instrument relative to the Earth, and the vertically averaged flow $\bar{U}^*$ can be determined. The velocity profile $U(z)$ can then be estimated over the entire water column from eqn [3].

See also

Bottom Landers. Ocean Circulation. Sonar Systems.

Further Reading

Anderson SP, Terray EA, Rizoli-White JA and Williams AJ (1999) *Proceedings of the IEEE sixth working conference on current measurement*. Piscataway, NJ: IEEE Press, 333 pp.

Baker JD (1981) Ocean instruments and experiment design. In: Warren BA and Wunsch C (eds) *Evolution of Physical Oceanography*. Cambridge, MA: MIT Press.

Collar PG (1993) *A Review of Observational Techniques and Instruments for Current Measurement in the Open Sea*. Institute of Ocean Science, Deacon Laboratory, Report No. 304.

Emery WJ and Thomson RE (1998) *Data Analysis Methods in Physical Oceanography*. New York: Elsevier.

Pinkel R (1980) Acoustic Doppler techniques. In: Dobson EF, Hasse L and Davis R (eds) *Air–Sea Interaction*, pp. 171–199. New York: Plenum Press.

PROPAGATING RIFTS AND MICROPLATES

Richard Hey, University of Hawaii at Manoa, Honolulu, HI, USA

doi:10.1006/rwos.2001.0095

Introduction

Propagating rifts appear to be the primary mechanism by which Earth's accretional plate boundary geometry is reorganized. Many propagation episodes are caused by or accompany changes in direction of seafloor spreading. Propagating rifts, oriented at a more favorable angle to the new plate motion, gradually break through lithospheric plates. A propagator generally replaces a pre-existing spreading center, causing a sequence of spreading center jumps and leaving a failed rift system in its wake. This results in changes to the classic plate tectonic geometry. There is pervasive shear deformation in the overlap zone between the propagating and failing rifts, much of it accommodated by bookshelf faulting. Rigid plate tectonics breaks down in this zone. When the scale or strength of the overlap zone becomes large enough, it can stop deforming, and instead begin to rotate as a separate microplate between dual active spreading centers. This microplate tectonic behavior generally continues for several million years, until one of the spreading boundaries fails and the microplate is welded to one of the bounding major plates. Active microplates are thus modern analogs for how large-scale (hundreds of kilometers) spreading center jumps occur.

Propagating Rifts

Propagating rifts are extensional plate boundaries that progressively break through mostly rigid lithosphere, transferring lithosphere from one plate to another. If the rifting advances to the seafloor spreading stage, propagating seafloor spreading centers follow, gradually extending through the rifted lithosphere. The orthogonal combination of seafloor spreading and propagation produces a characteristic V-shaped wedge of lithosphere formed at the propagating spreading center, with progressively younger and longer isochrons abutting the 'pseudofaults' that bound this wedge. Although propagation rates as high as 1000 km per million years have been discovered, propagation rates often have similar magnitudes to local spreading rates. **Figure 1** shows several variations of typical mid-ocean ridge propagation geometry, in which a pre-existing 'doomed rift' is replaced by the propagator.

Geometry

Figure 1A shows the discontinuous propagation model, in which periods of seafloor spreading alternate with periods of instantaneous propagation, producing *en echelon* failed rift segments, fossil transform faults and fracture zones, and blocks of progressively younger transferred lithosphere. **Figure 1B** shows the pattern produced if propagation, rift failure, and lithospheric transferral are all continuous. In this idealized model a transform fault migrates continuously with the propagator tip, never existing in one place long enough to form a fracture zone, and thus V-shaped pseudofaults are formed instead of fracture zones. **Figure 1C** shows a

