The main types of passive margins : an introduction

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The knowledge about the spatial and temporal evolution of a passive continental margin has increased considerably during the last few years reflecting a progressively intensified research effort. This activity has been encouraged both by the development of new geophysical techniques and the realisation that rock units containing major accumulations of hydrocarbons might lie beneath the passive margins.

The passive margins have formed as a part of the fundamental geodynamic cycle which includes the break-up of the continental crust and the subsequent formation of a deep ocean. These major evolutionary stages are often referred to by the key words rifting and drifting representing phases of continental extension and sea floor spreading respectively. Relatively simple tectonic models have normally been chosen to depict the passive margin development (Fig. 1). The typical tectonic sequence consists of : extension, rift formation, initiation of sea floor spreading and maturation by subsidence and sedimentation. Recent results, however, indicate that the margins often exhibit complex structural patterns revealing a great variety in structural style as well as depositional regime. Thus, at the present state of the art it appears difficult to synthesize the available information into one or a few type sections. Some of the fundamental questions relate to how the change from continental to oceanic crust takes place along the margin. A major objective is therefore to obtain a better understanding of the series of events associated with the break-up of the continental crust and how the original structures are being preserved as the margin matures.

Reviewing the investigations on the passive margins it is probably fair to state that we are now entering a "second generation" of margin research. Prior to 1975 most investigations were of an exploratory nature relying on conventional geophysical techniques and sampling of the near surface rocks (Fig. 2). The main limitation was the shallow penetration obtained by the one-channel seismic profiler. However, these surveys have yielded crucial information both in terms of the structural and depositional framework of many margins. Particularly, detailed surveys combined with an integrated approach of interpretation of the various kinds of geophysical data have proved most useful.

At present, new technology coupled with a series of experiments designed to develop geological models describing the present and past history of the margin characterize what we consider the "second generation" of research. A consequence of the more sophisticated techniques is that the surveying and data processing have become increasingly expensive requiring skillful design and execution of the experiments.

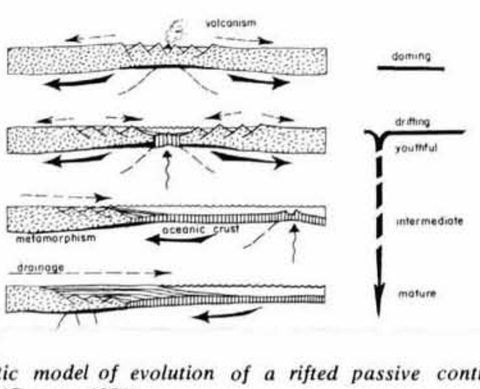

Figure 1
Schematic model of evolution of a rifted passive continental margin (Curray, 1980).

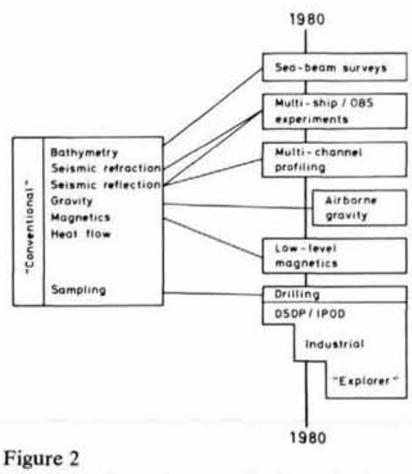

Figure 2
Methods of passive margin investigations.

Some of the new experiments are (Fig. 2) :

— mapping of the sea floor by the "sea beam" wide cone echosounder. It allows mapping of a swath of ocean floor using a wide cone signal and computerised data reduction. Many continental slopes are transected by deep canyons. Detailed bathymetric mapping as a precursor to sampling, for example by submersibles, may be a valuable complement to drilling ;

— the multi-channel seismic reflection technique originally developed by the petroleum industry is now actively used also by the research institutions. Its main advantage is increased penetration although a reliable definition of the entire basement surface is still lacking across most margins. On the other hand, the large penetration gives important constraints on magnetic, gravimetric and thermal modeling. We expect that the depth resolution will gradually improve as one introduces bigger energy sources and gains experience in processing and display of the data from deep and intermediate water depths ;

