

# **BEDROCK GEOLOGY ALONG THE COURSE OF PADDLE GEORGIA 2010**

## **INTRODUCTION**

Welcome to Paddle Georgia 2010! This trip will offer a multitude of opportunities to observe our natural world. The bedrock geology along the route is world famous and it offers a unique chance to cross a portion of the deeply eroded core of the Appalachian Mountains. You will paddle through more than 600 million years of earth history, travel through ancient oceanic volcanoes and have the chance to see fragments of ancient sea floor that have been pushed up onto North America. This brief introduction to the geology of the route provides an overview of the types of rocks you will encounter and explains their occurrence in the context of plate tectonics.

The outer 80-85 miles of the Earth is a rigid shell called the lithosphere. It is composed of both ocean and continental crust as well as portions of the upper mantle. The lithosphere is broken into a number of fragments (“plates”) that are in relative motion and riding over underlying, hotter and less rigid portions of the mantle. The lithospheric plates are moving together (convergent boundaries), moving apart (divergent boundaries) or sliding past each other. Each of the possibilities manifests itself differently in the geology we see along the course of Paddle Georgia.



Figure 1. Map of the Appalachian Mountains.

## REGIONAL SETTING

Georgia is situated along the southern extremity of the Appalachian Mountains (Fig. 1), and is the only state to provide a complete cross section of the system. The mountains formed between approximately 325 and 300 million years ago during the collision of two large continental plates (Gondwana and Laurentia) to form a mega-continent known as Pangea (Fig. 2). This collision was similar to that which is presently occurring between India and central Asia to form the Himalayan Mountains. At the time of the ancient collision, mountains within central portions of the Appalachians were between 22,000 and 24,000 feet high. Throughout most of the Paddle Georgia route, you will be traveling over an erosional level that was initially 8-10 miles below the Earth's surface when the Appalachians first formed. It has been exhumed to the present surface as a result of prolonged erosion.

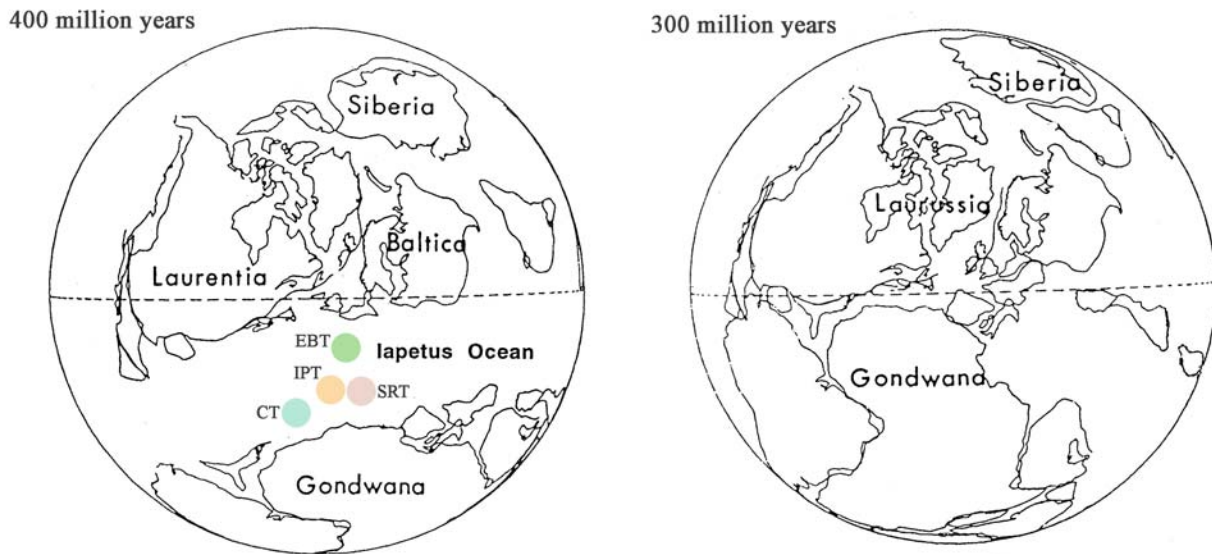


Figure 2. Continental reconstructions for 400 and 300 million years ago. Exotic terranes currently exposed in Georgia originated somewhere within the Iapetus Ocean tract that separated Laurentia and Gondwana, however their precise locations are uncertain (EBT – Eastern Blue Ridge Terrane, IPT – Inner Piedmont Terrane, CT – Carolina Terrane, SRT – Savannah River Terrane).

