Chapter 1

An overview of the continental shelves of the world

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This Memoir explores the variability and controlling processes of sedimentation, morphology and tectonics on the world’s continental shelves, with emphasis on their evolution during the last glacio-eustatic cycle. This work builds on some earlier volumes on continental shelves, notably those by Trumbul et al. (1958), Boillot (1978), De Batist & Jacobs (1996), Nittouer et al. (2007) and Li et al. (2012) among others, although there has not been a previous comprehensive global-scale synthesis.

The subject material presented here was developed in several International Geoscience Programmes (formerly the International Geological Correlation Programme, IGCP) concerned with shelves. Project 396 ‘Continental Shelves in the Quaternary’ (1996–2000) was followed by IGCP 464 ‘Continental Shelves during the Last Glacial Cycle: Knowledge and Applications’ (2001–2007) and finally by IGCP 526 ‘Risks, Resources and Record of the Past on the Continental Shelf’ (2007–2011). In this Memoir, 23 papers are devoted to the description of different aspects of shelves from all seven continents and which are representative of the world’s shelves. However, there remain significant gaps in our compilation. A glance at Figure 1.1 indicates the sparse coverage of data, particularly using modern techniques of investigation, for Africa, Russia and the Polar regions. However, new data are presented from some frontier provinces, such as Myanmar, Morocco and Ecuador.


Why study continental shelves?

The continental shelf is the part of the seafloor most used by society. Although shelf areas account for little more than 8% of the marine areas of the world, they are the part of the sea most used for navigation, recreation, fishing and aquaculture, mineral exploration, waste disposal and, increasingly in the future, in the production of renewable energy from wave, tidal currents and wind (Barrie & Conway 2014). It is worth noting that the continental shelf in geological terms (and, therefore, in this volume) differs from the ‘continental shelf’ as legally defined in international laws and treaties (Emery 1981). The latter encompasses the whole continental margin (shelf, slope and rise).

Mineral resources (Rona 1972; Archer 1973; United Nations 2004) include ore deposits: that is, relict shelf sandbodies or erosional lags made up of heavy minerals of direct economic interest (e.g. ilmenite, magnetite, cassiterite, chrome, rutile, zircon, rutile, gold and diamonds). Shelf sandbodies can also be exploited for aggregates (i.e. quartz-rich sand and gravels) to be used for concrete aggregate, beach nourishment and specific industrial manufacture. Hydrocarbons (oil and gas) are the most relevant economic resources of the shelf (Earney 1990). Oil production from continental shelves grew from a few per cent in the 1960s to 25% of global production by the beginning of this century. Since then, the shelf proportion has remained constant, with a decrease in onshore production offset by increasing deep-water production (US Energy Information Administration, http://www.eia.gov). Finally, phosphate occurs on some shelves as nodules, crusts, hardgrounds or placers in regions that experienced specific nutrient-rich bio-oceanographic conditions or received detritus from eroded phosphate-bearing formations (Filippelli 2011).

Not only do mineral resources make the shelf the most relevant part of the marine realm but shelf waters are also, by far, the richest part of the ocean (Wei et al. 2010) in terms of biomass, ecological system services and source of food for humans. The richness of life on the shelf is due to the concurrence of the large amount of nutrients provided by landmasses, and by the light penetration in shallow water that favours pelagic and benthic communities (in contrast to the darkness of abyssal waters). As a consequence, coasts and shelves furnish society with a large proportion of ecosystem services (Costanza et al. 1997), comparable to that provided by all terrestrial habitats (Tsunogai et al. 1999).

Shelves also preserve detailed and commonly unique archives of environmental changes in the complex interaction among climate, sea level and sediment input from landmasses, recorded in the depositional and erosional features of the subsurface (Gao & Collins 2014; Lobo & Ridente 2014). In detail, changes in rainfall and hydrology, and possibly storm energy and frequency, may leave their signature in shelf stratigraphy and morphology. Sediment cores collected on the shelf, because of the high deposition rate and proximity to sedimentary sources, are very sensitive to even minor changes in climate. They, therefore, can be used to distinguish between local and global effects, and possibly to assist in differentiating between human-induced and natural environmental changes (Asioli et al. 2001). The shift in the limits of ice sheets at high latitudes or the transition to and from carbonate sedimentation at low latitudes can be defined with precision on the shelves (Bailey & Flemming 2008). During the last sea-level lowstand, some shelf areas were flat coastal plains suitable for early human settlement. These experienced dramatic changes in sea level during deglaciation when an average rate of 1 m per century of sea-level rise occurred. The constant rise in base level and the damming of incised valleys by transgressive littoral barriers favoured river flooding and the formation of coastal marshes and swamps. On low-gradient shelves or in land-locked areas, fast to dramatic drowning of emerged land occurred. We can speculate that this process accelerated the dispersal of the Neolithic population, for instance into the interior of Europe at that time. Possible migration routes and civilization trends (compartmentalization of cultures during the Upper Palaeolithic for instance) may have a link with palaeoenvironmental changes on the shelf (Evans et al. 2014).