— relatively little is known about the nature of the deepest part of the thick sedimentary sequence at most margins. Furthermore, the understanding of how the physical properties of the underlying crust and upper mantle change across the margin is also limited. However, new refraction and wide-angle reflection experiments are now being developed to obtain additional information. Experiments of this kind most often require two, even three, ships. Particularly promising are experiments deploying long-range sonobuoys and ocean bottom seismometers together with expanding spread profiling and constant offset profiling. Expanded spread profiling is a two-ship technique which increases the effective array length of the common-depth-point method enabling increased precision in determining a velocity-depth curve, whereas constant offset profiling allows mapping of deep interfaces by recording arrivals at the critical distances ;

— The increased accuracy in navigation has made it possible to carry out reliable closely-spaced aeromagnetic surveys covering large areas. By flying at very low altitudes the data are almost comparable with shipborne data. Airborne measurements of the gravity field are also being developed although little actual surveying has yet been carried out. Measurements of this kind will be particularly important over high latitude ice-covered margins ;

— since 1968 the Deep Sea Drilling Project has collected core samples from many margins. Due to safety considerations and limited drilling capability all drill sites have terminated at relatively shallow depths. Deeper holes are needed to effectively correlate the geophysical data. A new drilling program with riser capability designed to drill deep holes at the continental margins is planned to start in 1983.

In order to develop type sections and compile the multitude of observations we need to develop a method of passive margin classification. The dissimilarity and complexity of the margins has lead to different schemes of classifications (Table). Here, we present classifications that are useful when analyzing the geologic history in space and time.

Physiography

The bathymetric map of the world reveals pronounced differences in the physiographic character of the various passive margins. The depth and width of the shelf, the steepness and width of the slope and the existence of a continental rise are all features that give each margin its characteristic physiographic signature. As the two end members there are the narrow margin with a typical steep slope and the wide margin with a gentle slope. A separate classification is applied where there is a marginal plateau. In many areas there is evidence that the physiography directly reflects the structural development. The margin off southern Sri Lanka and the Bay of Bengal are probably the most well defined examples of the two types of contrasting physiography, whereas the Blake Plateau and the Vøring Plateau are typical marginal plateaus.

Age

The age classification in the Table relates to the age of the oldest oceanic crust next to the margin. In other words, the time when sea floor spreading starded in the young immature ocean. Genetically, the margin may be considered older because the start of sea floor spreading is a relatively late stage in the geologic cycle forming a margin. For simplicity, the margins are classified as young, intermediate and mature. The Red Sea and Gulf of California are type examples of a young margin, the margin off southern Australia and those in the northern North Atlantic are intermediate and the East Coast of the United States typifies an old margin.

The age classification is not to be confused with that of Emery (1980) who has used *continuous seismic profiles* to form a genetic classification which applies to all of the world's margins.

Table

Schemes of passive margin classification.

Classification parameter		Physiography	Age	Continous seismic reflection profiles (Emery, 1980)	Structural framework	Overburden	Pre-rift geology
Margin Type	end member	Narrow (steep slope)	Young	Initial	Rifted	Starved	Craton
		Marginal plateau	Intermediate	Young	Sheared-rifted		
				Mature			
	end member	Wide (gentle slope)	Mature	Old age	Sheared	Sediment basin	Major basin

Structural framework

This classification is based on the structural evolution and refers basically to the geometry of the original plate boundary at the time of initiation of sea floor spreading. Consequently, the transform faults or offsets at the plate boundary will be reflected in the structural fundament of the margin and the margin may be divided into segments representing shear and extensional movements, the sheared and rifted margin segments respectively (Fig. 3). In the case of microcontinents a system of rifted and sheared margins will define the extent of the continental fragment. The margins of the Atlantic Ocean are dominated by rifted segments, however, sheared segments occur locally. The margin across the Agulhas Fracture Zone south of South Africa and off the Barents Sea in the Norwegian Sea are typical examples of sheared margins. A third combined sheared-rifted margin may occur when the pole of relative motion has changed in such a way that the original transform fault later became the locus of a new spreading axis. The most characteristic region lies between northeastern Greenland and western Svalbard.