## GEOLOGY OF GEORGIA

The deeply eroded roots of the ancient Appalachian Mountains are exposed in Georgia (Fig. 4). These rocks are overlain by an extensive sequence of much younger marine sedimentary rocks that were deposited during higher stands of sea level starting around 80 million years ago. The sedimentary sequences underlie all of southeastern Georgia forming the Coastal Plain Province. These sedimentary rocks were deposited on an erosional surface (what geologists call an angular unconformity) that represents a gap of approximately 220 million years in the geological record. The boundary between the sedimentary formations and underlying Appalachian roots is called the “Fall Line” by most Georgians.

The bedrock geology of northwest Georgia is dominated by a much older sequence of marine sedimentary rocks that were deposited along the ancient margin of North America between approximately 550 and 300 million years ago. The collision of Laurentia and Gondwana compressed, folded and pushed these rocks northwestward toward the interior of North America (Fig. 5). Differential erosion of the contrasting sedimentary rock types has produced a series of valleys and ridges thereby leading to the name “Valley & Ridge Province” (Fig. 4). The continental collision that occurred 325-300 million years ago forced some of the North American sedimentary rocks downward deep into the crust where they

experienced mineralogical and textural changes (metamorphism) as a result of the higher pressures and temperatures there. Today these rocks are exposed in the Western Blue Ridge.

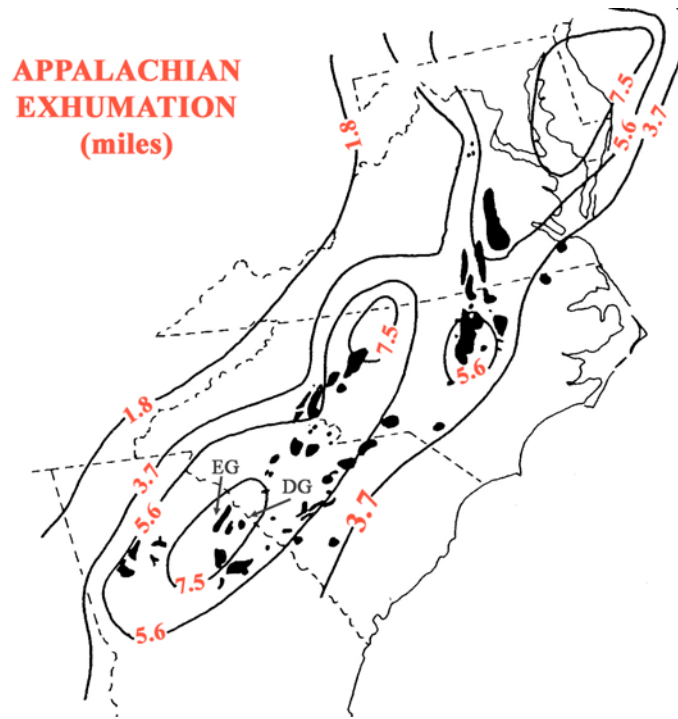


Figure 3. Map illustrating the extent of erosion with the central and southern Appalachians. Late tectonic granite intrusions like the Elberton and Danburg Granites (EG and DG) are shown in black.