Controlling factors

The processes controlling Quaternary sedimentation on continental shelves are complex and varied. Continental shelves are the result of interactions between endogenous (e.g. geodynamic) and exogenous (e.g. climate-related) processes (Fig. 1.2). Plate tectonics and geodynamics determine the overall physiography of the margin, its width and slope, the deep structure of the subsurface, and the relevance of mass wasting and steady-state erosion. By contrast, climate determines the type of sediment (carbonate in tropical areas, siliciclastic in temperate climes and glacial in high latitudes). Furthermore, sediment distribution as well as bedforms and sedimentary structures on the seafloor are the result of a complex interplay between hydrodynamic processes (waves, tides and currents), the position of sediment sources (rivers, estuaries, wind) and the amount of sediment delivered to each shelf. Shelf deposits make up the bulk of the continental margin with thicknesses of several kilometres if subsidence permits. Their stratigraphic architecture is fundamentally controlled by sea-level changes that migrate the shoreline and related depositional...

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Fig. 1.2. Factors that control shelf character, on both long- and short-term geological timescales.
systems across the shelf. The resulting deposits (systems tracts in sequence stratigraphy) may, in fact, be preserved or destroyed by the vertical mobility of the continental margin that may create the space to accommodate and, thus, preserve shelf sediments. Depth of palaeo-shelf-breaks may also be used to reconstruct such vertical movement (Fraccasucia et al. 2013).

Climate-driven eustatic changes played a particularly significant role in the last 2 Ma, when the combination of astronomically forced insolation cycles and the position of land masses (especially in the Northern Hemisphere) caused glaciation over large parts of North America and Eurasia, and forced sea level to fluctuate between its present position and a depth of 120–130 m at a fast rate. The shelves therefore underwent dramatic environmental changes, with repetitive cycles of emergence and submergence, displacement of the shoreline from the shelf break to the inner edge of the continental margin, with consequent alternation of sedimentation and erosion, whose traces can be found in the shelf shallow stratigraphy, inherited morphology and the presence of relict sediment.

This volume

The chapters in this Memoir are presented in an order starting from the western North Atlantic continental margin and progressing eastwards to the Mediterranean, Indian and Pacific Ocean shelves.

The methods used to study shelf sediments focus on stratigraphy, particularly seismic stratigraphy and coring, geochemistry and palaeoecology. The fact that no single chapter in this Memoir fully integrates all such aspects indicates that large teams of investigators (and resources) are required and emphasizes that much work remains to be carried out on shelf environments. In the first part of each chapter authors provide basic data for their shelf, such as size, geometry, climate, tides, geodynamic setting and sediment types, to facilitate intercomparison and to provide first-level information for readers unfamiliar with a given shelf. Thereafter, the chapter presents more specific aspects of the studied shelf, while maintaining a geographically broad perspective.

The wide continental shelves of Atlantic Canada are characterized by a series of banks separated by transverse troughs. Shaw et al. (2014) present a detailed description of the shelves, and focus on the glacial history in the last glacial cycle, the glacial land systems, the geographical changes caused by glacio-isostasy, the processes on the upper continental slopes and the sediment mobility on the offshore banks.

Miller et al. (2014) discuss sedimentation on the storm-dominated, microtidal, continental shelf and slope of the eastern US passive continental margin. The sediments record sea-level changes providing a classic example of the interplay between eustasy, tectonism and sedimentation.

The Brazilian shelf is described in two chapters by Vital (2014) (northern shelf) and Nagai et al. (2014) (southern shelf). In the former, a review of the shelf physiography and the spatial distribution of sediments are used to relate them to the sedimentological processes and physical characteristics of the environment, and to the sedimentary history of this shelf system. A key factor in the development of the southern Brazilian shelf is the influence of the northerly flowing sediment plume from the Rio de La Plata, the activity of which has varied throughout the Holocene. Other major factors include variability in sea level and the intensity of the south-flowing Brazil Current.

The Argentine continental shelf is one of the largest and smoothest siliciclastic shelves in the world, mostly emplaced on a passive continental margin. Violante et al. (2014) provide a full description of the shelf where sea-level fluctuations, sediment dynamics and climatic/oceanographic processes are the most important conditioning factors in the modelling of the shelf.

The Baltic Sea is a semi-enclosed intracoastal sea where thermohaline stratification of the waters occurs. Uścinowicz (2014) describes the evolution of the Baltic Sea caused by the evolution of the last Scandinavian ice sheet during the Pleistocene and the sediment distribution of the Quaternary cover of its seabed.

The NW Iberian continental shelf is a narrow, gently dipping, geomorphological structure with a well-defined shelf break. Rey et al. (2014) present a detailed overview of the most distinct features and processes on the shelf, among which waves and tides, seasonal upwelling, and coast-parallel currents are recognized.

