACIES IIIC

5D1. Ceduna Terrace

Cores from Yalata Canyon on the continental slope east of the Ceduna Terrace (66GC19; Willcox et al., 1988) include terrigenous turbidites and debris-flow deposits beneath a blanket of pelagic calcareous ooze. Two cores on the eastern slope of the Ceduna Canyon (66GC20 and 66GC21) encountered shell hash, quartz sand and rock fragments overlain by a cover of Quaternary age pelagic calcareous ooze.

5D2. Eyre Terrace

Deposition on the continental slope from the Eyre Terrace is dominated by pelagic sedimentation (foram-nanno oozes), with only minor terrigenous input. Bioturbation decreases down slope (102GC01 to 102GC05), and between 2500-4000 m burrow mottling and sulphide-filled burrows are observed (Feary et al., 1993).

5D3. Abyssal Plain

This facies has not been sampled on the abyssal plain and cannot be groundtruthed.

5E. FACIES IIID

This facies has not been sampled and cannot be groundtruthed.

Comparisons between the echo facies types distinguished in the study area (Figure 7) and the sediment characteristics described above indicate that there is a good correlation between the main echo types mapped and the sediment types recovered (Table 2).

Table 2 : Echo-facies and Sediment types mapped in the GAB

Echo facies	Sediment type	Confidence level
Facies IA	Grey firm foraminiferal silt massively bedded at surface	Verified in the GAB Marine Park with 2 samples
Facies IB	Pinky-beige bioturbated nanno-foraminiferal ooze	Verified by 26 samples
Facies IIA	Pale brown sandy foram-nanno ooze; decreasing sand below the surface	Only verified in the GAB Marine Park with 1 sample
Facies IIB	Light-grey foram-nanno ooze with abundant bioturbation and large burrows with black infill	Verified by 18 samples
Facies IIIA	Thin veneer of pale brown sandy foram-nanno ooze overlying brown or grey mudstone	Verified by 11 samples
Facies IIIC	Thin veneer of foram-nanno ooze overlying debris-flow deposits	Verified by 14 samples
Facies IIID	Unknown	Not sampled

The shelfal areas in the GAB characterised by Echo Facies I ('undisturbed' sediment), are mainly covered by nannofossil-foraminifer ooze. The Eyre and Ceduna Terraces are also mainly covered by nannofossil-foraminifer ooze, but are more affected by bioturbation. These areas typically contain Echo Facies II ('disturbed' sediment). The continental slope is covered by middle Eocene to Oligocene calcareous rocks, and, in the "deep holes" and along escarpments, siliciclastic rocks of Late Cretaceous age. These sediment types are typically associated with moderate (Echo Facies IIIC) and extreme (Echo Facies IIIA) topography. Only one dredge sample is available from the two E-W elongated areas on the abyssal plain that were mapped as Echo Facies II ('disturbed' sediment). The dredge recovered several rock types, including laminated pelloidal grainstone/packstone, manganese-rich mudstone, manganese nodules and tholeiitic basalt. This diverse composition of the seabed indicates a complex depositional history and an environment subject to episodically fluctuating bottom current conditions and generally affected by low sedimentation rates and sea-floor spreading processes. The southern limit of the northern E-W ridge of Echo Facies II correlates with a recent interpretation of the Continent-Ocean Boundary (Sayers et al., 2001; location on Figure 7).

6. DISCUSSION AND CONCLUSIONS

The current study was mainly confined to the terraces, slope and abyssal plain of the GAB region. The shelfal area has been studied in detail by James et al. (2001).

6A. SHELF FACIES (JAMES ET AL., 2001)

James et al. (2001) have mapped the sedimentary facies and benthic habitats (Figure 10), and their link to modern oceanographic parameters (Figure 12) for the continental shelf in the GAB. Sediments are a mixture of latest Pleistocene intraclasts and Holocene biofragments on the shelf and upper slope in the Marine Park. In the GAB, active inshore sedimentation gives way to arrested mid-shelf sediment production, inhibited by the presence of a summer warm, oligotrophic saline water pool in the NW of the GAB (the GAB Plume). Seasonal upwelling generates local bryozoan-rich sedimentation across the outer shelf. The sediments down to 500 m depth are divided into 10 facies by James et al. (2001; Figure 10): Rhodolith Gravel (A), Quartzose Skeletal Sand and Gravel (T1-T2), Mollusc-Intraclast Sand (MR), Intraclast Sand (R), Intraclast-Mollusc Sand and Gravel (RM), Intraclast-Bryozoan Sand (RB), Bryozoan Sand and Gravel (B), Bryozoan-Intraclasts Sand (BR), Spiculitic Branching Bryozoan Mud (SB), and, Delicate Branching Bryozoan Sand and Gravel (BB).

The western GAB shelf is composed of “a large prograding wedge of fine-grained Quaternary carbonate sediment” (Feary and James, 1998; James et al., 2001). Inshore environments are locally rich in grasses with abundant modern carbonate production. The outer shelf is characterised by bryozoan growth down to 90 m water depth. Below this depth, however, the seafloor differs significantly and contains mainly fine sand and mud with only scattered bryozoans. This facies distribution is interpreted to reflect year-round downwelling (Feary and James, 1998; James et al., 2001). A combination of off-shelf transport and reduced in-situ bryozoan growth is confirmed by the nature of the Quaternary sediment wedge that downlaps onto the Eyre Terrace (Feary et al., 2000). The eastern GAB shelf is extremely wide and lies mostly between 50 and 110 m water depth, with an outer shelf zone up to 50 km wide. In this area, the influence of wind-generated and/or wave-generated currents is profound: sediments are almost all relics with virtually no modern sediment production/accumulation. Nevertheless, there is a prominent tongue of bryozoan-rich modern sediment that extends inshore some 60-70 km from the normal edge of the Bryozoan Sand Facies (Facies B of James et al., 2001), which traces the zone of summer up-welling onto the shelf" (James et al., 2001, p.565-566).

6B. UPPER SLOPE - ABYSSAL PLAIN FACIES (CURRENT STUDY)

The interpretation of an echo-type can differ according to its location on the margin and the environment. From the upper slope down to the abyssal plain, the distribution of acoustic facies indicates that the major sedimentary process in the GAB is the deposition of pelagic sediments. Reworking of sediments by both bottom currents and gravity flows is probably limited to submarine canyons.

Based on the distribution of echo facies, sediment characteristics and oceanographic parameters, the following interpretation of seabed character in the deep water GAB is proposed.

- Facies I represents areas of pelagic deposition with predominantly suspended sediment transport in a low energy depositional environment.

- Facies II occurs in areas with low gradient topography, such as the terraces and abyssal ridges, and broader channels, and is likely to represent: (1) Nanno-foraminiferal ooze with abundant bioturbation and few sandy turbidite layers on the terraces, and (2) outcrops on the abyssal plain subject to episodically fluctuating bottom current conditions and generally low sedimentation rates. It is possible that the more disturbed echo character observed on the terraces indicates that a degree of sediment transport, either by small-scale slumping or turbidite transport has occurred (or is occurring), like it is observed on the Otway and East Tasmanian margins (Passlow, 1997).

- Facies IIIA represents extreme topography found along steep slopes, scarps and in "deep holes" within canyons. The erosional nature of these areas has exposed older sedimentary rocks. Very little or no modern sedimentation is taking place in these high-energy environments. Facies IIIC represents moderate topography of scarps, ridges, canyons and rough slopes. A blanket of pelagic calcareous ooze in those areas overlies terrigenous turbidites and debris-flow deposits. Facies IIID represents lower relief topography on the continental slope and adjacent to canyons or at canyon heads. This facies has not been sampled but it may be similar to the slumped sediments feeding into canyon heads described by Von der Borch and Hughes-Clarke (1993).

Strong seasonal changes are known to affect waters along the southern Australian margin and affect carbonate sediment production and accumulation (James et al., 2001). "Summer heating in the NW of the GAB generates a pool of warm, oligotrophic, saline water (GAB plume) that drift slowly eastward across the shelf during summer and early autumn months. The eastern GAB is subject to summer coastal up-welling. The central GAB is an area of year-round down-welling. The slope in the western part is occupied by the oligotrophic, warm-water Leeuwin current in winter, whereas the shelf may be partially covered by cool, nutrient-rich waters of the Flinders Current during summer months" (James et al., 2001, p.566). Such shelf-following currents and/or strong up-welling would inhibit the movement of sediment down the slope and thus would explain the apparent lack of shelf-sourced sediment on the southern margin slope. Beside the Leeuwin Current, which is not a strong current and which is limited in its depth, it is possible that a lack of shelf sediment on the slope may be lack of recognition due to low sampling density and/or lack of accumulation on the outer shelf reducing supply to the slope. Figure 11 seems to support a lack of production as a cause for low sedimentation rates. Active inshore sedimentation gives way to arrested mid-shelf sediment production, inhibited by the presence of the GAB plume. The blanket of pelagic ooze encountered on canyon floors indicates that these are currently not actively transporting sediments. However, the Topgallant Canyon (Figure 2) on the eastern edge of the Ceduna Terrace, may be active as indicated by outcropping of Middle Eocene to Late Oligocene calcareous rocks and Late Cretaceous siliciclastic rocks. During intervals of lower sea level in the Neogene and the Quaternary, the canyons were very likely active. Abyssal plain sediments off southern Australia are composed of fine grained shelf sands, aggregates and calcreted lithoclasts. Canyons were the probable conduits for these sediments, given the absence of any evidence of down slope sediment transport in the cores collected.