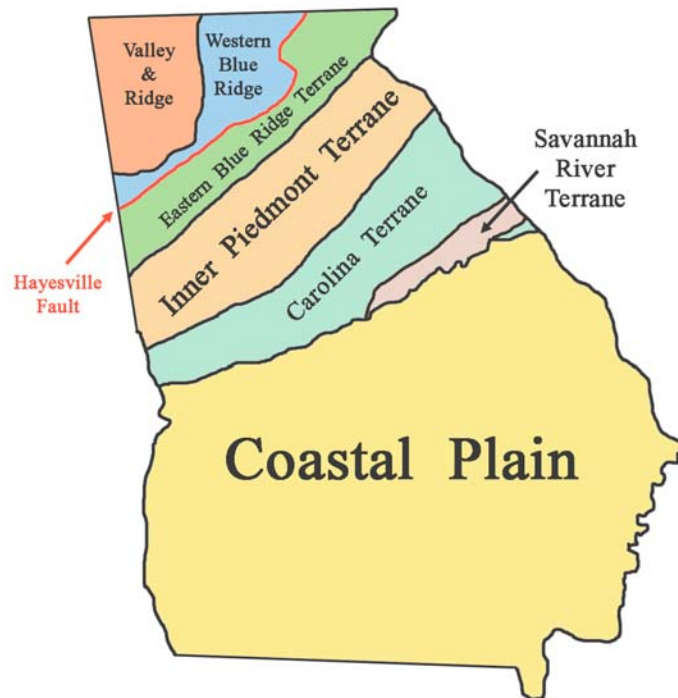


Figure 4. Geological provinces of Georgia.

The eastern boundary of the Western Blue Ridge Province is defined by the Hayesville Fault, the most important fault exposed in Georgia. West of this fault, rocks within both the Valley & Ridge and Western Blue Ridge are of North American affinity. However, all Appalachian rocks exposed east of the Hayesville Fault initially formed in different geological environments that were geographically separated from North America by significant expanses of ocean (Fig. 2). These “exotic” sequences are termed tectonic “terranes”. They collided with North America sometime prior to 325 million years ago and then overrode North American crust as they were pushed westward along gently inclined thrust faults during the continental collision that occurred 325-300 million years ago (Fig. 5). A sequence of volcanic rocks that comprise the Eastern Blue Ridge Terrane are exposed immediately east of the Hayesville Fault. These formed far removed from North America within an intra-oceanic subduction zone, where one oceanic plate dives beneath another. Rocks that you will see on Paddle Georgia 2010 are exposed east of the Eastern Blue Ridge Terrane, and include the Inner Piedmont, Carolina and Savannah River Terranes (Fig. 4).

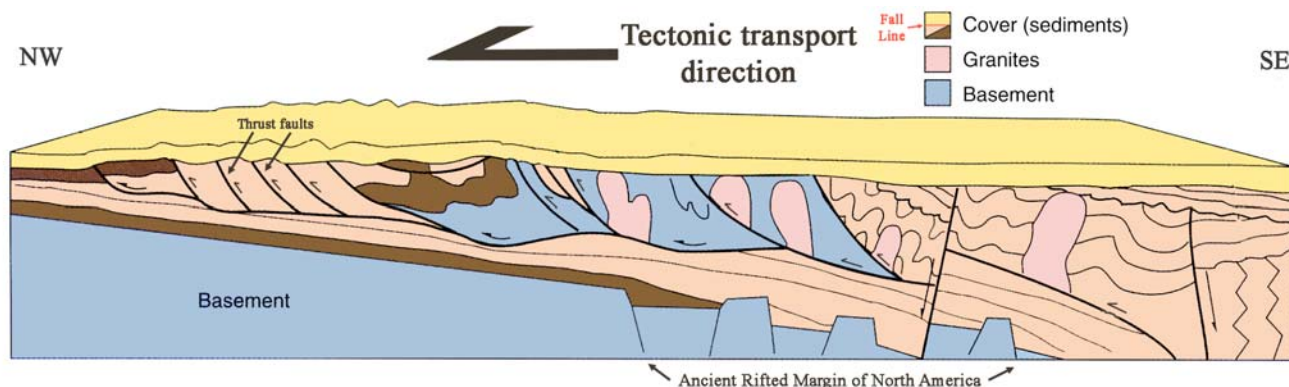


Figure 5. Geologic cross section across the eroded roots of the southern Appalachian Mountain system. Arrows indicate relative fault offset.

