INVITATION TO OCEANOGRAPHY 7TH EDITION Pdf Free

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Scientific American 5 : 48— Lonsdale, P. Ridges and rises: A global view. Oceanus 34 4 : 26— Macdonal, K. The crest of the East Pacific Rise. Scientific American 5 : — Menard, H. The deep-ocean floor. Scientific American 3 : — Pinter, N. How erosion builds mountains. Scientific American 4 : 74— Powell, C. Peering inward. Scientific American 6 : — Pratson, L. Panoramas of the seafloor. Scientific American 6 : 82—

Reves-Sohn, R. Unique vehicles for a unique environment. Oceanus 42 2 : 25— Taylor, S. The evolution of continental crust. Scientific American 1 : 76— Watson, L. The Water Planet. New York: Crown. White, R. Volcanism at rifts. Scientific American 1 : 62— There where the long street roars hath been The stillness of the central sea. The hills are shadows, and they flow From form to form, and nothing stands; They melt like mist, the solid lands, Like clouds they shape themselves and go. The Earth is a pulsating planetary body, engaging in grand geologic cycles as its immense ocean basins expand and contract, and its towering mountains are raised upward and beveled downward.

But change they do, as we will discover. According to current theories, the oceans and continents are continually created and recreated. This colossal geologic drama is the central topic of this chapter. O ne of the main concerns of marine geologists is tracing the development of the ocean basins since their formation on the Earth. Despite the fact that these basins are composed of rigid rock, their shape and size change slowly but surely with time.

How is this possible? Indeed they are—from year to year, and even from generation to generation. As you read this, the building where you are is drifting slowly, but relentlessly, with the continent on which it is located. Our maps represent merely still photographs of continents in motion over geologic time; the geography we see as so permanent is not.

Prominent bulges of land are matched across the sea by equally imposing embayments with similar geometries. This parallelism is most noticeable in the opposing edges of Africa and South America Figure 3—1. In fact, careful matching of the edges of all the continents shows that they can be reassembled into a single large landmass of immense size. This implies that the continents have moved vast distances relative to one another, making the present geography of the Earth quite different from what it was in the geologic past. According to Wegener, geologic and paleontological fossil information indicated that the present continents had been part of a much larger landmass more than million years ago.

He surmised that some million to million years before the present, this large landmass, which he called Pangaea Figure 3—1 , splintered apart, and the fragments the present-day continents slowly drifted away from one another, opening new ocean basins between them. Relying on detailed geographic and geologic reconstructions and abundant fossil and paleoclimatological ancient climates evidence, Wegener proposed that Pangaea broke apart along a global system of fractures, or geologic faults, that shattered the granitic crust of the land. Concurrently, fresh basalt was injected into the widening gap between the Americas and Africa-Europe, creating a juvenile Atlantic Ocean. During this drifting episode, the leading, western edges of North and South America were buckled into the Rocky and Andes mountains when the dense basalt crust of the Pacific Ocean resisted the drift. Just what caused the continents to drift was not apparent to Wegener.

The notion that these huge continental masses of granite were adrift struck many scientists of the time as being a bit far-fetched, more like science fiction than natural science. Besides, the geophysicists showed that the driving mechanism for continental drift proposed by Wegener was not possible according to their calculations. Later work by geological oceanographers confirmed the mobility of the continents, elevating the continental-drift idea from the realm of the impossible to a status as certain as any theory in science can hold. What to make of it? How and when was it formed? Was this submarine mountain belt in some way connected to the formation of mountains on land, of which a great deal was known? Or did it originate in an entirely new and independent way? Much needed to be learned. It was apparent that the midocean ridge in the Atlantic Ocean, aptly called the Mid-Atlantic Ridge because of its position along the center line of the Atlantic basin, mimics clearly the shape of the continental edges of the bordering continents see Figure 2—2.

Detailed geophysical surveys of this midocean ridge revealed a number of remarkable features. For example, the enormous flanks of the Mid-Atlantic Ridge rise to a sharp crest. A prominent valley that is 50 kilometers 31 miles wide and 1 kilometer 0. The floor of this valley is composed of freshly crystallized young basalt and bounded by prominent normal faults—topographic scarps steep rock faces where crustal rocks have broken and dropped past one another creating the valley Figure 3—2a. Faulting at the ridge axis consists of normal faults of the rift valley and transform faults that offset the ridge crest. Clearly, the Mid-Atlantic Ridge, as well as other midocean ridges, is geologically active, being the site of widespread volcanism, faulting, and earthquakes.