The role of geological inheritance on the geomorphology and sediment facies in the GAB is quite important. For instance, the inflection of the continental margin in the western GAB may be an expression of older structural boundaries that affect the present shelf morphology. Deposition of a thick and regionally extensive progradational delta in the Late Cretaceous produced a broad shelf zone in the GAB that has subsequently subsided to become the Ceduna Terrace. The carbonate-dominated Tertiary shelf margin is located inboard of this relict Late Cretaceous shelf margin. The correspondence of numerous well-developed large-scale canyons on the slope to areas of onshore crystalline shield rocks is thought to be related palaeo-drainage systems on these cratons and/or tectonically active fault zones across these cratons which may have offshore expression and controlled the location of canyons.

7. ACKNOWLEDGMENTS

The authors wish to thank Jennifer Totterdell and Vicki Passlow for editing and reviewing a draft of this report, Joe Mifsud for finalizing the figures, Irina Borissova and Andrea Cortese for helping in technical issues (eg GIS).

8. REFERENCES

Buchanan, C., 2000. Geoscience Australia 30 arc second digital bathymetry of the Australian Region.

Damuth, J.E., 1973. The Western Equatorial Atlantic: Morphology Quaternary sediments, and climatic cycles. PhD Thesis, Columbia University, Palisades, N.Y. 602pp (unpubl.).

Damuth, J.E., 1975. Echo character of the western equatorial Atlantic floor and it's relationship to dispersal and distribution of terrigenous sediment. Marine Geology, 18, 17–45.

Damuth, J.E., 1978. Echo character of the Norwegian-Greenland sea: relationship to Quaternary sedimentation. Marine Geology, 28, 1-36.

Damuth, J.E., 1980. Use of high frequency (3.5 - 12 kHz) echograms in the study of near bottom sedimentation processes in the deep sea. Marine Geology*,* 38, 51-75.

Everingham, I.B., 1968. Seismicity of western Australia. Department of National Development, BMR, Geology and Geophysics, Report 132.

Feary, D.A. and James, N.P., 1998. Seismic stratigraphy and geological evolution of the Cenozoic cool-water Eucla Platform, Great Australian Bight. AAPG Bulletin, 82 (5A), 792-816.

Feary, D.A., Hine, A.C., Malone, M.J., et al., 2000. Proceedings of ODP, Initial Reports, 182: College Station, TX (Ocean Drilling Program).

Feary, D.A., Birch, G., Boreen, T., Chudyk, E., Lanyon, R., Petkovic, P. and Shafik, S., 1993. Scientific post-cruise report – R/V Rig Seismic cruise 102 – Geological sampling in the Great Australian Bight. Geoscience Australia Record 1993/18, 128 pp.

Fellows, M., in prep., Gravity Cores collected during the GABSEEPS survey (Geoscience Australia's survey S231) on the R/V Franklin in collaboration with CSIRO Exploration and Mining (in Binns, R.A. et al., in prep.).

Flood, R., 1980. Deep Sea Sedimentary Morphology: Modelling and interpretation of echo-sounding profiles. Marine Geology, 38, 77-92.

Foucault, A. and Raoult, J.F., 1988. Dictionnaire de géologie, 3ème édition, Ed. Masson.

Geological Survey of Western Australia, 1990. Geology and Mineral Resources of Western Australia, Memoir 3, Department of Mines Western Australia.

Harris, P., Radke, B., Smith, A., Glenn, K., Rollet, N., Exon, N., and Passlow, V., 2000. Marine geological data collected during Southern Surveyor Voyage 01/00: Eastern Bass Strait and Great Australian Bight, Geoscience Australia Research Cruise No. 224. Geoscience Australia Record 2000/43, pp.83.

Hill P.J., Rollet, N. and Symonds, P., 2001. Seafloor mapping of the South-east Marine Region and adjacent waters - AUSTREA-1 final report: Lord Howe Island, south-east Australian margin (includes Tasmania and South Tasman Rise) and central Great Australian Bight, Geoscience Australia Record 2001/08 (Geoscience Australia survey 222), pp137.

Hill, P.J., Rollet, N., Rowland, D., Calver, C. and Bathgate, J., 2000. Seafloor mapping of the South-east Region and adjacent waters - AUSTREA-1 (survey 222) Geoscience Australia report: Lord Howe Island, south-east Australian margin and central Great Australian Bight, Geoscience Australia Record 2000/06, pp76.

Hollister, C.D., 1967. Sediment distribution and deep circulation in the Western North Atlantic. PhD Thesis, Columbia University, Palisades, NY (unpubl.).

James, N.P., Bone, Y., Collins, L.B., and Kyser, T.K., 2001. Surficial sediments of the Great Australian Bight: facies dynamics and oceanography on a vast cool-water carbonate shelf. Journal of Sedimentary Research, vol. 71, No 4, 549-567.

James, N.P., Collins L.B., Bone, Y., and Hallock, P., 1999. Sub-tropical carbonates in a temperate realm: modern sediments on the southwest Australian Shelf. Journal of Sedimentary Research, vol.69, 1297-1321.

James, N.P., Boreen, T.D.., Bone, Y., and Feary, D.A., 1994. Holocene carbonate sedimentation on the west Eucla Shelf, Great Australian Bight: a shaved shelf. Sedimentary Geology, 90, 161-177.

Kennett, J., 1982. Marine Geology, Prentice-Hall, Inc., Englewood Cliffs, N. J. 813p.

Krassay, A.A. and Totterdell, J., in prep. Seismic stratigraphy of a large, Cretaceous shelf-margin delta complex, offshore southern Australia.

McIlreath, I.A. and James, N.P., 1984. Carbonate slopes. In Walker, R.J., (ed), Facies Models. Geoscience Canada Reprint Series, Second Edition, 1, 245-258.

Moore, A.M.G., Stagg, H.M.J. and Norvick, M.S., 2000. Deep water Otway Basin: a new assessment of the tectonics and hydrocarbon prospectivity. APPEA Journal, 40 (1).

Norvick, M.S. and Smith, M.A., 2000. The separation of Australia from Antarctica and its stratigraphic signal in southern Australian basins. Geological Society of Australia, Abstract No. 59, 15th Australian Geological Convention, Sydney, July 2000, 365.

Passlow, V., 1997. Slope sedimentation and shelf to basin sediment transfer: a cool-water carbonate example from the Otway margin, southeastern Australia. In James, N.P. and Clarke, J.A.D. (Eds) Cool-Water Carbonates. SEPM Special Publication No. 56, 107-125.

Petkovic, P., Brett, J., Morse, M.P., Hatch, L., Webster, M.A. and Roche, P., 1999. Gravity, magnetic and bathymetry grids from levelled data for southwest Australia - Great Australian Bight. Geoscience Australia Record 1999/48.

Radke, B., 2000. Sedimentology of surficial sediments collected on RV Southern Surveyor Cruise SS 01/00. Unpublished.

Radke, B., 2001. Description of Gravity Cores from the R.V. Franklin Cruise FR0101 (Geoscience Australia 231), Great Australian Bight. Unpublished.

Rollet, N. and Glenn, K., 2000. Scientific post-cruise report - R/V Southern Surveyor cruise SS001, Leg 3, Geoscience Australia Record 2000/224.

Rollet, N., 2000. Gapping holes found by Bight Marine Park research, AUSGEO News, Geoscience Australia, June/July 2000, No58.

Sayers, J., Symonds, P., Direen, N.G. and Bernardel, G. 2001. Nature of the continent-ocean transition on the non-volcanic rifted margin of the central Great Australian Bight. *In*: Wilson, R.C.L., Whitmarsh, R.B., Taylor, B. and Froitzheim, N. 2001. Non-Volcanic Rifting of Continental Margins: A Comparison of Evidence from Land and Sea. Geological Society, London. Special Publications, 187, 51-77.

Totterdell, J.M., Blevin, J.E., Struckmeyer, H.I.M, Bradshaw, B.E., Colwell, J.B. and Kennard, J.M., 2000. A new sequence framework for the Great Australian Bight: Starting with a clean slate. APPEA Journal, 40 (1), 95-118.

Turekian, K. K., 1968, Oceans. Prentice - Hall Inc. pp120.

Vanney, J.R. and Stanley, D.J., 1983. Shelfbreak physiology: an overview. SEPM Special Publication No. 33, p. 1-24.

Von der Borch, C.C. and Hughes-Clarke, 1993. Slope morphology adjacent to the cool-water carbonate shelf of South Australia: GLORIA and Seabeam imaging. Australian Journal of Earth Sciences, 40, 57-64.

Von der Borch, C.C., 1968. Southern Australian submarine canyons: their distribution and ages, Marine Geol., 6, 267-279.

Willcox, J.B., Stagg, H.M.J., Davies, H.L. and others, 1988. Rig Seismic research cruises 10 and 11: geology of the Central Great Australian Bight region. Bureau of Mineral Resources, Geology and Geophysics, Report 286.

Whitmore, G.P. and Belton, D.X., 1997. Sedimentology of the South Tasman Rise, south of Tasmania, from 'groundtruthed' acoustic facies mapping. Australian Journal of Earth Sciences 44, 677-688.

Young, M., 2001. Fossil Dinoflagellates as age indicators from deep marine holes in the Great Australian Bight Benthic Protection Zone, South Australia, Geoscience Australia report (draft).

FIGURE CAPTION

Figure 1. Location map and bathymetry for the SSW region.

Figure 2. Location of cratons and basins in the SSW region.

Figure 3. Geomorphology of the SSW Region.

Figure 4. Seismicity of the SSW region overlain on geological provinces.

Figure 5. Location of data sets used for this study.

Figure 6a. Echo-types recorded during AUSTREA-1 Cruise (Hill et al., 2000) used to define acoustic facies in the GAB.

Figure 6b. Echo-types recorded during the Geoscience Australia seismic survey 199 used to define acoustic facies in the GAB.

Figure 7. Line-based echo-character interpretation and interpreted echo-facies of surface sediments in the GAB.

Figure 8. Confidence levels on acoustic facies interpretation in the GAB based on data quality and density of 3.5 kHz records and sediment samples.

Figure 9a. Echo type IA and IB with seismic correlation.