## BEDROCK GEOLOGY OF THE PADDLE GEORGIA ROUTE Days 1-5

Geological relationships exposed along the route of days 1-5 are illustrated in the attached map and portrayed in a geological cross section in Figure 6. Days 1-3 will explore the Broad River in its course across the Inner Piedmont Terrane. The Inner Piedmont represents an “exotic” fragment of continental crust derived from an unknown source and location. Rock types are dominated by high-grade metasedimentary and metaigneous rocks that experienced very high temperatures and pressures. Most of these rocks were heated to the point where they began to melt, forming what are called “migmatitic” textures. Melted minerals form light-colored bands; darker bands are composed of minerals that melt only at higher temperatures. Metasedimentary rocks types include migmatized biotite gneiss made up of the minerals feldspar, quartz and biotite (black mica) together with subordinate muscovite (white mica). Trace minerals often include garnet and sillimanite. Most of the metaigneous rocks found along our route are granite gneisses with mineralogy similar to the metasedimentary rocks. Some of the deformed igneous rocks within the Inner Piedmont Terrane are up to 650 million years old. Extensive chemical weathering has reduced most surficial exposures of Inner Piedmont rocks to red clay with only quartz grains and shiny muscovite flakes surviving from the original rocks (that’s why the dirt “sparkles”).

During final stages of the 325-300 million year continental collision, a series of granitic magmas were intruded into the southern Appalachians. These crystallized to form several large tracts of granite. Stone Mountain is the most famous, but others include the Panola, Siloam, Sparta and Appling Granites

as well as the Elberton and Danburg Granites exposed along the route of days 3 & 5 of Paddle Georgia 2010 (Fig. 3). These intrusions generally have sharp contacts with surrounding metamorphic country rocks indicating that the granites were not derived by local melting, but, instead, were derived from greater depths in the crust. The Elberton Granite is the largest of these late granites exposed in Georgia, covering more than 600 square miles. Geophysical investigations indicate that the granite extends to a depth of approximately 1.5 miles where it appears to be truncated by a gently inclined fault. The granite is remarkably uniform in texture and composition. It is fine- to medium-grained, and is composed primarily of quartz and feldspar. Biotite mica is the only other significant mineral. The Elberton Granite magma was emplaced between 325 and 320 million years ago at temperatures of 1300-1375° F and at a depth of about 10 miles. Its uniform color and texture makes it an ideal ornamental stone and it supports a large quarry and monument industry in the surrounding area.

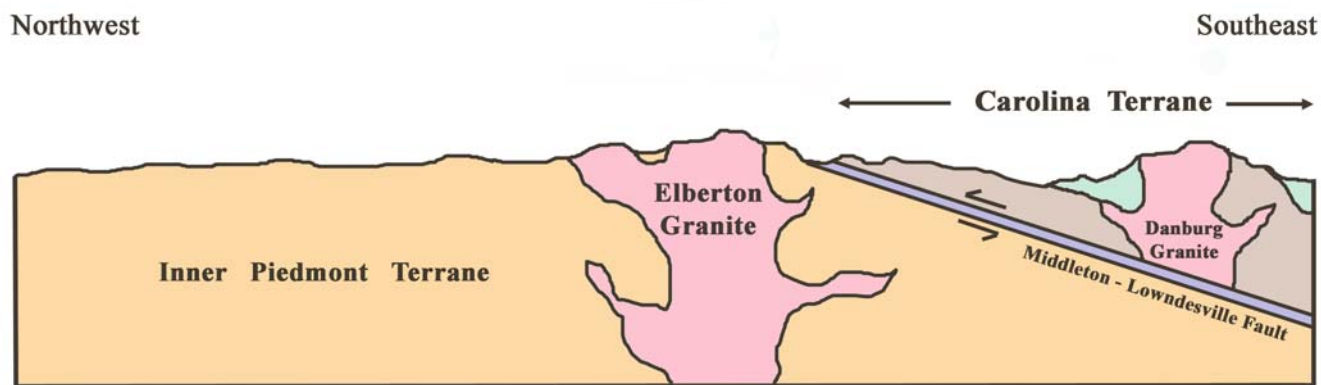


Figure 6. Vertical geological cross section across the Paddle Georgia route for days 1-5. Arrows indicate relative fault offset.