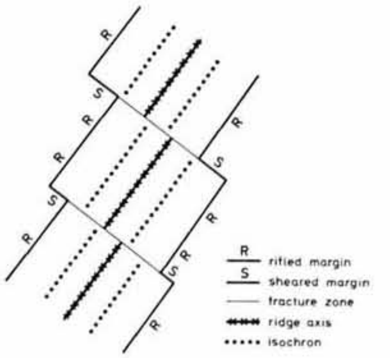

Figure 3
Sketch of rifted and sheared segments along a passive margin.

Pre-rift geology

Several surveys have revealed that the structural style of the margin is to some extent governed by the continental geology prior to the rifting. One end member of this type represents break-up of the continent in a craton with little or no sediment cover, the other being break-up within a major shallow sedimentary basin of for example, the North Sea type. Surprisingly little attention has yet been brought towards the pre-rift geologic configuration, although this is a parameter which may turn out to be fundamental in defining important events during the later margin development.

Overburden

The amount of overburden is in many regions closely associated with the pre-rift geology. Areas which are representative of little or no sediment cover represent the starved margins, whereas regions exhibiting thick sequences of sediments may be classified as sediment basin margins.

In a discussion of the various margin types one has to make assumptions about the nature of the ocean-continent boundary. This boundary has been visualized both as a sharp crustal boundary and a transitional area between the typical oceanic and continental crust. Recent investigations imply that although there might be a variety in styles of the continent-ocean transition it appears that the change in the two types of basement, that is the surface or the uppermost kilometers of the basement, occurs quite rapidly in many areas (Fig. 4). Volcanic activity as reflected by basalt flows and layers of pyroclastic material has also been associated with the late phase of rifting and the early phase of sea floor spreading. The observations imply a relatively complicated sequence of break-up, volcanic activity and sea floor spreading during the first stage of formation of a deep ocean.

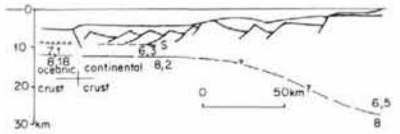

Figure 4
Crustal section across the northern Biscay margin (de Charpal et al., *1978).*

A region of contaminated crust underlying the margins has sometimes been proposed assuming that dyke injection and/or thermal alteration is responsible for the contamination.

On the other hand, a relatively sharp transition between the two kinds of basement does not rule out a modified deeper crust and upper mantle which have gradually been transformed by mechanisms which have not yet been fully understood. The apparent isostatic equilibrium across most passive margins suggests that a pronounced modification in the physical properties of the lower crust and adjacent upper mantle must have occurred contemporaneously with the process of maturation and subsidence of the continental margin.

Below the lower part of many continental slopes there are areas of relatively elevated basement. These structures have been called marginal highs or outer highs. The marginal highs are generally of volcanic nature, whereas the outer highs have been proposed to reflect an elevated outer edge of the continental crust. It is not known whether these highs indeed represent a similar stage in the margin evolution and if they exist along most margins. A classification and understanding of these structures must be of high priority for the research during the next decade.

We stated earlier that it appears difficult to develop typical crustal models across a passive margin. However, if one uses both the structural framework and the pre-rift geological configuration as main methods of classifying the various types of passive margins we believe that a series of type sections may represent the evolutionary history of various margin types. We stress that a better understanding of the history of subsidence is crucial to developing such type sections. Today relatively simple models explaining the subsidence history of these areas have been proposed. On the other hand, drilling results often show pronounced local variations in subsidence history along the strike of the margin.

In the future, one needs for areas representing different stages of development and structural styles, a careful definition of the structural framework of the pre- and post-rift history of evolution and of the continent-ocean boundary.

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