Figure 9b. Echo type IIA and IIB with seismic correlation.

Figure 9c. Echo type IIIA and IIIB with seismic correlation.

Figure 9d. Echo type IIID with seismic correlation.

Figure 10. Sedimentary facies with biological discrimination for shelfal areas in the GAB, after James et al. (2001).

Figure 11. Carbonate sediment production in the GAB according James et al (2001).

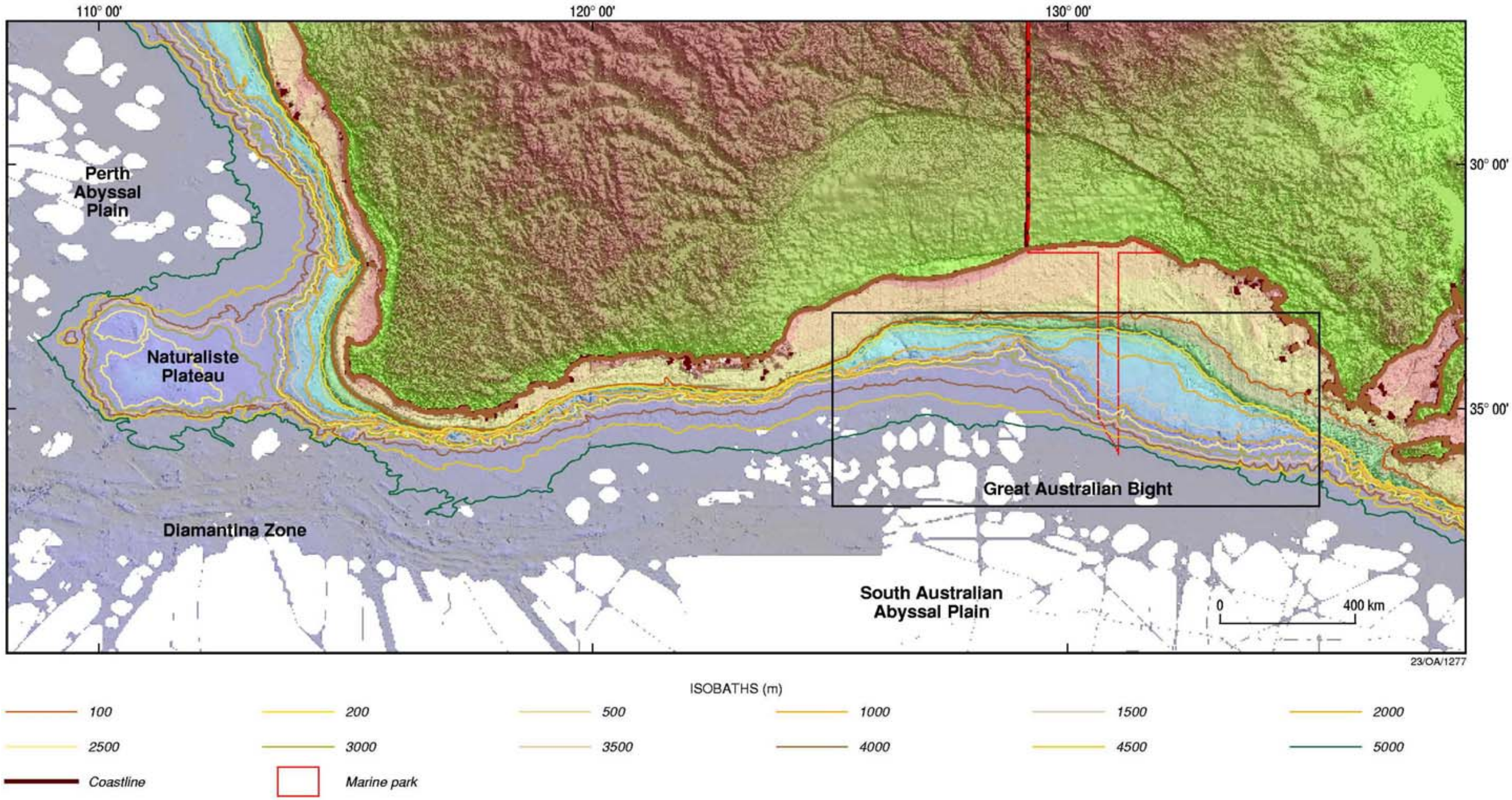


Figure 1. Location map and bathymetry for the SSW region.

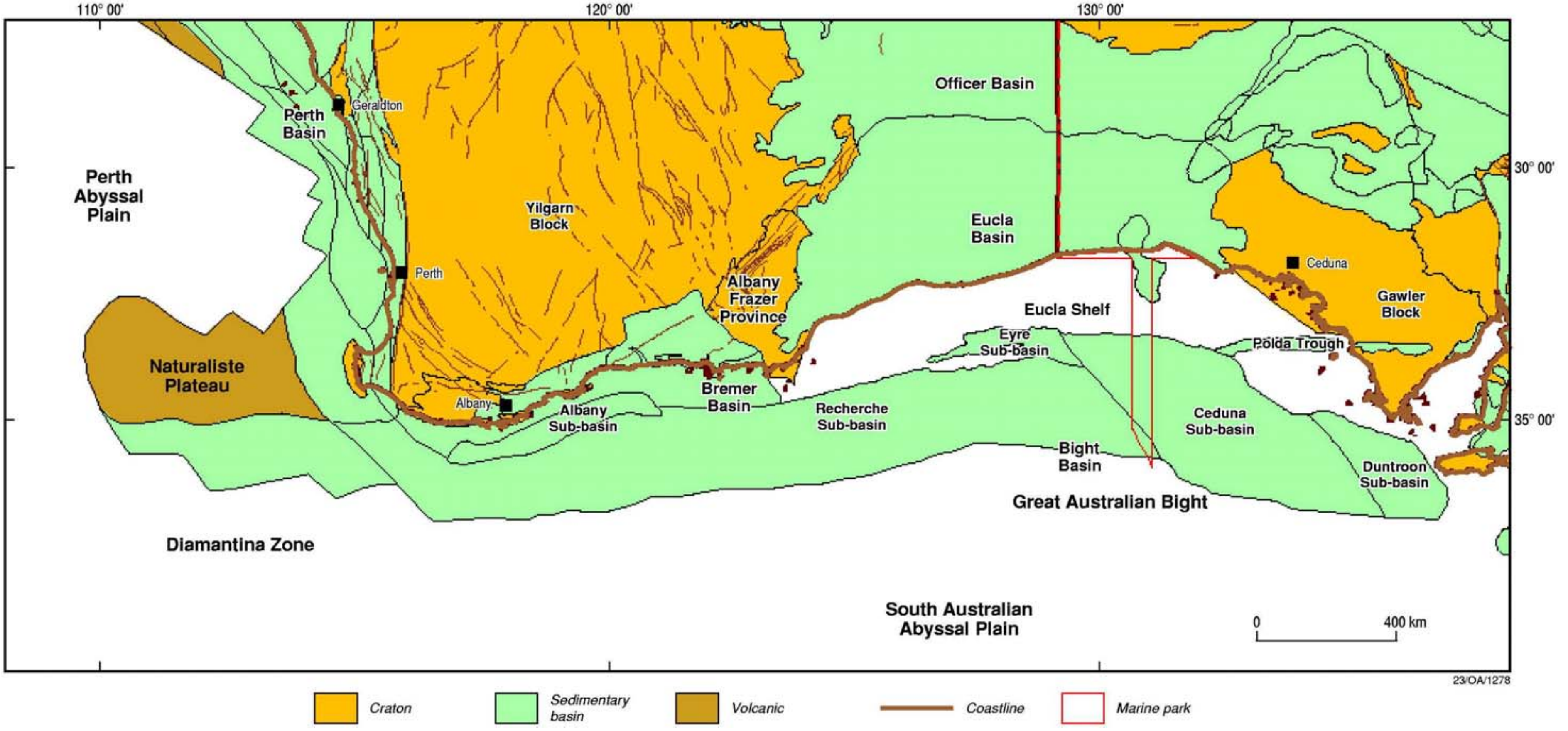


Figure 2. Location of cratons and basins in the SSW region.