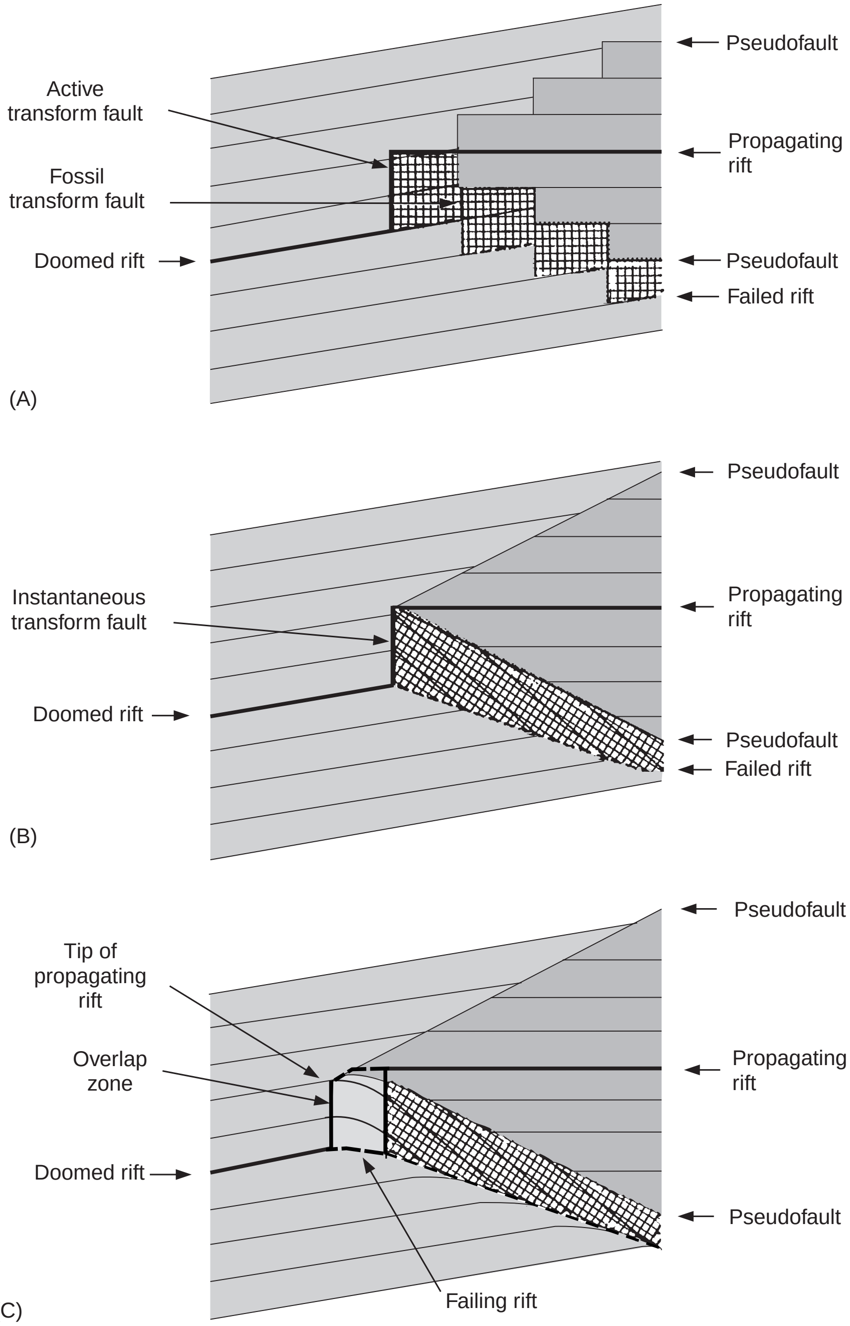

Figure 1 (A) Discontinuous, (B) continuous, and (C) non-transform zone oceanic propagating/failing rift models. Propagating rift lithosphere is marked by dark stipple, normal lithosphere created at the doomed rift is indicated by light stipple, and transferred lithosphere is cross-hatched. Heavy lines show active plate boundaries. In (C), active axes with full spreading rate are shown as heavy lines; active axes with transitional rates are shown as dashed lines. The overlap zone joins these transitional spreading axes. (Reproduced with permission from Hey *et al.*, 1989.)