In the southern part of Atlantic Iberia, Lobo et al. (2014b) describe the outer part of the Gibraltar Strait (Gulf of Cadiz), where the influence of northward-flowing intermediate water pouring out of the Mediterranean interacts with shelf morphology and structural features.

Mhammedi et al. (2014) present a summary of the state of knowledge of the recent sedimentation and processes in the NW African shelf in the Atlantic Sea. The sedimentary processes along the shelf are driven both by long-term (Quaternary glacial–interglacial periods) and short-term factors (fluvial and aeolian sediment supply, local climate and hydrodynamic conditions).

The Iberian Mediterranean shelf, mostly emplaced on a passive area (2014a) into three different geographical segments (the Northeastern Shelf, the Southeastern Shelf and the Northern Alboran Sea Shelf), where the Quaternary stratigraphic architecture is controlled, respectively, by regressive–transgressive cycles, a declining fluvial influence and short mountain rivers.

Martorelli et al. (2014) describe the structure of the shelves surrounding the Italian peninsula. Despite its small extent, Italy shows a variety of geodynamic domains (back-arc to foredeep to foreland), so that the striking differences in shelf morphology and stratigraphy can be used to depict the controlling factors on continental shelf physiography and sedimentology.

The Hellenic shelf, located within one of the most seismically active areas of the world, is presented by Ferentinos et al. (2014). The tectonic activity – coupled with eustatic sea-level changes and water-circulation patterns – controls the configuration and processes of the shelf, and the occurrence of a variety of geological hazards.

The semi-enclosed Black Sea received an influx of Mediterranean-sourced water during multiple openings of the Marmara Gateway during the Quaternary. Nicholas & Chivas (2014) provide evidence for the most recent marine transgression into the Black Sea from the stratigraphic subdivision of sediments from cores, and from the surface distribution of bivalve molluscs on the mid and outer NW shelf.

The Indian shelves are presented by Faruque & Ramachandran (2014) (western shelf) and Faruque et al. (2014) (eastern shelf). Precambrian peninsular India is tectonically stable, although there are horst- and graben-segmented sections of the west coast that control and define distinct shelf provinces. By contrast, the eastern shelf is characterized by major rivers and deltas that contribute sediment, with the interdelta regions being generally sediment-starved.

The central Myanmar (Burma) shelf (Ramawamy & Rao 2014) lies in a tectonically subsiding embayment fed by some of the largest sediment-transporting rivers, including the Irrawaddy and Salween. Tidal redistribution of the suspended sediments has produced an extensive turbid zone and mud belt that characterizes the shelf.

A representative west Antarctic shelf, around Prydz Bay and Mac.Robertson Land, is described by O’Brien et al. (2014). The narrow shelf is scoured by icebergs calved from the adjacent Amery Ice Shelf. There is a thin sedimentary cover, deposited and eroded by successive glacial advances throughout the Quaternary.

Collins et al. (2014) provide an overview of the western continental margin of Australia. This is an enormous tectonically stable area with little fluvial input, spanning 20° of latitude from tropical to temperate climate and, accordingly, is largely carbonate.
dominated. The southern Australian margin is, by contrast, a high-energy cool-water carbonate province, although of equally large proportions (Murray-Wallace 2014). Silicilastic sediments are more significant in SE Australia, where there are fluvial sediment sources.

The NE Chinese shelf (Yang et al. 2014) is fed by two of the world’s largest sediment sources, the Changjiang (the Yangtze River) and the Huanghe (the Yellow River). The shelf is particularly wide, traversed by palaeovalleys, and dominated by silicilastic sediments and eddy-current mud deposits.

Barrée et al. (2014) describe Canada’s western continental shelf, dividing it into three geographical regions: the Salish Sea, the Pacific North Coast and the Vancouver Island Shelf. The authors reveal the contributions to each region’s physiography by glaciation, tectonism, oceanography and sea-level change.

Covault & Fildani (2014) show that the tectonically active Oceanside shelf offshore southern California has served as a conveyor of sediment from land to the deep sea during millennia of significant climatic fluctuations. The authors highlight the importance of shelf physiography, coupled with climatic forcing, and timescale of observation in assessing the role of shelves as sediment conveyors.

Dumont et al. (2014) identify and describe three different segments along the continental margin of Ecuador. On the basis of three-dimensional (3D) numerical modelling of a curved subduction plane, the authors demonstrate the strong relationship between the geometry of the continental boundary and the occurrence of uplift or subsidence along the continental margin.

References


Miller, K. G., Browning, J. V., Mountain, G. S., Sheridan, R. E., Sugarmas, P. J., Glenn, S. & Christensen, B. A. 2014. History of continental shelf and slope sedimentation on the US middle...
INTRODUCTION