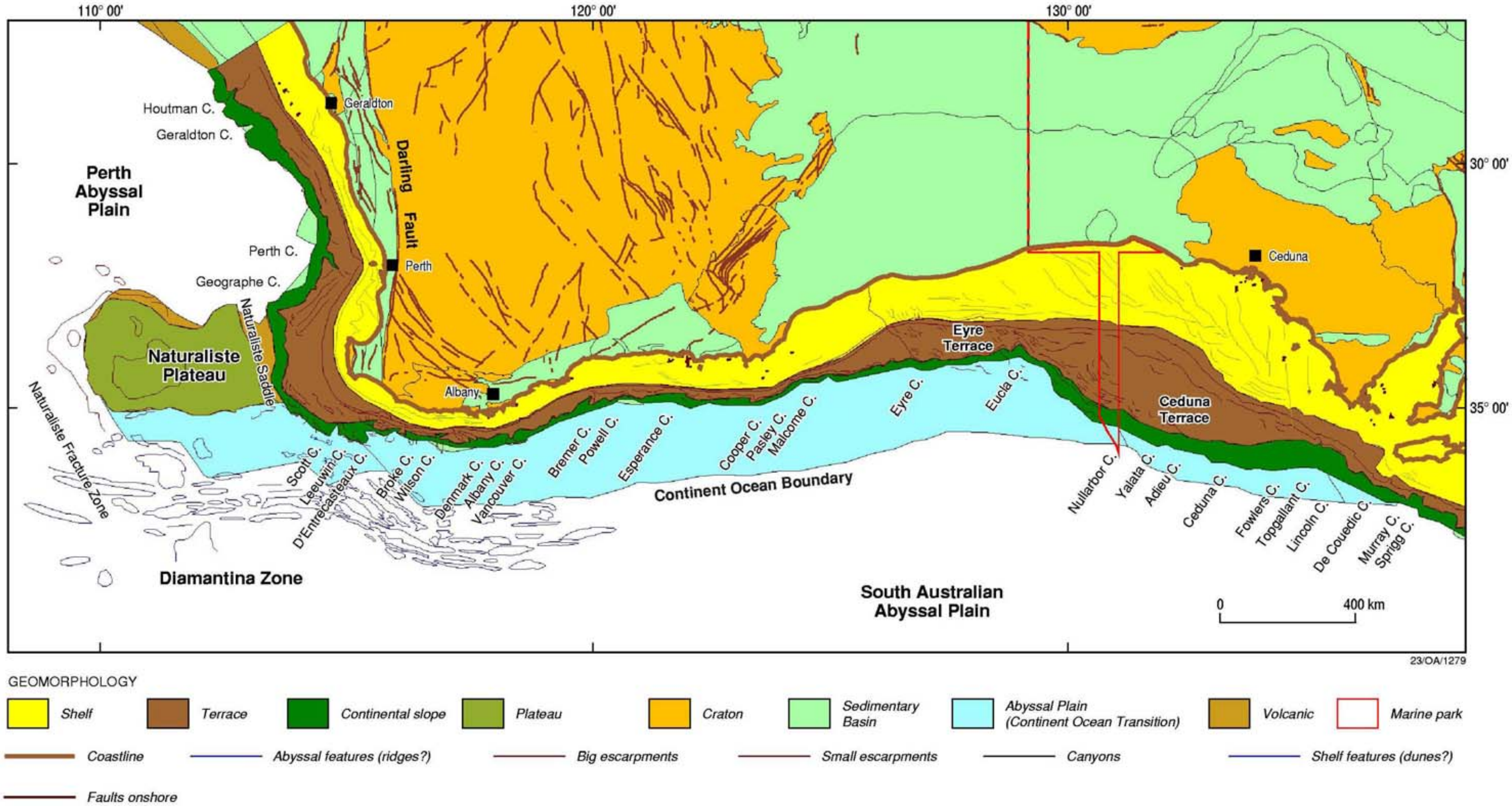


Figure 3. Geomorphology of the SSW Region.

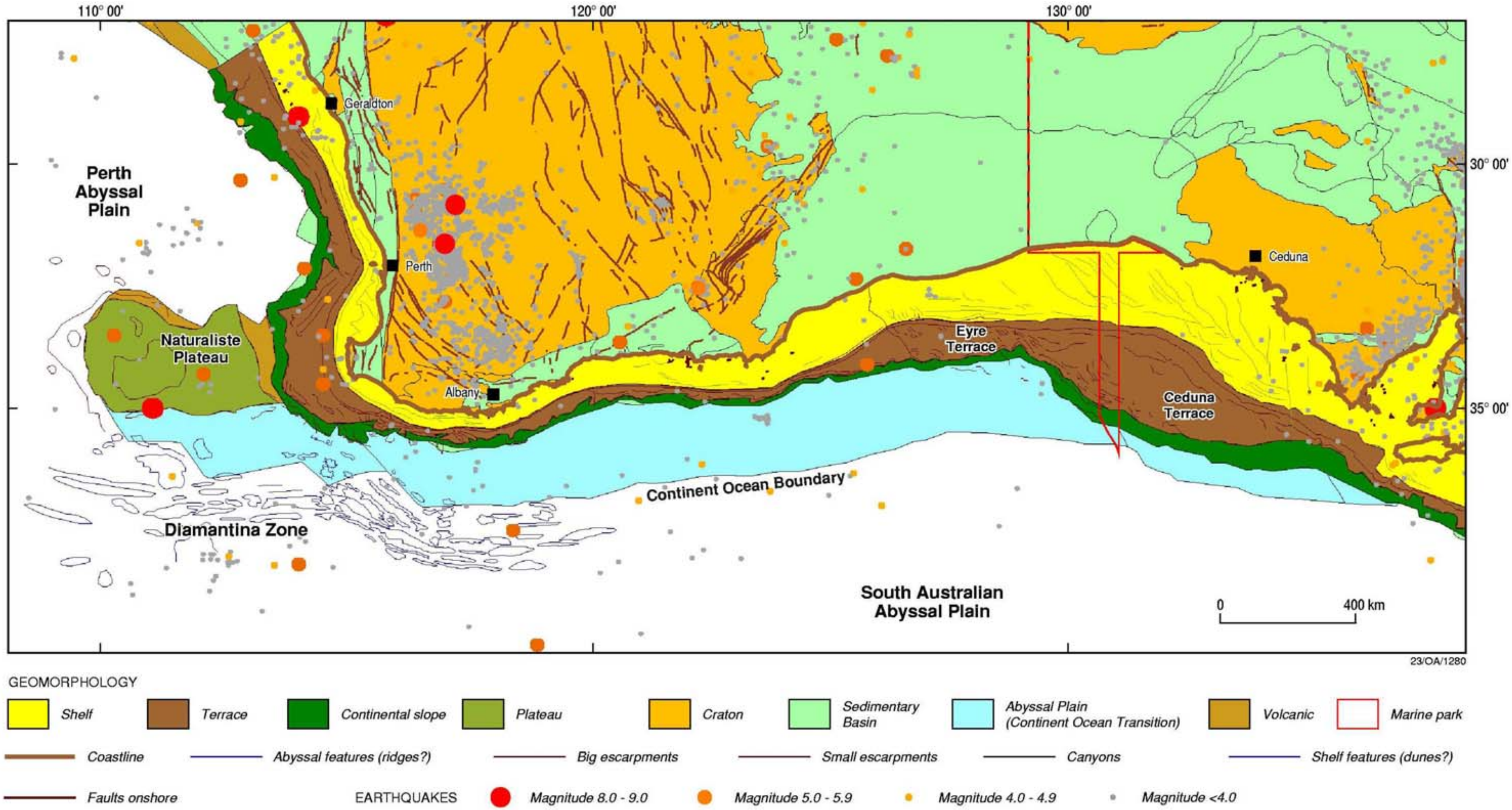


Figure 4. Seismicity of the SSW region overlain on geological provinces.

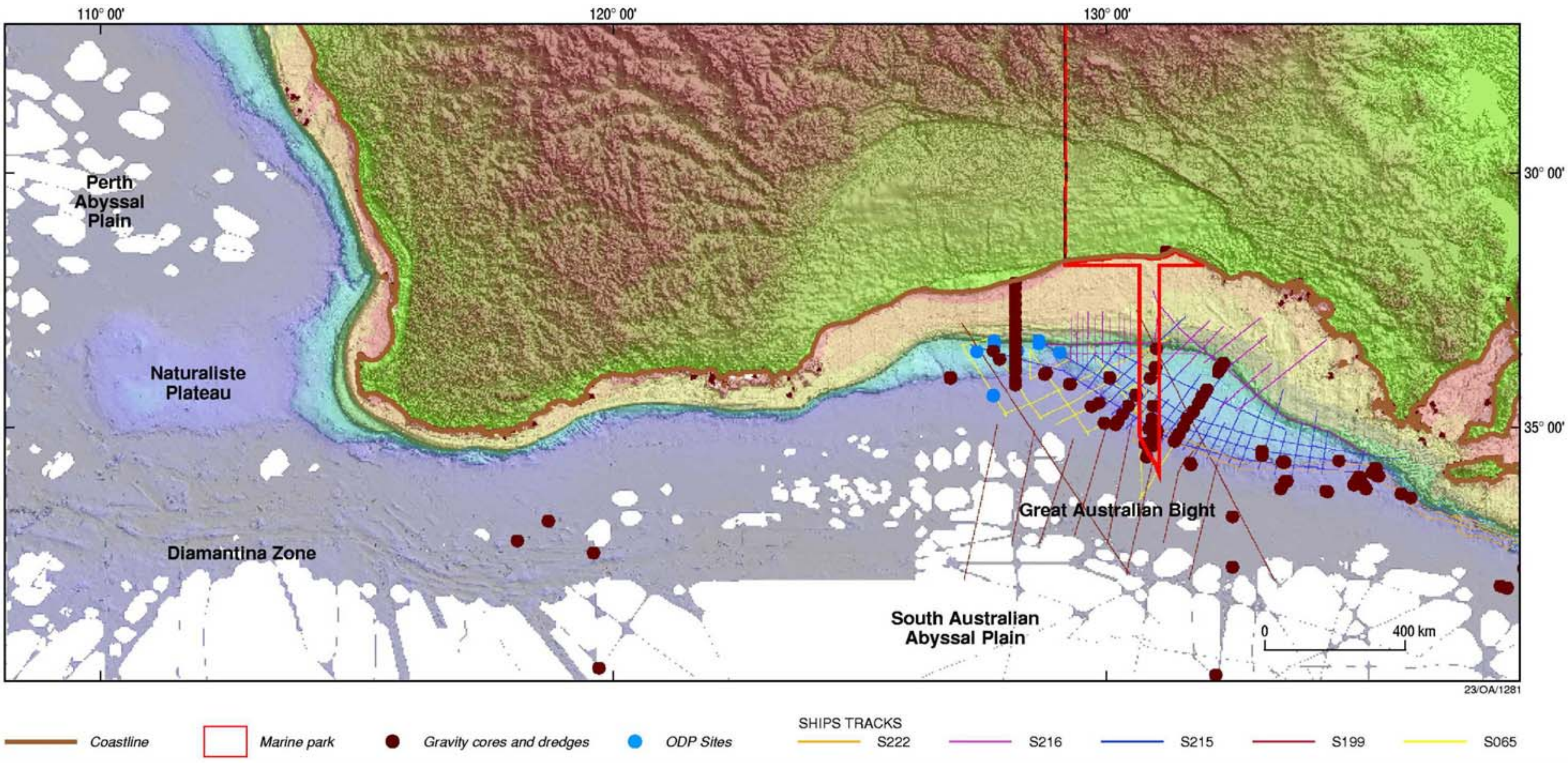


Figure 5. Location of data sets used for this study.

