Chapter 11: Continental Margin Types and Divergent Margins

I. Introduction
   A. Definition of topic, continental margins
      1. Continental margins are the "sutures" between oceanic and continental crust.
      2. Note: we're not talking about plate margins: but the change from one type of crust to another; plate and continental margins may or may not co-occur.
   B. Slopes occupy 9% of the sea floor by area, shelves occupy 7%, and rises 14%, so not very much of Earth’s surface by area.
   C. Relative amount of sediments associated with each part of passive margin (Table 11-1)
      1. Continental slopes and rises store the most sediment of the oceans despite the fact that they comprise only a small portion of the surface area.
      2. Slopes alternately function as regions of sediment accumulation and regions of sediment by-passing through deep-sea canyons. You will see more about this later in the course.
   D. Simple conceptual model
      1. A, leading margins
      2. B, trailing margins
      3. We know things aren't quite this simple, but the models do portray some of the features of the two widely recognized continental margin types.

II. Continental Margin Types
   A. Divergent margins
      1. They are passive tectonically because they are seated in the middle of a plate. They subside due to cooling and isostatic loading under sediment eroded from the continent, but that is about the only activity that involves them (unless a hotspot pops up under them).
      2. They are aseismic, meaning that they do not have earthquakes, except left-overs from structures created during previous active conditions millions of years prior to rifting.
      4. The continent and the neighboring sea floor lie on the same plate
   B. Convergent margins
      1. Tectonically active, meaning that moving plate boundaries are involved.
      2. Seismic, meaning that there are earthquakes and associated crustal movement, with arc volcanics and perhaps large transform faults.
      4. The convergent margin is destructive with compressional tectonics.
      5. The continent and neighboring sea floor lie on different plates at convergent margins.
   C. Transform margins
      1. Characterized by translational motion of shear faulting.
D. Location of the various margins (see figures in presentation)
E. Today’s lecture will deal with **passive margins**.

III. Evolution of passive margins

A. The most significant complication regarding divergent margins is that the continent-ocean crust transition is obscured by thick sediments beneath the present continental slope. Resort to indirect observations.

1. **East Coast magnetic anomaly** (ECMA) lies beneath the slope. The magnetic anomaly (a large positive anomaly) is associated with continental crust intruded by Fe-rich basalts during initial rifting.
2. **Magnetic quiet zone** seaward of the ECMA. The magnetic signal is exceedingly weak. The ECMA is associated with metamorphism caused during stretching and rupture of the continent at the time of rifting.
3. Free-air gravity anomaly near the shelf break, near a subsurface ridge - the **shelf edge gravity high**. The subsurface ridge (*marginal basement high*) has more mass compared to its surroundings, and the excess causes the positive gravity anomaly.
4. The shelf edge gravity high and the ECMA parallel the continent continuously.

B. Use the eastern coast of North America as an example (because of COST, JOIDES holes, DSDP drilling and USGS seismic reflection profiling. In other words, great data is available to evaluate the margin and it is in the public domain (not military or industrial).

C. Stages Rifting of continents and formation of passive margins: a number of stages can be recognized in the evolution of a divergent margin (see figures in presentation).

1. Initial doming, volcanism, and erosion of the continent during onset of rifting. The doming is due the injection of mantle heat into the crust. Such sites are known at present in New Mexico and the rift lakes of Africa, the more advanced of these two examples. Horst and graben terrain is formed and much terrigenous clastic and volcaniclastic sediment fills the graben basins.
2. Substantial thinning of continental crust. Also with volcanism and faulting.
   a. Subsidence as continental crust thins (reduction in mass becomes more important than buoyancy due to heat, so it sinks). The Rockall basin might is a reasonable example of this phase. At this stage, the thinned continental crust may be at or below sealevel, so evaporites and shallow marine sediments commonly cover the surface.
3. When rifting is complete and the continental crust ruptures, then ocean crust is extruded. It is more dense, so lies distinctly lower, 500-1000 m below sea level and distinctly lower than the continental crust next to it. The Red Sea is a great example of this stage.
   a. The rifted continent is often asymmetrical on the conjugate margins, with one side being more stretched. The crust also tends to pull apart in layers so one margin gets the upper continental crust and the other gets the deeper and more metamorphosed continental crust.
b. While the continental crust is still near the spreading center, sheeted dykes of basalt may be intruded into the nearby continental crust.

4. As the continental margin moves away from the new spreading center, cooling allows subsidence.
   a. Subsidence due to cooling behaves just like oceanic crust,
      (1) depth vs age curves.
      (2) most rapid sinking during early, rapid heat loss. Heat flux, $q \propto 1/t$, where $t$ is time.

<table>
<thead>
<tr>
<th>Heat flow (cal/cm²/sec)</th>
<th>Time (y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0316</td>
<td>1000</td>
</tr>
<tr>
<td>0.0100</td>
<td>10000</td>
</tr>
<tr>
<td>0.0032</td>
<td>100000</td>
</tr>
<tr>
<td>0.0010</td>
<td>1000000</td>
</tr>
</tbody>
</table>

b. Crust also sinks due to sediment loading, debris mostly eroded from the continent.
   c. Further subsidence permits accumulation of sediments in shelf basins, usually the old grabens formed and weakened during the doming and stretch phases.

