Subduction zones, island arcs and active continental margins

Subduction zones are created when two lithospheric plates move against each other and one of the two plates descends under the other through the process of subduction. However, only oceanic lithosphere is able to sink deeply into the Earth’s mantle to become reincorporated there. Continental crustal material is generally too light to be subducted to great depth. The interaction of the subduction zone and the asthenosphere of the mantle generates the melts that rise to feed the volcanism typical of island arcs and active continental margins.

Subduction zones are critical to the dynamics of the Earth because they represent the essential driving force behind the movement of plates. Moreover, magmatism initiated by subduction is responsible for the creation of continental crust through a series of complex processes. The continental crustal material generated in this fashion has a low specific weight and remains at the outer rind of the Earth and is not reintegrated into the mantle. Without this light-weight continental crust, which forms high topographic features on the Earth, our planet would have a completely different face. The total length of global subduction zones sums to more than 55,000 km, a length only slightly shorter than the total length of the mid-ocean ridges (60,000 km).

Four types of convergent plate boundaries are recognized (Figs. 7.1, 7.2): The first type occurs when oceanic lithosphere is subducted below other ocean lithosphere ("intra-oceanic subduction zone") to create a volcanic island arc system built on oceanic crust ("ensimatic island arc"; sima – artificial word first used by Wegener made from silicon and magnesium to characterize ocean floor and Earth’s mantle). Examples for intra-oceanic, ensimatic island arc systems include the Mariana Islands in the Pacific and the Lesser Antilles in the Atlantic.

The second type occurs where oceanic lithosphere is subducted beneath continental lithosphere and an island arc underlain by continental crust forms ("ensialic island arc"; sial – silicon and aluminum for continental crust). The island arc of this system is separated from the continent by a marine basin underlain by oceanic crust. Examples for island arc systems underlain by continental crust are the Japanese Islands and the eastern Sunda Arc.

Structure of plate margin systems with subduction zones

The third type of convergent plate boundary represent the active continental margins where oceanic lithosphere is subducted beneath continental lithosphere without a marine basin behind the volcanic arc; rather, the arc is built directly on the adjacent continent. The continental margin is connected directly to the hinterland, although a shallow marine basin may exist behind the volcanic arc. Examples for active continental margins are the Andes, SE Alaska, and the western and central Sunda Arc that includes Sumatra and Java.

The fourth type of convergent margin occurs along zones of continent-continent collision. If two continental masses collide during continuous subduction, they eventually merge. Telescoping of the two plates and the buoyancy of the subducting continent eventually leads to a standstill of subduction within the collision zone. The oceanic part of the subducting plate tears off and continues to drop down, a process referred to as "slab breakoff". Continent-continent collisions ultimately result in the formation of mountain ranges like the Himalayas or the Alps.

The third type of convergent plate boundary represent the active continental margins where oceanic lithosphere is subducted beneath continental lithosphere without a marine basin behind the volcanic arc; rather, the arc is built directly on the adjacent continent. The continental margin is connected directly to the hinterland, although a shallow marine basin may exist behind the volcanic arc. Examples for active continental margins are the Andes, SE Alaska, and the western and central Sunda Arc that includes Sumatra and Java.

Subduction zones, island arcs and active continental margins

Subduction zones are created when two lithospheric plates move against each other and one of the two plates descends under the other through the process of subduction. However, only oceanic lithosphere is able to sink deeply into the Earth’s mantle to become reincorporated there. Continental crustal material is generally too light to be subducted to great depth. The interaction of the subduction zone and the asthenosphere of the mantle generates the melts that rise to feed the volcanism typical of island arcs and active continental margins.

Subduction zones are critical to the dynamics of the Earth because they represent the essential driving force behind the movement of plates. Moreover, magmatism initiated by subduction is responsible for the creation of continental crust through a series of complex processes. The continental crustal material generated in this fashion has a low specific weight and remains at the outer rind of the Earth and is not reintegrated into the mantle. Without this light-weight continental crust, which forms high topographic features on the Earth, our planet would have a completely different face. The total length of global subduction zones sums to more than 55,000 km, a length only slightly shorter than the total length of the mid-ocean ridges (60,000 km).

Four types of convergent plate boundaries are recognized (Figs. 7.1, 7.2): The first type occurs when oceanic lithosphere is subducted below other ocean lithosphere ("intra-oceanic subduction zone") to create a volcanic island arc system built on oceanic crust ("ensimatic island arc"; sima – artificial word first used by Wegener made from silicon and magnesium to characterize ocean floor and Earth’s mantle). Examples for intra-oceanic, ensimatic island arc systems include the Mariana Islands in the Pacific and the Lesser Antilles in the Atlantic.