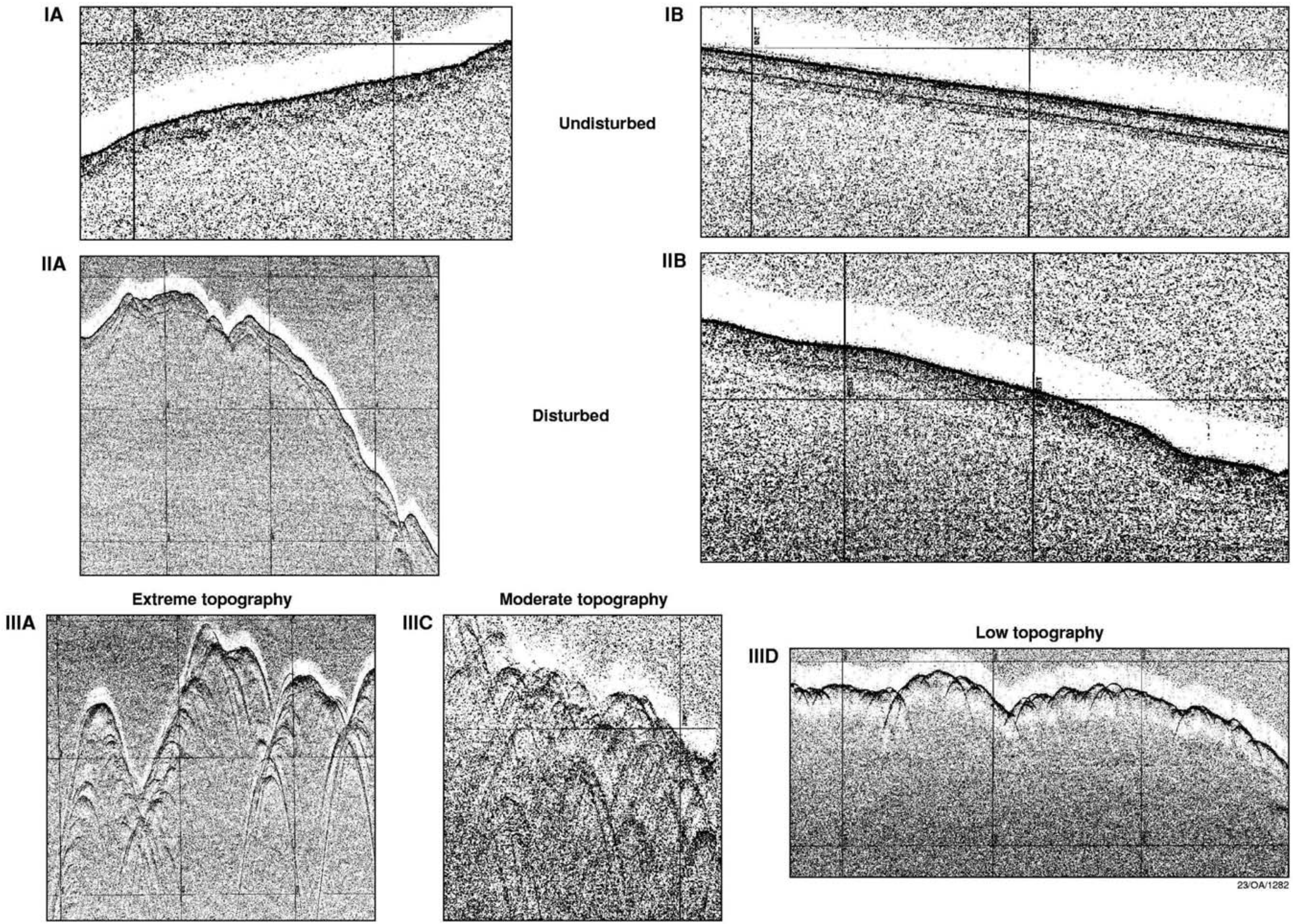


Figure 6a. Echo-types recorded during AUSTREA-1 Cruise (Hill et al., 2000) used to define acoustic facies in the GAB.

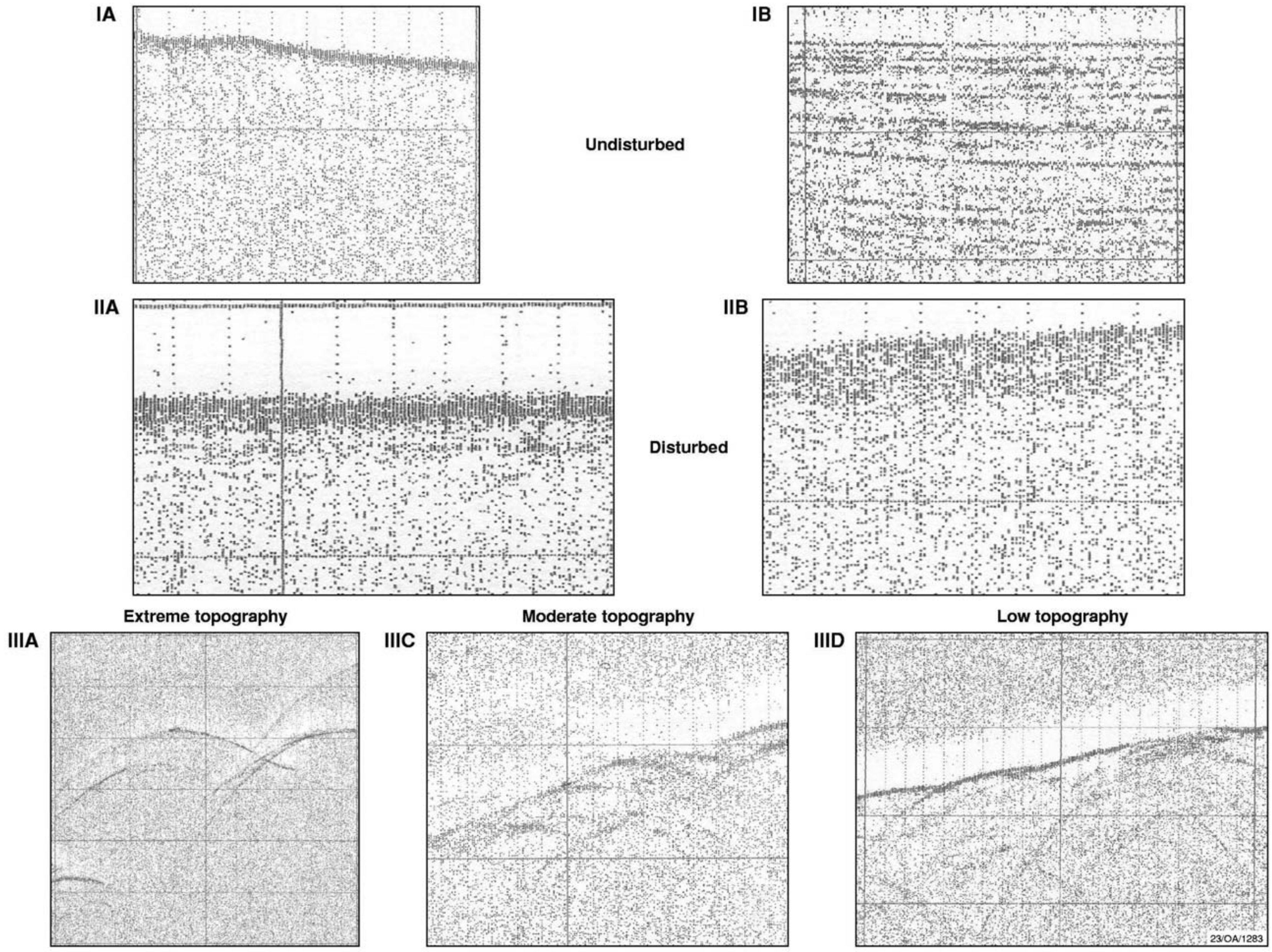


Figure 6b. Echo-types recorded during the GEOSCIENCE AUSTRALIA seismic survey 199 used to define acoustic facies in the GAB.