geologically more plausible model, in which the spreading rate accelerates from zero to the full rate over some finite time and distance on the propagating spreading center with concomitant decreases on the failing spreading center, so that lithospheric transferral is not instantaneous. Instead of a transform fault, a migrating broad 'non-transform' zone of distributed shear connects the overlapping propagating and failing ridges during the period of transitional spreading. Deformation occurring in this overlap zone is preserved in the zone of transferred lithosphere, cross-hatched in **Figure 1.** This zone is bounded by the failed rifts and inner (proximal) pseudofault. Even more complicated geometries occur in some places on Earth where the doomed rift, instead of failing monotonically as the propagator steadily advances, occasionally itself propagates in the opposite direction. In these 'duelling propagator' systems, both axes curve toward each other. Even in simple propagator systems, the failing rift often curves toward the propagating rift, resembling the smaller scale overlapping spreading center '69' geometry (*see* **Mid-Ocean Ridge Tectonics, Volcanism and Geomorphology**), but with about a 1:1 overlap length to width aspect ratio, in contrast to the 3:1 aspect ratio characteristic of overlappers.

Classic plate tectonic geometry holds for the area outside the pseudofaults and zone of transferred lithosphere, but rigid plate tectonics breaks down in the overlap zone where some of the lithosphere formed on the doomed rift is progressively transferred to the other plate by the rift propagation and resulting migration of the overlap zone. Shear between the overlapping propagating and failing rifts appears to be accommodated by bookshelf faulting, in which, for example, right-lateral plate motion shear produces high angle left-lateral slip, apparently along the pre-existing abyssal hill faults. This produces oblique seafloor fabric, with trends quite different from the ridge-parallel and -perpendicular structures expected on the basis of previous plate tectonic theory. **Figure 2** is a shaded relief map of the type example propagating rift, at 95.5°W along the Cocos-Nazca spreading center. This propagator is breaking westward away from the Galapagos hot spot through 1 million-year-old Cocos lithosphere at a velocity of about 50 km per