The second type occurs where oceanic lithosphere is subducted beneath continental lithosphere and an island arc underlain by continental crust forms ("ensialic island arc"; sial – silicon and aluminum for continental crust). The island arc of this system is separated from the continent by a marine basin underlain by oceanic crust. Examples for island arc systems underlain by continental crust are the Japanese Islands and the eastern Sunda Arc.

The third type of convergent plate boundary represent the active continental margins where oceanic lithosphere is subducted beneath continental lithosphere without a marine basin behind the volcanic arc; rather, the arc is built directly on the adjacent continent. The continental margin is connected directly to the hinterland, although a shallow marine basin may exist behind the volcanic arc. Examples for active continental margins are the Andes, SE Alaska, and the western and central Sunda Arc that includes Sumatra and Java.

The fourth type of convergent margin occurs along zones of continent-continent collision. If two continental masses collide during continuous subduction, they eventually merge. Telescoping of the two plates and the buoyancy of the subducting continent eventually leads to a standstill of subduction within the collision zone. The oceanic part of the subducting plate tears off and continues to drop down, a process referred to as "slab breakoff". Continent-continent collisions ultimately result in the formation of mountain ranges like the Himalayas or the Alps.

Structure of plate margin systems with subduction zones

Systems of convergent plate boundaries are characterized by a distinct topographic and geologic subdivision. Although the plate boundary itself is...
Subduction zones, island arcs and active continental margins

only represented by a line at the surface, commonly within a deep sea trench, a zone several hundreds of kilometers wide is formed by processes which are related to subduction. The volcanic zone above the subduction zone, in many cases expressed as an island arc, is the dominating element of this plate boundary system. We use arc as shorthand for the terms volcanic arc or magmatic zone. The arc is the point of reference for the convergent boundary that is usually divided into three parallel zones: from the trench to the arc is the forearc zone, the arc zone comprises the magmatic belt, and the region behind the arc is the backarc zone (Fig. 7.3). This generally agreed upon subdivision of three parts turned out to be practical in order to describe the complex structures of convergent plate boundary systems.

Deep-sea trenches form the major topographic expression at convergent plate boundaries. These deep, narrow furrows surround most of the Pacific Rim and small portions of the rims that surround the Indian and Atlantic oceans. Oceanic lithosphere is bent downward under the margin of the “upper plate” and dives into the asthenosphere. The result is an elongated deep trench that is located between the abyssal plains and the border of the upper plate. The deepest trenches, with water depths of about 11,000 m, are known from the Challenger and the Vitiaz deep (named after an English research vessel and a Russian researcher) in the southern Mariana trench. Water depths of more than 10,000 m are also known from the Kurile, Izu-Bonin, Philippine and Tonga-Kermadec trenches (Fig. 7.1).

Convergent plate boundaries are responsible for the greatest differences of relief on the Earth’s surface. Differences in altitude of 10 km between the deep sea trench and volcanoes of the magmatic arc are not unusual. A relief of 14,300 m across a distance of less than 300 km can be observed between Richards Deep (−7636 m) and Llullaillaco (+6723 m) in the Chilean Andes, the highest active volcano on Earth.

In a transect from the trench onto the upper plate, the following morphological features generally occur (Fig. 7.3). The landward side of the deep sea trench is part of the upper plate and consists of a slope with an average steepness of several degrees. In front of the Philippine Islands the angle exceeds 8° where a rise from −10,500 m to −200 m occurs over a distance of 70 km. The outer ridge follows behind the slope. In most cases, the ridge remains substantially below sea level; however, in several cases, islands emerge above sea level (Sunda Arc: Mentawai; Lesser Antilles: Barbados). The outer ridge is not always distinctive. Next in the transect, directly in front of the volcanic arc, lies the forearc basin, another prominent morphological element.

Fig. 7.2 Examples of different types of plate margins with subduction zones. The island arc of the Marianas developed on oceanic crust, that of Japan on continental crust. The volcanic zone of the Andes is built on the South American continent (active continental margin). The collision of two continents produces a mountain range like the Himalayas – subduction wanes, leading to slab breakoff.

Fig. 7.3 Examples of different types of plate margins with subduction zones. The island arc of the Marianas developed on oceanic crust, that of Japan on continental crust. The volcanic zone of the Andes is built on the South American continent (active continental margin). The collision of two continents produces a mountain range like the Himalayas – subduction wanes, leading to slab breakoff.