On land, large mountain belts such as the Appalachians, the Rockies, the Alps, and the Himalayas are the result of tremendous pressures that squeeze rocks together, causing them to be folded and faulted. Folds result from compressional forces Figure 3—2b. This is analogous to laying the palms of your hands flat on a tablecloth and bringing them together. This action results in the cloth being folded by compression.

The rocks of the midocean ridges are not folded. Rather, all the geologic evidence indicates that these mountains have been stretched and pulled apart, creating the normal faults at the shoulders of the crestal rift valley and allowing molten melted basalt to rise along the cracks and spill out on the surface as lava. This www. Unlike the normal faults, where rocks have moved vertically, a careful examination of the transform faults indicates that the sense of relative motion of the broken rocks is lateral, or as geologists say, strike-slip. There are two distinct types of fault systems associated with midocean ridges see Figure 3—2a , and the two should not be confused. The normal faults that occur along the edges of the rift valleys are zones where the crustal rocks are displaced vertically in a relative sense.

The transform faults offset the ridge axis and represent fractures in the crust where the movement of rocks is essentially horizontal. The oddest and most problematic feature of the midocean ridges pertains to their magnetic properties. To investigate these properties, magnetometers, instruments that detect and measure the intensity of magnetism, were towed by ships back and forth across the crests of the midocean ridges. Magnetic anomaly stripes run parallel and are symmetrically arranged on both sides of the midocean ridge axis. For example, anomalies B and C on the eastern ridge flank have counterparts B' and C' on the western flank that are the same distance from the crestal anomaly A. Each magnetic profile across this ridge showed alternating high magnetic readings positive peaks and low magnetic readings negative peaks.

This means simply that positive magnetic anomalies are stronger than expected, negative readings weaker than expected. This is the case for the Reykjanes Ridge see Figure 3—3. Here distinct magnetic anomaly stripes are evident, running parallel to the ridge line. More surprisingly, these magnetic bands are symmetrically distributed about the ridge axis.

That is, each magnetic anomaly on one flank of the ridge has a counterpart on the opposite flank at the same distance from the ridge crest. In Figure 3—3 note that the central anomaly A, located over the ridge crest, is flanked by anomalies B and B', C and C', each pair being equidistant from the ridge line. This regular, symmetric pattern of magnetic anomaly stripes has been found along most of the midocean-ridge system, and is seen as one of its fundamental properties. What created such regularity, and what could possibly be its significance? Answers to these questions awaited the study of the magnetic properties of rocks on land. This dipole creates a magnetic field, invisible lines of magnetic force that surround the Earth and are capable of attracting or deflecting magnetized material.

The intensity of the geomagnetic field is strongest at the magnetic poles, where magnetic lines of force are vertically oriented. When lava extrudes and cools, minerals crystallize systematically out of solution as the lava solidifies into a rock, in the same way that solid ice crystals form in liquid water that is cooled below its freezing temperature. A few of these early forming minerals are magnetic and tend to align themselves with the geomagnetic field in a way that is similar to the pull on your compass needle.

As other minerals crystallize, they lock in and trap, so to speak, the alignment of these magnetic grains. This means that the rocks record the strength and direction of the geomagnetic field at the time they crystallized into a solid. As paleomagnetic measurements on sequences of basalt flows were collected from a particular area, something quite odd appeared in the data. What could this possibly mean? All these data taken together could mean only one thing—the geomagnetic field had flipped repeatedly back and forth over time see Figure 3—4b , sometimes oriented as it is at present normal polarity and sometimes oriented in the opposite direction reverse polarity.

This information led to the development of a paleomagnetic polarity time www. During any reverse polarity, the northseeking compass needle would point to the south rather than to the north geographic pole. As we shall see, this knowledge of magnetic field reversals finally helped geologists understand the significance of magnetic anomaly stripes on the sea floor. Few geologists accepted this radical hypothesis. By the mids, however, geologists and geophysicists studying all the data pertaining to the midocean ridges proposed a bold new hypothesis: new ocean floor and crust are created continuously by the intrusion and extrusion of basalt at the crest of all midocean ridges. Gradually, the newly formed crust moves laterally down the flanks of the midocean ridges, making space at the crest for the formation of more basalt crust. This process, called sea-floor spreading, leads to ocean basins that widen with time.