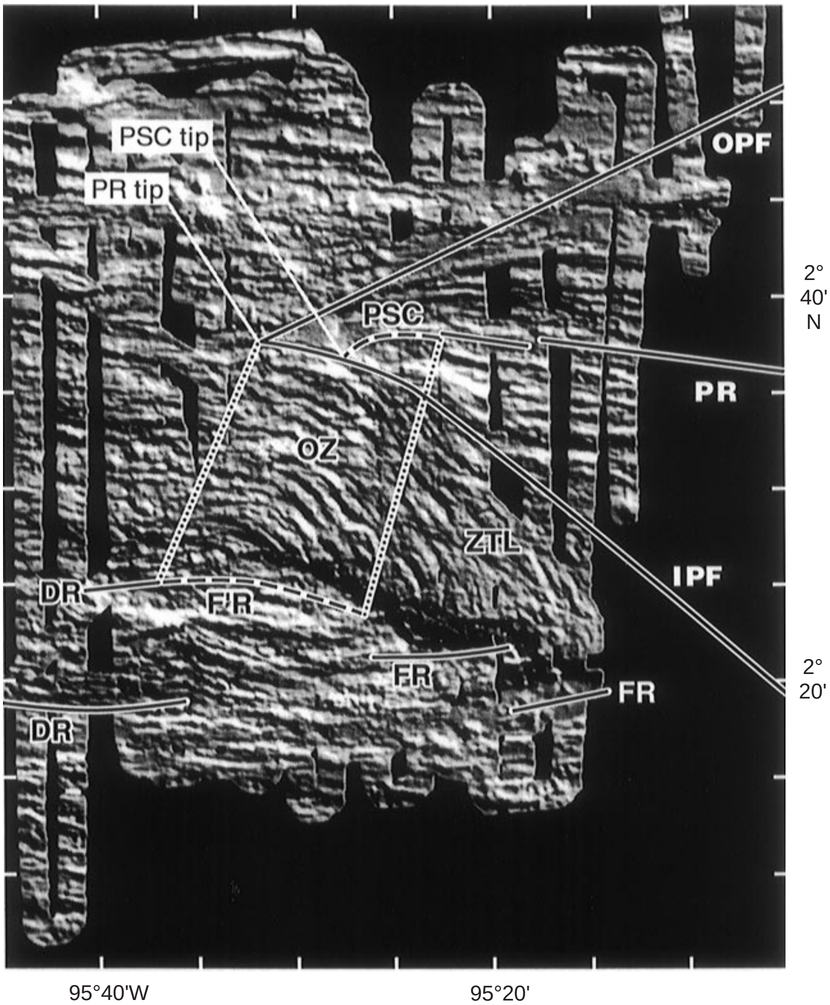

Figure 2 Shaded relief map of digital seabeam swath bathymetry at the Galapagos 95.5°W propagating rift system. The relative plate motion is nearly north–south. Propagation is to the west. The oblique structures in the overlap zone and its wake, the zone of transferred lithosphere, are clearly evident. PR, propagating rift; PSC, propagating spreading center; OPF, IPF, outer and inner pseudofaults; OZ, overlap zone; ZTL, zone of transferred lithosphere; DR, doomed rift; F'R, failing rift; FR, failed rift grabens. (Adapted with permission from Hey *et al.*, 1989.)

million years. Well organized seafloor spreading begins about 10 km behind the faulting, fissuring, and extension at the propagating rift tip. This 200 000 year time lag between initial rifting and the rise of asthenosphere through the lithospheric crack to form a steady-state spreading center suggests an asthenospheric viscosity of about 10^{18} Pa-s. The combination of seafloor spreading at about 60 km per million years and propagation produces a V-shaped wedge of young lithosphere surrounded by pre-existing lithosphere. The propagating rift lithosphere is characterized by unusually high amplitude magnetic anomalies and by unusual petrologic diversity, including highly fractionated ferrobasalts. This propagator is replacing a pre existing spreading system about 25 km to the south, and thus spreading center jumps and failed rifts are being produced. Although propagation is continuous, segmented failed rift grabens seem to form episodically on a timescale of about 200 000 years. This has produced a very systematic pattern of spreading center jumps, in which each jump was younger and slightly longer than the preceding jump. The spreading center orientation is being changed clockwise by about 13°, and more than $10^4\,\text{km}^3$ per million years of Cocos lithosphere is being transferred to the Nazca plate. The active propagating and failing rift axes overlap by about 20 km, and are connected by a broad and anomalously deep zone of distributed shear deformation rather than by a classic transform fault. Most of the seismic activity occurs within this 'non-transform' zone, where the pre-existing abyssal hill fabric originally created on the doomed rift is sheared and tectonically rotated into new oblique trends. Simple equations accurately describe this geometry in terms of ratios of propagation and spreading rates, together with the observed propagating and doomed rift azimuths. For example, for the simplest continuous propagation geometry, if u is the spreading half rate and v is the propagation velocity, the pseudofaults form angles $\tan^{-1}(u/v)$ with the propagator axis, and the isochrons and abyssal hill fabric in the zone of transferred lithosphere have been rotated by an angle $\tan^{-1}(2u/v)$.

Thermal and Mechanical Consequences

The boundaries of the Galapagos high amplitude magnetic anomaly zone, of the ferrobasalt province, and of the spreading center jumps identified from magnetic anomalies, are all essentially coincident with the pseudofaults bounding the propagating rift lithosphere. All of these observations can be explained as mechanical and/or thermal consequences of a new rift and spreading center breaking through cold lithosphere, with increased viscous head loss and diminished magma supply on the propagating spreading center close to the propagator tip. This leads to an unusually deep axial graben, unusually extensive fractional crystallization, and unusually high petrologic diversity.