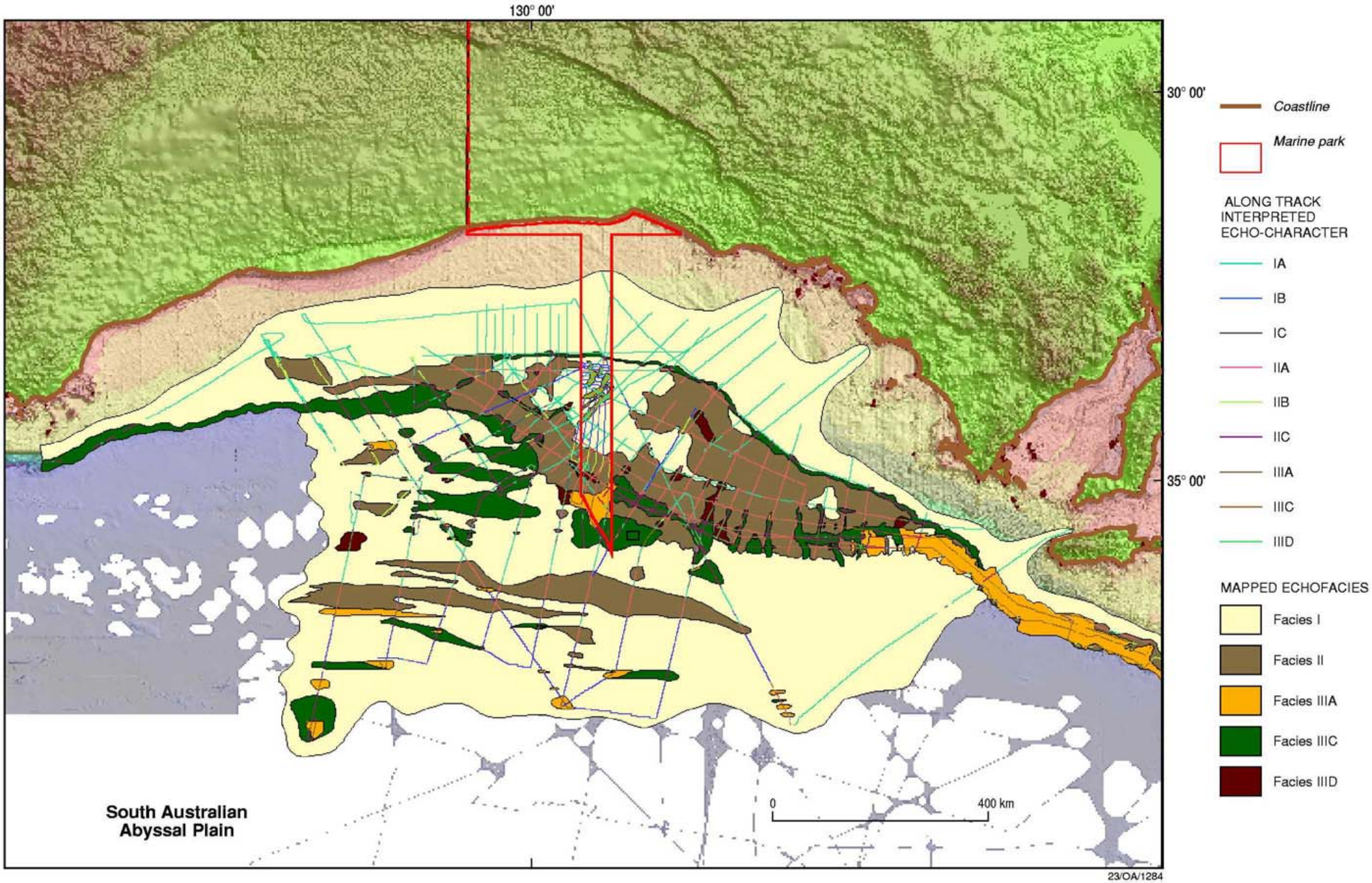


Figure 7. Line-based echo-character interpretation and interpreted echo-facies of surface sediments in the GAB.

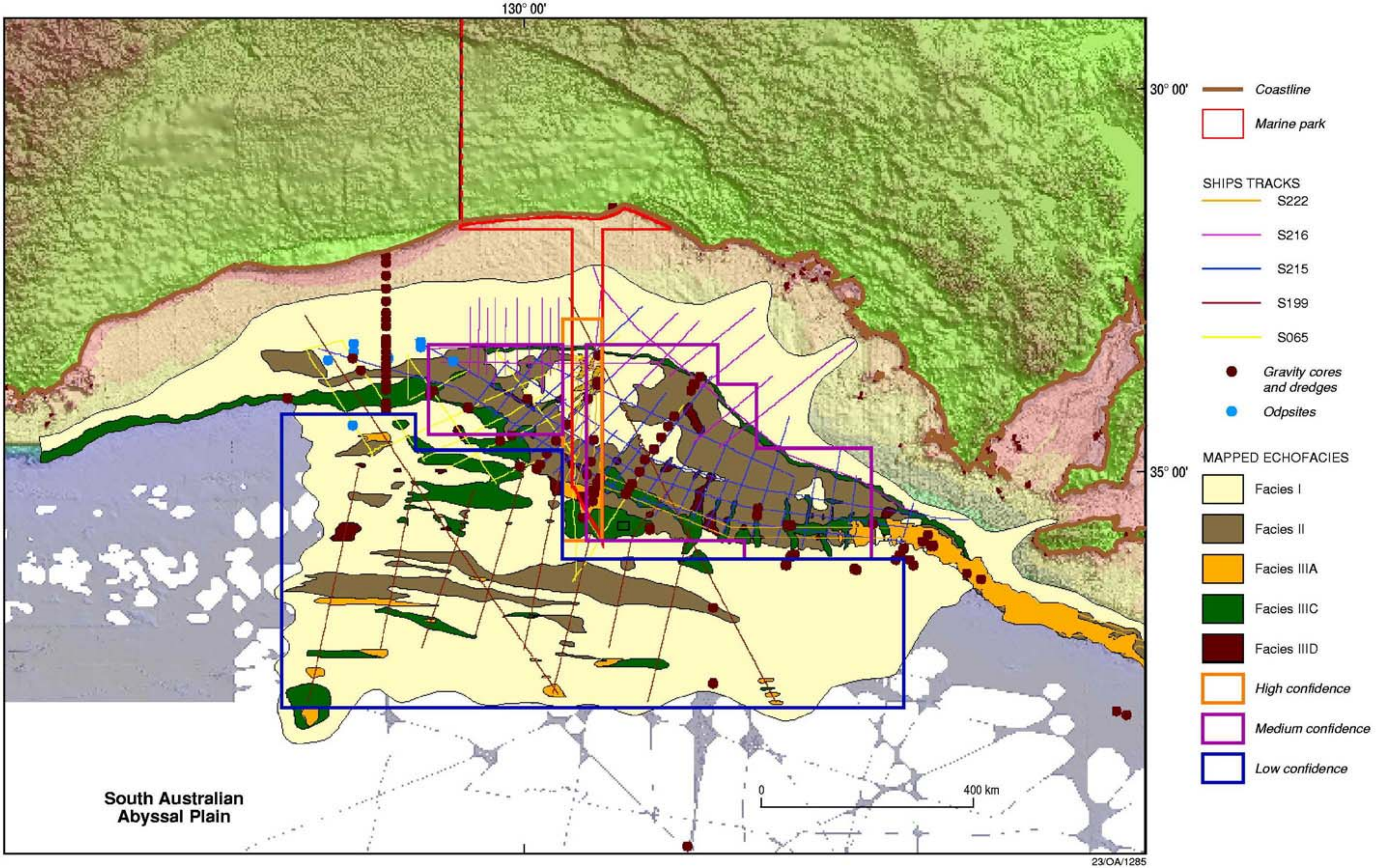


Figure 8. Confidence levels on acoustic facies interpretation in the GAB based on data quality and density of 3.5 kHz records and sediment samples.

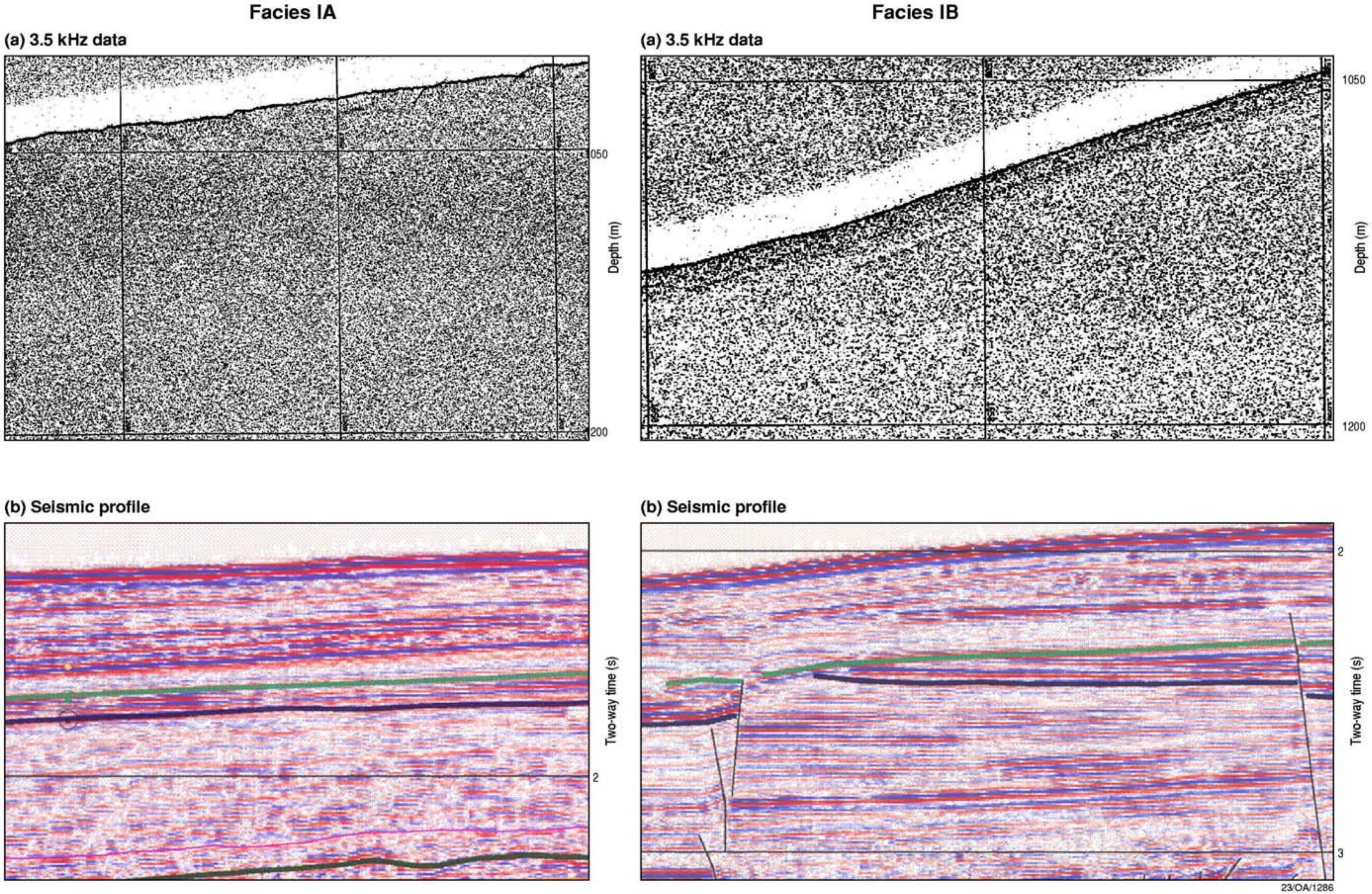


Figure 9a. Echo type IA and IB with seismic correlation.