The Inner Piedmont is bordered on the east by the Middleton-Lowndesville Fault Zone. This is a 200-500 foot-wide zone that marks one of the most significant faults in the southern Appalachians. Faulting occurred at high temperatures and pressures deep within the crust, therefore fault textures are “ductile” in nature. Rather than fracturing, rocks in the fault zone bent like warm butter. Characteristics of the fault fabric suggest that overall fault offset was from southeast to northwest (Fig. 6). Small muscovite mica grains grew within the fault as the ductile layering developed. These mica grains yield ages of 300 million years, suggesting that the fault formed relatively late in the tectonic evolution of the Appalachian system.

The Carolina Terrane is exposed in eastern sectors of the Paddle Georgia 2010 route on days 4 & 5. This exotic terrane is comprised of a variety of rock types representing the eroded remnants of an ancient system of volcanic islands that developed along an intra-oceanic subduction zone, very much like the present-day Philippine Archipelago (Fig. 7). The Carolina Terrane includes both “intrusive” igneous rocks (that crystallized in magma chambers beneath the volcanoes) and a series of “extrusive” volcanic rocks including lava flows, ash fall layers and associated sedimentary horizons. These formed in both submarine and subaerial environments. All the Carolina Terrane has been metamorphosed to some extent. Subvolcanic igneous rocks include granite as well as rocks containing more iron, magnesium and calcium. These include diorite and gabbro. The extrusive rocks include metavolcanics, quartz-sericitic phyllite and schist (altered ash falls), along with phyllite and mica schist (metasedimentary rocks). Lower and Middle Cambrian trilobite fossils (550-530 million years old) have been described within metasedimentary sequences of the Carolina Terrane exposed in South Carolina. Because these fossils are unlike trilobites of similar age found either in North America or Africa, they indicate that the Carolina Terrane trilobites evolved within an isolated oceanic tract somewhere far from the coast of either continent. Radiometric ages from volcanic lava flows within the Carolina Terrane range from 570 to 550 million years.

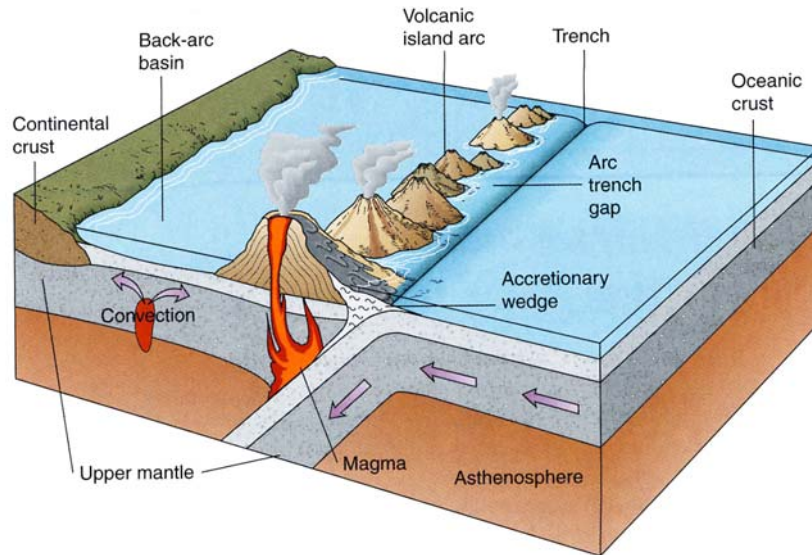


Figure 7. Intra-oceanic volcanic island arc system similar to that represented by the Carolina Terrane.