Vine and Matthews hypothesized that, as the sea floor spreads, the basalts become normally or reversely magnetized depending on the orientation of the geomagnetic field at their time of cooling see Figure 3—4b. This magnetic parallelism causes a reinforcement, so that a magnetometer measures a higher than normal reading, resulting in a strong or positive magnetic anomaly Figure 3—4d. In contrast, all rocks that formed during a period of reverse polarity have a fossil magnetic orientation opposite to that of the presentday geomagnetic field.

This contrary alignment reduces the magnetic reading over reversely magnetized basalt, producing a low or negative magnetic anomaly. In other words, the magnetic profiles on either flank of the midocean ridges are mirror images of each other. In the vicinity of the Mid-Atlantic Ridge, seafloor spreading is causing symmetrical expansion of the Atlantic Ocean basin; the ocean is growing in size as fresh basalt is extruded at its center. In the process, continents on either side of the basin are traveling along with the moving ocean floor as part of the plate—which explains continental drift as Wegener described it, but does away with the idea of light granitic crust plowing through denser oceanic crust.

Rather, the granite of the continents is simply being carried along by the expanding sea floor. Moreover, if we reverse the process of sea-floor spreading and go back into the distant geologic past, the Atlantic basin shrinks in size until it disappears, and all the continents rejoin one another into a much larger continental landmass, Pangaea. When in the distant past did this colossal megacontinent break apart? At what rate does the sea floor spread? Actually, it turns out to be easy to measure rates of spreading using magnetic profiles measured perpendicular to the crests of midocean ridges Figure 3—5b.

The timing of geomagnetic polarity reversals is easily established by dating basalt flows. This, then, makes it possible to infer the age of the magnetic anomaly stripes of the sea floor, because each of these formed during unique magnetic reversals. Dividing that distance of transport kilometers by the age of the sea floor 10 million years yields an average spreading rate of 10 kilometers per million years or 1 centimeter per year for each flank of the ridge.

The lavas at each site are stacked on top of one another, with the oldest lava on the bottom and the youngest on top of the sequence. Note that the volcanic rocks of the same age in all areas are either all normally or all reversely magnetized. This effect results from the geomagnetic dipole flipping its polarity back and forth over geologic time. During a reversal, the geomagnetic north pole flips with the geomagnetic south pole so that it lies adjacent to the geographic south pole. Cox, Science : — Several important findings are explained by the sea-floor spreading model. For instance, sea-floor spreading means that the oceanic crust that lies to either side of the ridge moves apart. This separation produces tensional forces that create normal faults and rift valleys at ridge crests. Also, spreading of the ocean floor implies that the basaltic crust becomes increasingly older with distance from the ridge line.

Eventually, as the basaltic crust is transported down the ridge flank, it becomes covered with sediment. This sedimentary cover gets steadily thicker with distance from the ridge axis, because the older the sea floor, the longer is its history of sediment accumulation. Since the breakup of Pangaea during Jurassic time some million years ago , the Atlantic Ocean has grown from a young, narrow basin to its current size. This has been true for the other ocean basins as well. The presence of magnetic anomaly stripes parallel to the crest and flanks of midocean ridges in the Indian, Arctic, and Pacific Oceans indicates that their floors are spreading and that these basins must be widening as well. Think about an orange. If you wanted to add more peel, you would need to make the orange bigger, that is, increase its diameter. However, geologists have determined that the diameter of the planet has not changed appreciably for hundreds of millions, if not a billion, years.

What to do? There is one way around this problem. If that were the case, then sea-floor spreading could occur on the Earth with a fixed diameter. Where, then, are the areas in which oceanic crust is being destroyed? An examination of world seismicity—the frequency number , magnitude strength , and distribution of earthquakes— reveals two distinct groupings of earthquakes on the Earth Figure 3—6a. One grouping consists of a narrow clustering of shallow, relatively weak disturbances that closely follow the crest line of the spreading midocean ridges and their transform faults. The earthquakes along the ridge axis result from volcanism and normal faulting along the crestal rift valley; those along the transform faults are generated by the strikeslip motion of the crust to either side of the fault.

But, what is the significance of the second grouping of seismic events, which appears as a broad band of strong, shallow-to-deep earthquakes that follow the western edges of North and South America, arc around the western and northwestern Pacific, and extend across the southern Asian mainland through the Himalayas and across the European Alps see Figure 3—6a? The frequency and magnitude of the earthquakes in this seismic belt signify intense tectonism, a term that denotes deformation buckling, folding, faulting, crushing of the crust. Around the Pacific Ocean, earthquakes are associated with deep-sea trenches and volcanic arcs.