5. There are, however, “major asymmetries in the width and faulting style of continental rifting between margin conjugates” (Louden and Chian, 1999, ). These involve various combinations of pure and simple shearing of continental crust and lithosphere with one end-member producing much volcanism (Greenland style) and the other producing very little volcanism. In a third type (Clift, 2003, EOS 84(15): 139-), “the lower crust is mobile and flows into the rift axis from under each conjugate margin, resulting in strong subsidence with little upper crustal faulting” (Taiwan model). So on a case by case basis, the structure of the conjugate continental margins can be variable and complicated (beyond the scope of the course).

   a. The new continental margins begin to be covered by debris eroded from the continent interior. At first it fills the graben of the newly rifted margin. Then when these are filled it spills over the shelf edge. The cover becomes thicker and thicker with increasing age.
   b. Continued onlap of marine sediments after filling of marginal basins.

D. Example of the U.S. East Coast, which rifted ~180 Ma.
   1. Late Jurassic and early Cretaceous rocks are mostly thick, non-marine sands, volcanics and silty shales, overlain by shallow marine, evaporite deposits, then shallow marine sediments that were clastic near shore and more limy toward seaward margin of the shelf where a carbonate reef was growing.
   2. A shelf-edge reef served as a sediment dam to capture sediment eroded from the continent until mid-Cretaceous time, when the reef builder animals perished (widespread event).
   3. After the reefs ceased growing, sediment overtopped the shelf basin and spilled on to the slope, which became the depocenter.
4. Mid to late Cretaceous and Tertiary sediments are largely clastics in the form of a prograding wedge that overtopped the carbonate reef dam and built thick clinoforms on the slope. The clastic wedge progrades at a rate of about 1 km/10^6 y (Boillot et al., 1981), so this is another way that continents grow in size (at least laterally).

5. Summary of Atlantic: the classic passive margin.

E. Some activities that affect these margins

1. Sediment damming behind different kinds barriers, which are described below. These form the base of modern continental shelves. These dams are typically the source of the free-air gravity high.
   a. Marginal basement high
      (1) Like the one in the Great Australian Bight, a piece of continental basement snipped off during reorganization of early rifting, a sort of accident.
      (2) It served as a dam behind which sediments were trapped.
   b. Coralgal reefs
      (1) Such as one that served as sediment dam at seaward edge of Blake Escarpment and most of the U. S. East Coast until the middle Cretaceous.
      (2) The reef nearly surrounded the entire Gulf of Mexico until mid-Cretaceous
   c. Diapirs
      (1) Most often made of salt. There is such a thing as a mud diapir, but I am not considering those.
      (2) There are many salt structures on the Louisiana coastal plain, continental margin and slope, where they form extensive fields of diapirs and salt ridges.
      (3) The diapirs and ridges make good traps for petroleum and gas.

2. Starved versus mature margins
   a. A starved margin is thinly veneered with sediment and may be either young or old. Examples are the Blake Plateau and Western Australia, where currents sweep away sediments. The sediments don’t have a chance to build up a thick cover.
   b. A mature margin that isn’t starved is thickly sedimented. Examples include the East Coast off Delaware and the south coast of Australia. These regions typically have extensive continental rises.

3. Mesozoic shelf basins that formed behind the carbonate reef dams along North American Atlantic margin have been the sites of exploratory drilling for hydrocarbons:
   a. Scotian Basin - some oil/gas
   b. Georges Bank - all D&A abandoned.
   c. Baltimore Canyon Trough - some, but Great Stone Dome a disappointment
   d. Carolina Trough
   e. Blake Plateau Basin

4. Ridge jumps
   a. Spreading centers halt and spreading commences in an adjacent area.
b. Causes pieces of continental crust to lie amid oceanic crust.
c. Not at all uncommon, recent examples along modern oceanic ridges that are near newly rifted continents.
d. This sort of change happened in the Atlantic rifting, and it happened in south Australia as well, where the initial rifting ended and sea floor spreading began in earnest not only in a new locale (ridge jump), but the spreading was in a new direction and at a much faster rate. Rifting is often slow, and when complete, it speeds up and remains nearly constant to the end of the lifespan of the plate.

IV. Atlantic Ocean Margin Types
A. Divergent margins are found around most of the Atlantic [although convergence occurs in the Caribbean Lesser Antilles and Scotia Sea areas, and there are also areas of translation/convergence and simple translation (= shear)]

B. Look at some cross sections of the North Atlantic margin and point out some features:
   1. Cape Cod
      a. Magnetic Anomaly
      b. Gravity anomaly: high free air
      c. Cretaceous reef: even in Cape Cod, algal
   2. Blake Plateau, a starved margin
      a. complicated region
      b. carbonate platform
      c. escarpment on eastern side, extremely steep
      d. the escarpment is an ancient reef which eventually was overwhelmed by subsidence in the middle Cretaceous: depth lower than other margin sediments is caused by flexure due to sediment loading
   3. Gulf of Mexico
      a. once nearly surrounded by reef complex
      b. lots of evaporites deposited there during the Jurassic
      c. lots of salt domes now
      d. lots of oil trapped