Along easternmost sectors of the Paddle Georgia route for days 4 & 5, the Danburg Granite intrudes the Carolina Terrane. This pluton is part of the late tectonic series exposed in Georgia and it was emplaced between 315 to 310 million years ago. Although its mineralogy is generally similar to the Elberton Granite, the Danburg Granite is much coarser grained, suggesting that the parent magma cooled relatively slowly as it crystallized.

## **BEDROCK GEOLOGY OF THE PADDLE GEORGIA ROUTE Days 6 & 7**

Geological relationships exposed along the route of days 6 & 7 are illustrated in the attached map and portrayed in a geological cross section in Figure 8. The route on these last two days carries the Appalachian transect to the Coastal Plain. It begins on Day 6 at Clark Hill Dam within the Savannah River Terrane, another unique and independent exotic Appalachian tectonic element. The Modoc Fault separates the Savannah River Terrane from the Carolina Terrane. Highly metamorphosed sedimentary rocks including biotite gneiss and schist characterize the Savannah River Terrane. Horizons of dark rocks called amphibolite likely represent metamorphosed basaltic lava flows or shallow intrusions. The amphibolites and the metasedimentary rocks have been intruded by numerous granitic magmas. Along the western edge of the core of the Savannah River Terrane, the Burks Mountain Complex features a series of unique dark rocks that include serpentinite and talc schist. The chemical characteristics of these rocks suggest that they are metamorphosed fragments of deep ocean crust and upper mantle. These unusual rocks contain high concentrations of magnesium, chromium and nickel that are quite toxic to most plants. About all that will grow on these outcrops are dwarf blackjack oak and pine along with sparse grassy areas. The presence of this oceanic crustal material along with the character of the metasedimentary rocks suggest that the Savannah River Terrane represents an ancient accretionary complex that developed along a subduction zone adjacent to a continent (Fig. 9). This complex formed as material was scraped off a descending oceanic lithospheric plate along a continental margin. When and where the Savannah River Terrane formed is uncertain.

The Augusta Fault marks the eastern boundary of the Savannah River Terrane. Movement on this fault has dropped down a segment of the Carolina Terrane next to the Savannah River Terrane. Farther

east, Late Cretaceous and Lower Paleocene sedimentary rocks of the Coastal Plain overlie both terranes. These sedimentary rocks were deposited approximately 80-60 million years ago following extensive erosion and exhumation of the ancestral Appalachian system.