The distinctive volcanic landmasses have been built up by the abundant extrusion of andesite, a lava with a chemical composition intermediate between granite and basalt see Table 2—2. Furthermore, sedimentary and volcanic deposits, which lie between the active volcanoes and the deep-sea trench, are highly deformed, buckled, and fractured, implying that the oceanic crust here is being shortened by powerful compressional forces, crudely analogous to the effect of pushing together the two sides of a tablecloth and creating folds in the fabric. The accurate recording of seismicity at volcanic arc-trench systems discloses that earthquakes are not randomly distributed here, but are arranged in quite an orderly pattern. For example, seismicity plotted on a cross section of the Tonga Trench in the southwestern Pacific Figure 3—6b appears as a band of earthquakes dipping at about 45 degrees.

This feature, called the Benioff zone after its discoverer, the American seismologist Hugo Benioff, has been found at other deep-sea trench sites as well. What could this odd pattern possibly mean? An analysis of earthquake waves reveals that the rocks immediately beneath the Benioff zone are sliding downward relative to the rocks above them, suggesting that large slabs of rocks are converging, with one mass riding over the other see Figure 3—6b. The slab going down generates strong earthquakes as its upper surface slips and scrapes against the rocks above it. The hot, buoyant molten fraction then rises to the surface and spews out of volcanic island arcs as andesite lava. These sites where basaltic crust is being destroyed are called subduction zones. The volcanic arc-trench systems are consuming the ocean floor that is being created at the spreading midocean ridges.

Interestingly, few subduction zones are evident in the Atlantic, Indian, and Arctic oceans; here the spreading midocean ridges are the principal tectonic features. This indicates that the Pacific plate is being subducted beneath the south Fiji Basin. One additional conclusion should be obvious to you as well. This, in turn, implies that the Pacific Ocean is shrinking rapidly in a geologic sense at a pace equal to the combined production rates of the entire midocean ridge system. Also, bear in mind that although the size of the Pacific basin is diminishing over time, new ocean floor continues to be created along its midocean ridge, the East Pacific Rise, as clearly indicated by earthquakes and fresh basalt at the ridge crest and the presence of magnetic anomaly stripes that run parallel to the ridge axis.

This theory formulated in the s revolutionized thinking about the geologic history of the Earth. These plates may consist mainly of sea floor, or more commonly some combination of sea floor ocean crust and landmass continental crust. The plate boundaries extend downward through the entire lithosphere, which is the brittle outer shell of the Earth that includes the crust and uppermost mantle Figure 3—7b. Geologists refer to them, therefore, as lithospheric plates. There are three fundamental types of plate boundaries Table 3—1 : 1. Midocean ridges are boundaries where two plates under tension move apart from one another. Each plate grows by the process of sea-floor spreading, which adds new lithosphere crust plus upper mantle to the trailing edges of the two diverging plates. Subduction zones are plate boundaries where compression is dominant, as two plates converge, one overriding and destroying the other.

The ocean floor can be thrust downward beneath another ocean plate ocean-ocean collision , common in the western Pacific, or beneath a continent, as along western South America ocean-continent collision , where the andesite volcanoes, rather than being submarine landforms, appear as volcanic peaks in the high Andes. Subduction zones are also present where two or more continental masses are actively colliding continent-continent collision , as along the Himalayan mountain range of Asia. On a globe with a fixed surface area over geologic time, subduction plate destruction at convergent boundaries is balanced by sea-floor spreading plate growth at divergent edges. Transform faults are plate boundaries where ocean floor is neither created nor destroyed. Rather, the lithosphere along transform faults is conserved as plates slide laterally strike-slip motion past one another.

Although there are various transform boundaries, the most common type is the one that connects two midocean ridge segments such that they are offset from each other. The plate edges are, however, not merely surface ruptures. They extend downward through the entire lithosphere, which includes the crust and the uppermost mantle. The arrows indicate relative plate motions. Ocean Science. If drawn to scale, the lithospheric plates are pancake thin, because they are between ten and fifty times wider than they are thick. Characteristics of plate boundaries Relative Plate Type Motion Topography Earthquakes Volcanism Examples Midocean ridge Divergent Ocean ridge Shallow, weak Volcanoes and Mid-Atlantic to moderate intensity Subduction zone Ridge Convergent Ocean-ocean collision Ocean-continent collision Continent-continent Deep-sea trench and volcanic arc Deep-sea trench and volcanoes Strike slip Shallow to deep, weak to strong intensity Shallow to deep, weak to strong intensity Mountain belt Shallow to deep, Offset ridge crest Shallow, weak collision Transform fault lava flows arcs Volcanic arcs above and convect rise upward.