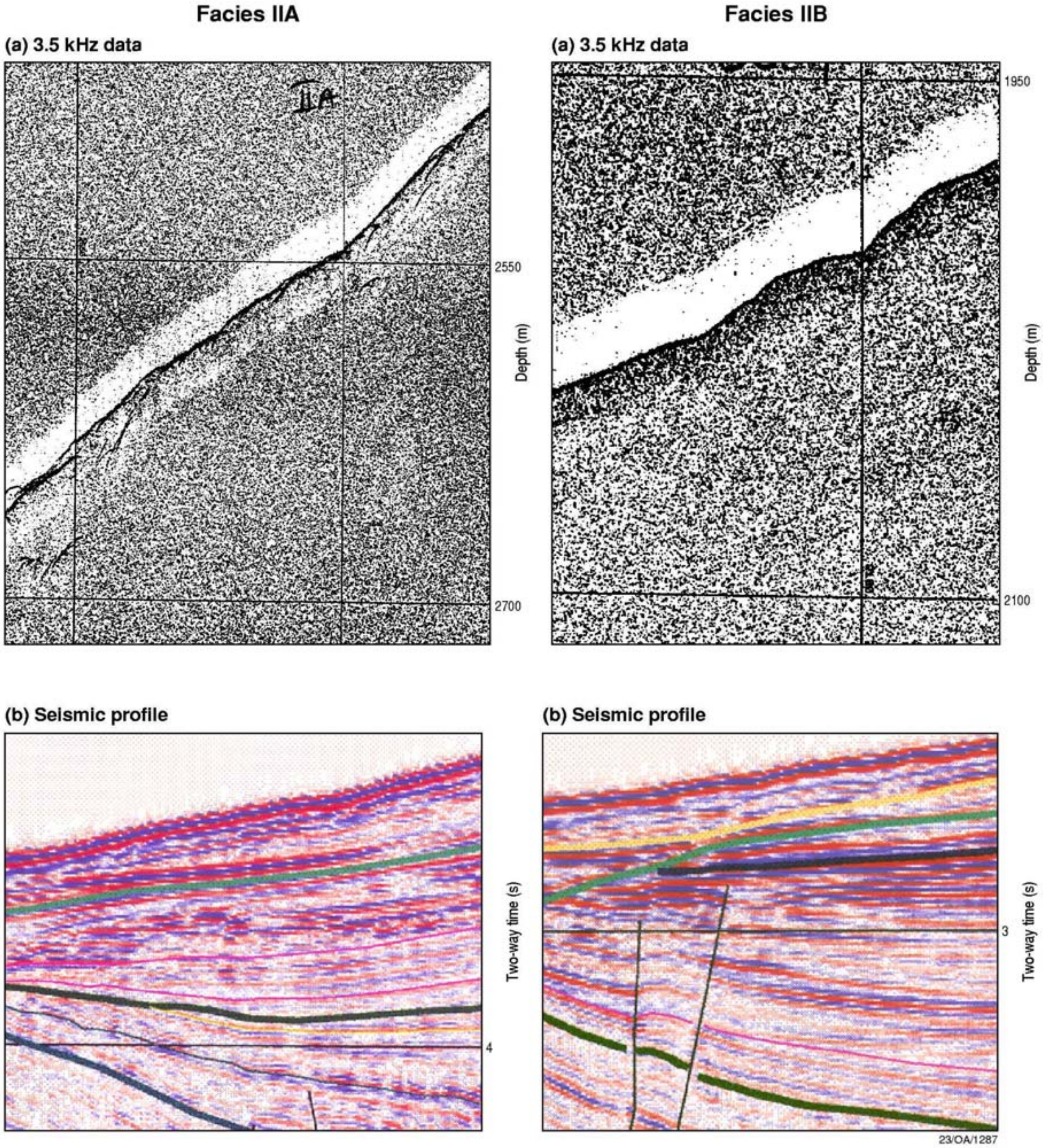


Figure 9b. Echo type IIA and IIB with seismic correlation.

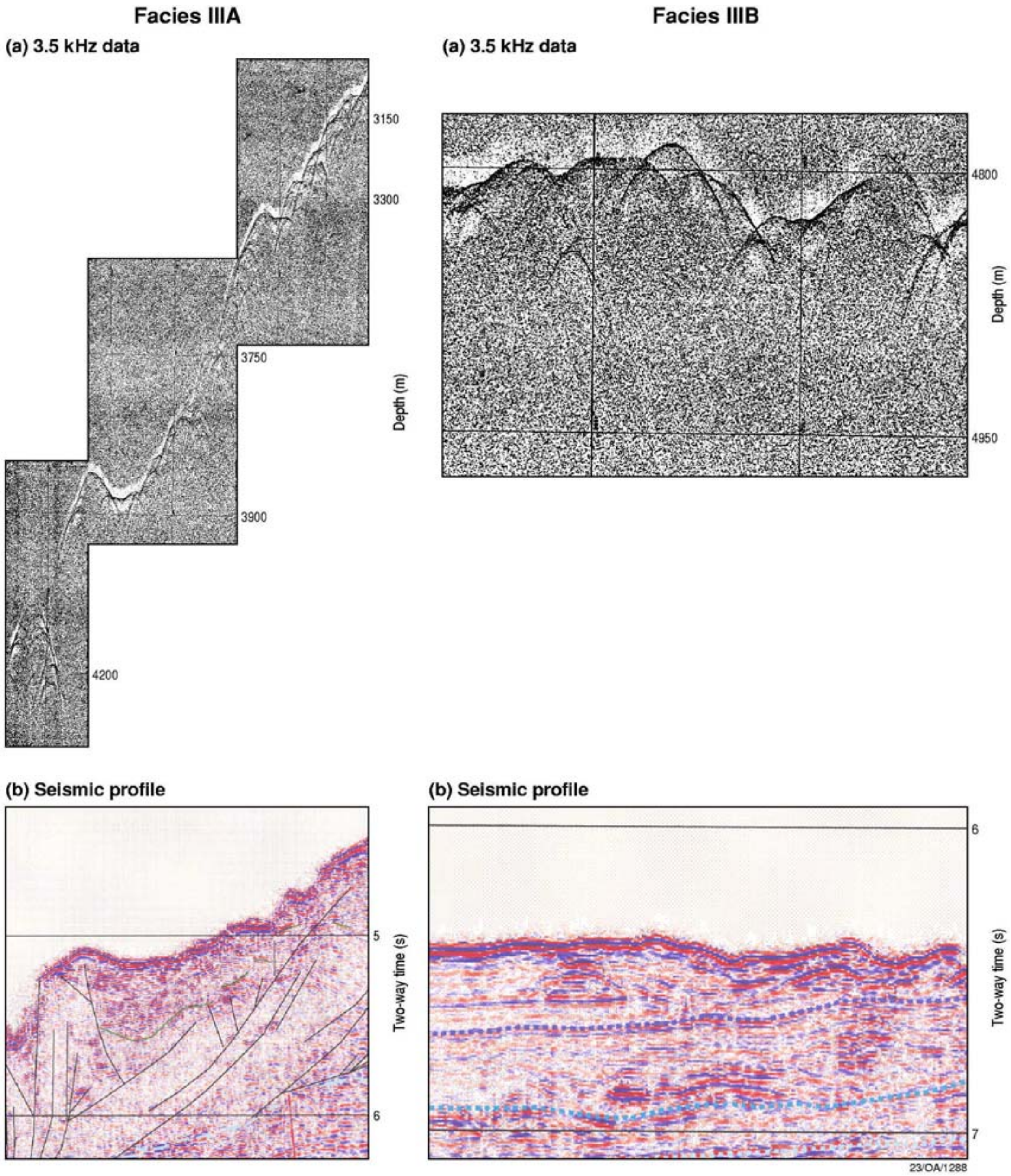


Figure 9c. Echo type IIIA and IIIB with seismic correlation.