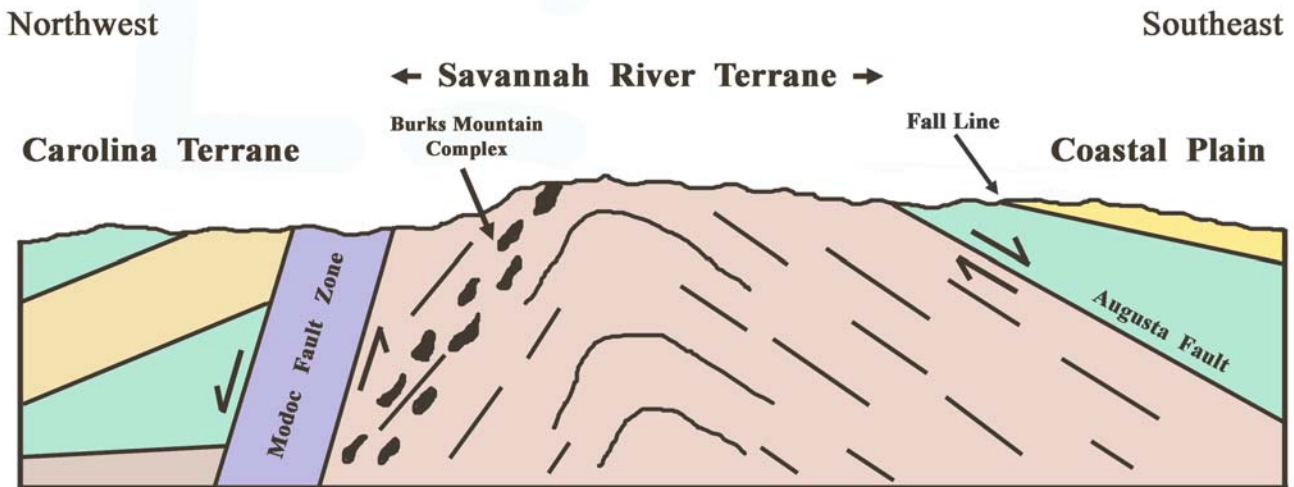


Figure 8. Vertical geological cross section across the Paddle Georgia route for days 6 & 7. Arrows indicate relative fault offset.

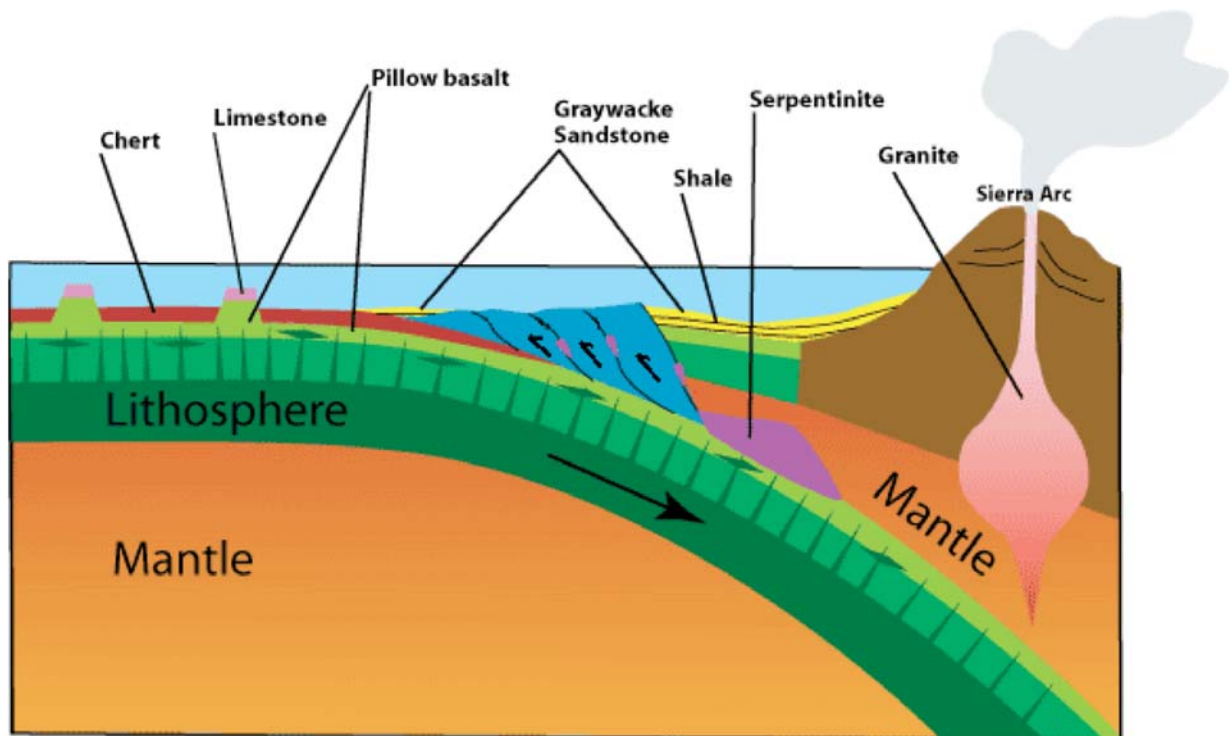


Figure 9. Cross section illustrating formation of an accretionary complex along a subduction zone bordering a continent. The complex develops as material is scraped off a descending oceanic plate and can include deep ocean sedimentary and volcanic rocks as well as fragments of the upper mantle.