This process is most obvious at the spreading ocean ridges, where a large quantity of internal heat associated with molten rocks is being dissipated by convective heat transfer. These slow-moving currents in the asthenosphere exert drag on the bottom of the lithospheric plates, setting them in motion Figure 3—8. Furthermore, the cold, dense edge of the downgoing lithosphere at subduction zones pulls the plate downward as it sinks into hotter and less dense asthenosphere.

An accurate understanding of these driving mechanisms must await additional theoretical and experimental studies. Basalt lava spews out of the spreading ocean ridges, and andesite lava is produced at subduction zones. Less common, but impressive, outpourings of lava also occur in the interior of plates, thousands of kilometers away from the plate edges. A case in point is a west-to-northwest-trending linear chain of volcanoes located in the center of the Pacific plate, the Hawaiian Islands Figure 3—9a. Mantle plumes are places where molten rock originates deep below the asthenosphere, probably very near the outer core. This molten rock rises and melts its way through the lithosphere, spilling out as lava on the top of the plate Figure 3—9c.

With time, large quantities of lava are added to the pile, creating a vol- Aleutian Islands Andes Mountains None Himalayan None San Andreas weak to strong intensity to moderate intensity www. Many such cones rise out of the water as islands. Eventually, the motion of the plate, as a result of sea-floor spreading, transports the newly formed island beyond the mantle plume cutting off its supply of lava.

At this stage, the island stops growing, and erosion begins to wear down its rocks. Concurrently, a new volcanic island forms updrift over the plume and grows in size until drift takes it, too, beyond its source of lava. The growth of volcanic islands by mantle-plume injection results in the formation of a linear chain, such as the Hawaiian Islands. The islands become older, more eroded, and lower in elevation downdrift. Chains of volcanic islands that trace the path of a plate over a hot spot have been discovered all over the world.

Recent findings indicate that mantle plumes are not fixed in place as originally thought. Convection in the asthenosphere drags lithospheric plates away from the crests of ocean ridges. Note the drift track of India and its eventual collision and suturing with Asia, raising the Himalayas. The Himalayas were raised when the ocean sedimentary layers were crushed between the two continental masses. This photograph was taken out of the window of the space station from an altitude of nautical miles.

Running along the center of the Red Sea is a narrow trough with an average depth of about 1, meters 3, feet. Basalt—new ocean crust—is being injected into this deep axial trough as Arabia drifts away from Africa. In effect, the Red Sea is a miniature ocean Figure B3—4c , a classic juvenile ocean basin that is slowly widening as a result of sea-floor spreading. Ross, Mineral Resources Bulletin 22 : 1— It appears as if the Red Sea basin began to develop some 20 million to 30 million years ago as the granitic crust of East Africa and Arabia was stretched until it broke apart along a system of normal faults.

These large faults have splintered the thick granitic crust into large blocks see Figure B3—4c. Their presence indicates that much of the ocean dried up periodically as its water was evaporated and salt deposits were laid down on its bottom. To imagine what this was like, fill a glass with seawater and leave it in the sun for a few days. What will happen, of course, is that the water will disappear because of evaporation, and the bottom of the glass will be encrusted with salt. Not only is there salt on the sea floor, but the water itself, which fills the deeps of the axial trough—such as the Atlantis II deep Figure B3—5 , the Discovery deep, and the Oceanographer deep—is unusually salty. It is so much saltier than normal seawater that it is referred to as brine. The source of the unusual salt and metal content of the water in these deeps is the flow of groundwater subterranean water through fractures in the underlying rocks.

This briny groundwater is heated as it flows through the hot crust, becoming corrosive and leaching metals from the basalt rocks. Groundwater flowing through fractures in the basaltic crust is acidic and corrosive. These hot salty fluids leach out metals from the rocks. When they seep out of fractures, the very dense water is trapped in the deeps. Backer, Erzmetall 26 : — As the levels of dissolved metals iron, manganese, copper, silver, lead, and zinc build up, many of them are precipitated as sulfide deposits that impart bright colors to the sediment. Geochemical surveys indicate that the metal deposits of the Atlantis II deep are sufficiently concentrated to be exploited commercially. Several field tests indicate that it is feasible to mine this resource. High-pressure water jets large, powerful hoses in effect lowered from a vessel could convert the bottom sediment into a mud slurry, which would then be pumped to the surface at a rate estimated to be about , tons each day!