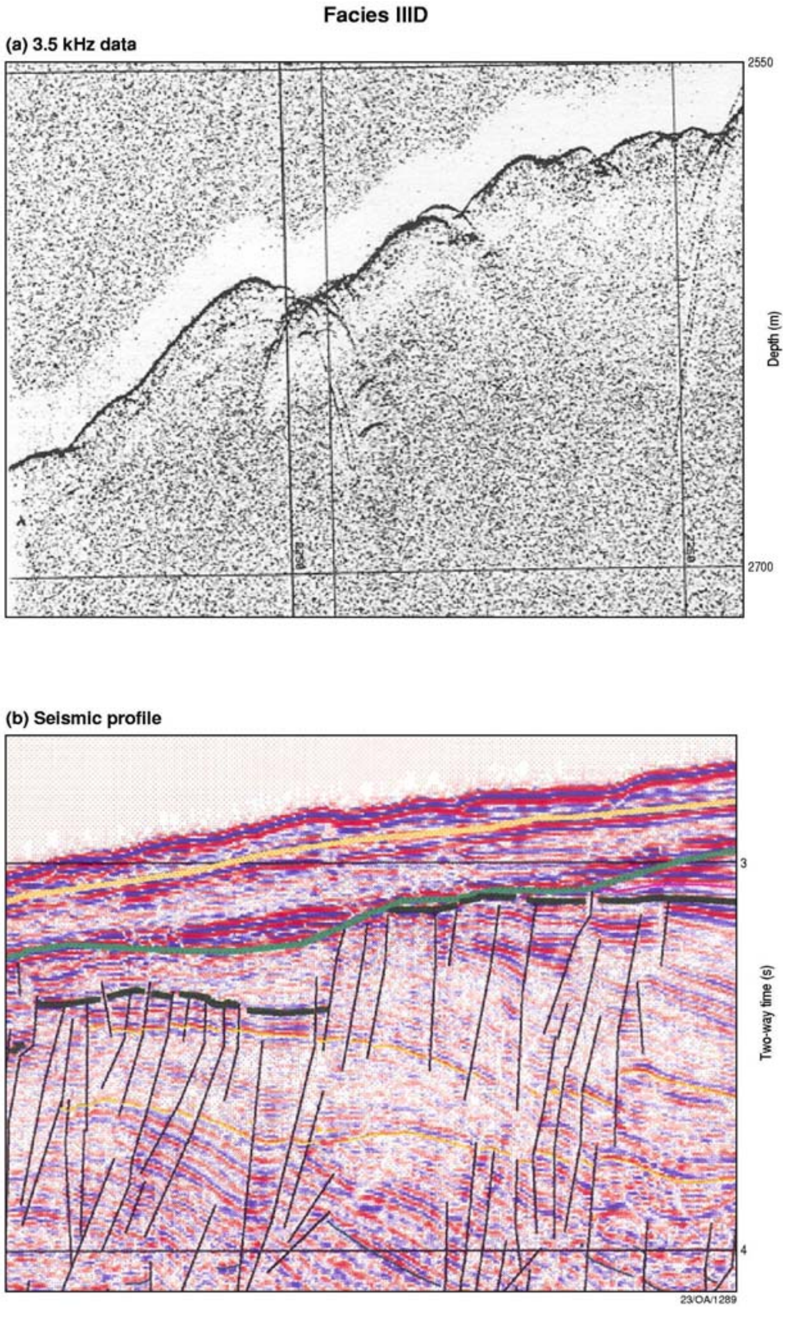


Figure 9d. Echo type IIID with seismic correlation.

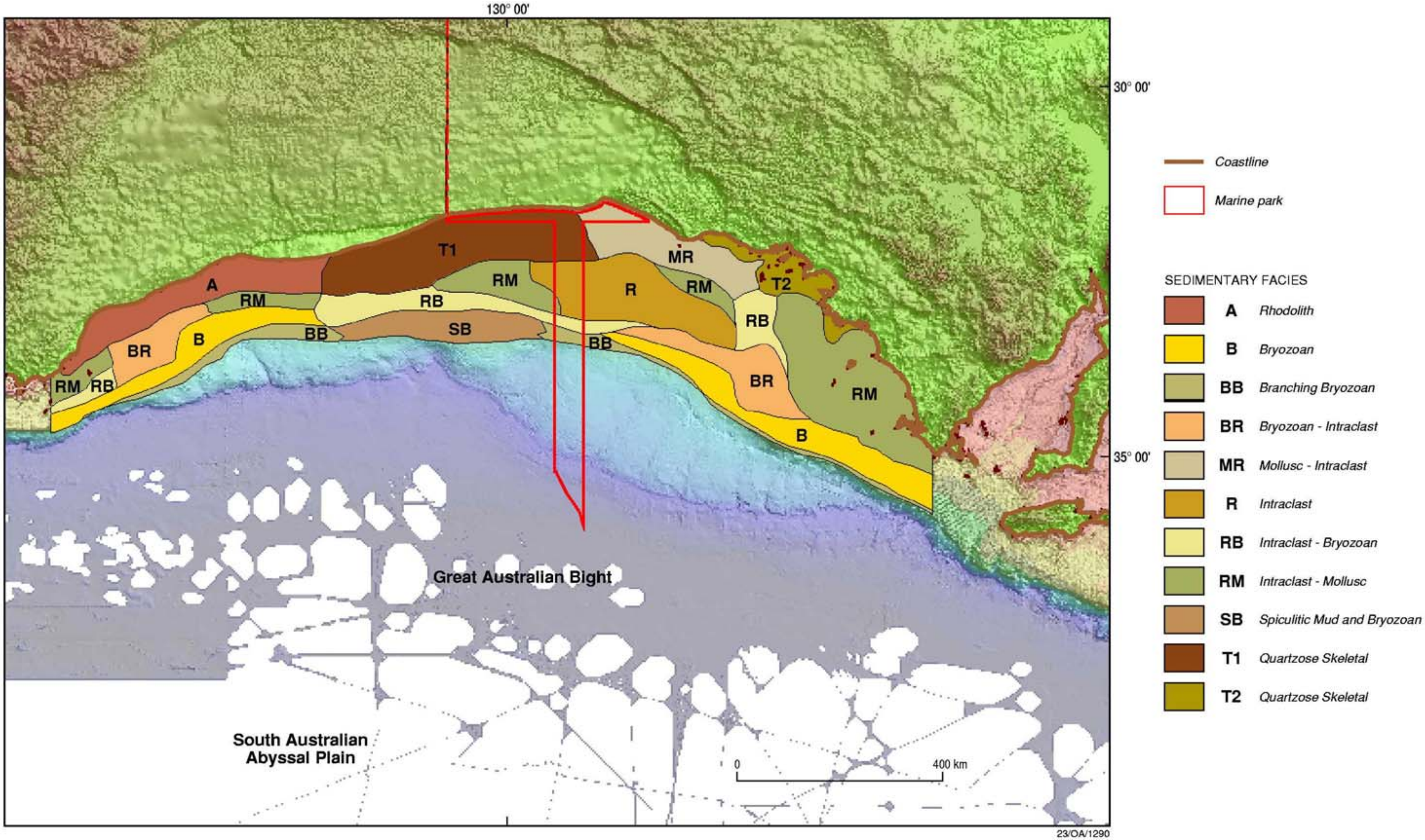


Figure 10. Sedimentary facies with biological discrimination for shelfal areas in the GAB, after James et al. (2001).

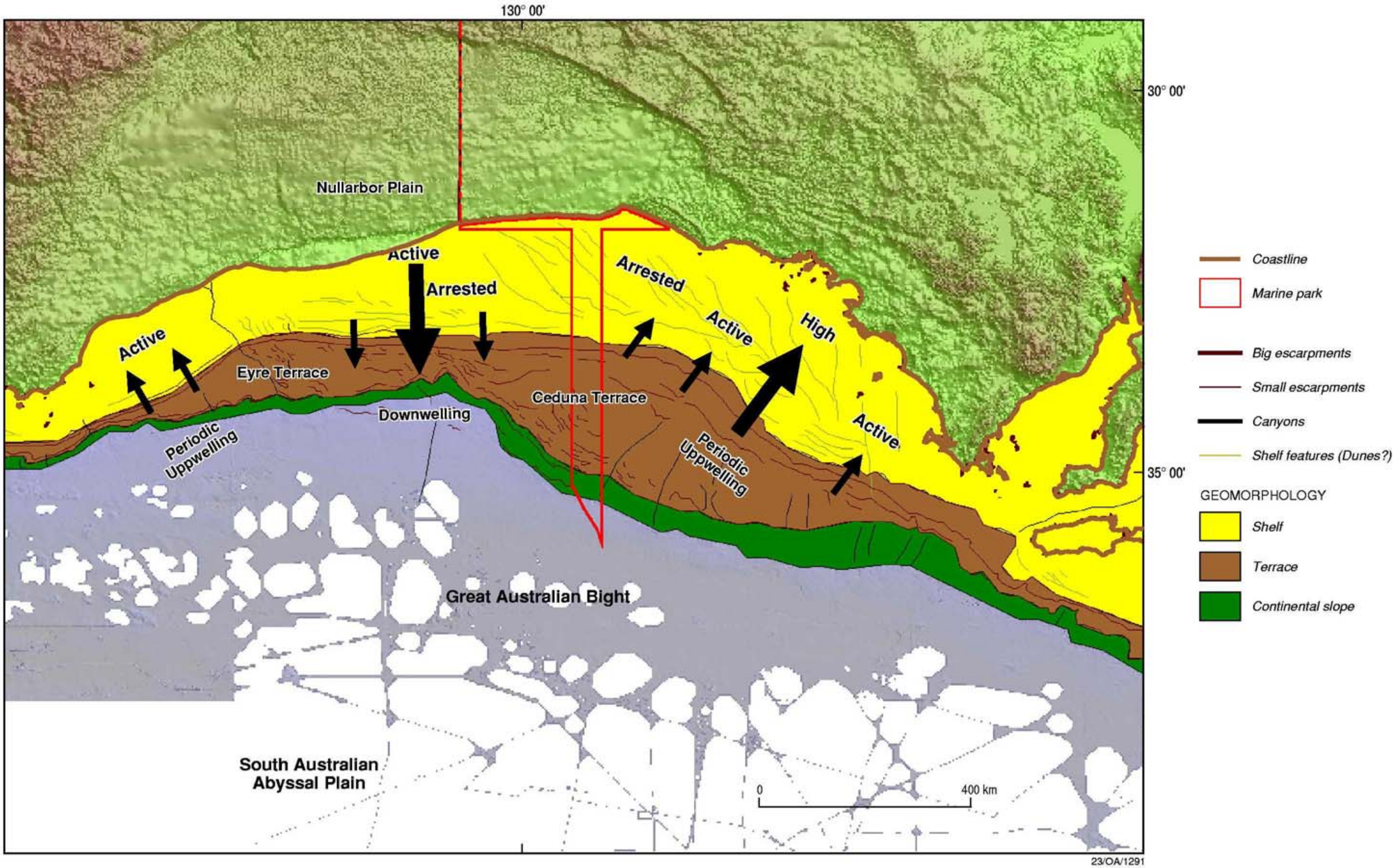


Figure 11. Carbonate sediment production in the GAB according James et al (2001).