This enormous volume of slurry would have to be processed aboard the mining vessel while at sea, because it would be too expensive to transport it to land. Unfortunately, once processed, the residue would become a major waste-disposal problem, because it contains highly toxic heavy metals. Engineers have developed a processing technique whereby only 1 percent of the metal concentrate would be transported to a smelter on land. Marine life is sparse at those depths in the Red Sea so the engineers reason that the effect of the metal toxins on the ecosystem of the area would be minimized.

Oceanic crust, once created, will slowly move away from the axis of the ridge. This means that the sea floor will have a speed. The sea floor is moving slowly, such that its speed cannot be measured directly with a stopwatch. Yet we can easily determine its speed its spreading rate by noting the age of the sea floor at any distance from the ridge. The older the sea floor is, the farther it will be from the ridge axis. Also, the faster the rate of sea-floor spreading, the farther the sea floor of a particular age will be from the ridge axis.

First, assume that we obtain a piece of basalt kilometers from the ridge axis and determine its age to be 10 million years old. This implies that this rock took 10 million years to travel a distance of kilometers. The number 10 million can be expressed as i. When you divide powers of 10, you merely subtract the exponents. When you multiply powers of ten, you merely add their exponents. This is the spreading rate for that side or flank of the midocean ridge. Some biologists believe that life itself may have begun at the bottom of the sea in sea-floor geysers located at spreading ridge crests.

These hydrothermal vents may have been sites where raw inorganic materials were miraculously shaped by chemical reactions into simple organic compounds that ultimately led to the origin of life some four billion years ago. Recently, a synthesis of satellite measurements, computer models, and laboratory experi- ments seems to verify that magnetic polarity reversals are the result of complicated convective flow patterns in the electrically conducting, liquid iron of the outer core. For the first time, theory and computer models are providing clues about how polarity reversals have occurred in the past and how they may occur in the future. Work continues on these fruitful lines of research. Finally, mountain belts, such as the Himalayas and Alps, are being mapped in detail. Their complicated patterns of deformed rocks are revealing important insights into collisions between continents along subduction zones.

Geologic and paleontological evidence supports the existence in the geologic past of an immense landmass known as Pangaea Figure 3—1b. This process is called continental drift. Studies of the magnetic properties of the sea floor reveal that the crests of the midocean ridges are sites where new oceanic crust is forming. The divergence of the basaltic crust away from the crestline of the ridge—a process called sea-floor spreading—leads to the expansion of ocean basins Figure 3—2a and to the drift of the continents.

The repeated flipping back and forth of the geomagnetic poles causes basalts ejected at spreading ocean ridge crests to be normally and reversely magnetized, giving rise to a symmetric pattern of magnetic anomaly stripes that run parallel to the ridge axis Figures 3—3 and 3—5. These magnetic anomaly stripes can be used to date the basaltic rock and to calculate the rate of sea-floor spreading. Basaltic crust is being destroyed at subduction zones, which are associated with volcanic arcs and deep-sea trenches. Here, large slabs of rock are being compressed as they converge and override one another, producing an inclined plane of earthquakes called the Benioff zone Figure 3—6b.

The lithospheric plates are cold, rigid, and brittle, and overlie a hot, ductile plasticlike layer of the mantle, the asthenosphere. Lithospheric plates have three kinds of boundaries Table 3—1 : spreading ridges that are under tension, where new lithosphere is formed; subduction zones that are under compression, where lithosphere is destroyed; and transform faults, where lithosphere is preserved as plates slip laterally strike-slip motion past one another.

The vast majority of volcanoes are formed at plate boundaries. Other volcanoes form along the crests of spreading ocean ridges as well, as lithospheric plates diverge and lava spills out of fractures onto the sea floor. These hotspots are now known to be mobile and not fixed as was originally believed. Ocean basins undergo a regular evolutionary history related to plate tectonics Figure 3— A narrow, embryonic basin forms between the splintered pieces of a continent; expands into a broad, mature ocean basin by the mechanism of sea-floor spreading; declines into old age as the basin is consumed by subduction; and disappears as colliding continental masses become tightly sutured together and form an immense mountain belt on land. Explain the concepts of continental drift, seafloor spreading, and global plate tectonics. How are they similar and how are they different? What exactly is a magnetic anomaly, and why does it appear as a stripe on the sea floor?

How do plate motions differ among a spreading ridge, a transform fault, and a subduction zone? Which of the three is characterized by the strongest earthquakes, the deepest earthquakes? How specifically have the following originated? Where in the oceans would you go to collect a sample of basalt, a sample of andesite? Give the reason for your choices. Account for the formation and symmetry of magnetic anomaly stripes associated with midocean ridges. Cite a variety of evidence that supports the notion of a continental drift, b sea-floor spreading, c subduction. Why do magnetic anomaly stripes of similar age have the same magnetic polarity, regardless of where they are discovered in the ocean? It is unlikely that magnetic anomaly stripes older than about million years will be found anywhere in the oceans. Does this mean that seafloor spreading did not occur before million years ago? In which ocean is the oldest oceanic crust likely to be found?

Explain your reasoning. Assume that you discover a series of large submarine volcanoes on the deep-ocean floor of the Pacific. How would you determine whether or 87 not these volcanoes had been created by a mantle plume? If the Atlantic, Indian, and Arctic Oceans are all expanding in size over time, what will be the fate of the Pacific Ocean in the distant future? Referring to the maps of Figures 3—7a and B3—4b, predict how the Red Sea basin will evolve over the next few hundred million years.

Referring to the maps of Figures 3—7a and B3—1, where will Baja end up several hundred million years into the future? Examine Figure 3—9a. In Figure 3—9a, has the rate of seafloor spreading varied over the past 70 million years? Convert 33 kilometers into centimeters: 4. Assume that magnetic anomaly C in Figure 3—3 is , years old. Calculate a spreading rate for the sea floor.

Now, using the calculated seafloor spreading rate, estimate the age of magnetic anomaly B in Figure 3—3. Assume that you are conducting geophysical work on the flank of a spreading ocean ridge that trends directly north-south. As the captain steers the vessel to the east, your magnetometer measures a series of magnetic highs and lows. A strong, broad magnetic high is positioned directly over the ridge crest. It is followed to the east by a magnetic low of modest width and, at 45 kilometers from the ridge crest, a narrow but prominent magnetic high. Determine the age of this latter magnetic high by consulting Figure 3—4c, and then determine the spreading rate in centimeters per year for this midocean ridge. In Problem 3 above, how many kilometers from the ridge crest would you have to sail to the west in order to be positioned over ocean crust that is 15 million years old? Consult Figure 3—9a. Given that 10 degrees of latitude equals about 1, kilometers, calculate an approximate rate of sea-floor spreading in centimeters per year for the North Pacific plate, assuming that mantle plumes do not drift over time.

What then would be the sea-floor spreading rate of the lithosphere in this case? New York: John Wiley. National Geographic. Bercovici, D. The relationship between mantle dynamics and plate tectonics: A primer. Geophysical Monograph 5— Bindeman, I. The secrets of supervolcanoes. Scientific American 6 : 36— Bloxam, J. Scientific American 6 : 68— Bonatti, E. The rifting of continents. Scientific American 3 : 96— Scientific American 3 : 44— Oceanic fracture zones.

Scientific American 5 : 40— Buffett, B. Science — Clift, P. He was a founding member of the Consortium for Ocean Science Exploration and Engagement, wrote a regular column for the journal Oceanography, and enjoyed writing for National Geographic magazine. Tom Garrison was an Emmy Award team participant as writer and science advisor for the PBS syndicated Oceanus television series, and writer and science advisor for The Endless Voyage -- a set of television programs in oceanography.

His widely used textbooks in oceanography and marine science are the college market's best sellers, and 42 years of teaching allowed him to pass his oceanic enthusiasm to more than 65, students in his career. Developed in partnership with the National Geographic Society, market-leading Oceanography: An Invitation To Marine Science 9th edition PDF , equips college students with a basic understanding of the scientific questions, complexities, and uncertainties involved in ocean use-as well as the role and importance of the ocean in nurturing and sustaining life on Earth. The 9th Edition features the work of a seasoned author and educator Tom Garrison along with new co-author Robert Ellis, an assistant professor in the Marine Science Department at Orange Coast College who has managed research projects and educational programs throughout the world.

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