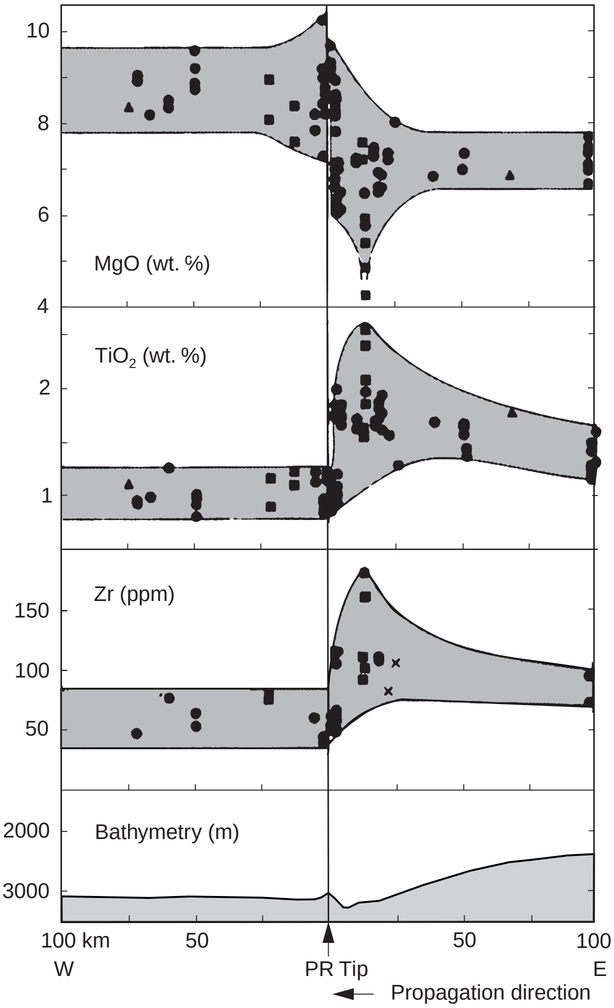

Figure 3 Relationship between lava compositions and distance from the 95.5°W propagating rift tip at the time of eruption. Bathymetric profile shows depth variation along the present-day spreading axis. (Reproduced with permission from Hey *et al.*, 1989.)

Basalt glasses erupted along propagating rifts are generally more differentiated than those erupted on normal and failing rifts (**Figure 3**). Furthermore, the Galapagos 95.5°W propagating rift lavas display a striking and unusual compositional diversity, in marked contrast to the narrow compositional range of basalt glasses from the adjacent doomed rift segment. With extremely rare exceptions, ferrobasalts (or FeTi basalts, enriched in iron and titanium) are confined to the wedge of propagating rift lithosphere. The compositional variation of the propagator lavas has been shown to be primarily attributable to shallow-level crystal fractionation of normal mid-ocean ridge basalt parental magmas (*see* **Mid-ocean Ridge Geochemistry and Petrology**), controlled by a balance between the magma cooling and supply rates. The observed variation in erupted lava compositions reflects the evolution of the rift from initial spreading toward the steady-state buffered magma chamber configuration of a normal spreading center. Lava compositions define gradients in mantle source geochemistry roughly centered about the Galapagos hot spot near 91°W. These data indicate that the 95.5°W propagator tip represents a boundary in mantle source geochemistry, implying that this rift propagation can be related to plume-related subaxial asthenospheric flow away from the hot spot. All six known active Galapagos propagators are propagating away from the Galapagos hot spot.

Causes of Rift Propagation

One important observation is that many rifts and spreading centers propagate down topographic gradients away from hot spots or shallow ridge axis topography. Rift propagation in the Galapagos area is associated with and probably caused by plume-related asthenospheric flow under and away from the Galapagos hot spot. This flow generates gravitational stresses on the shallow spreading center segments near the hot spot that promote crack propagation away from the hot spot. Flow of asthenosphere into these cracks produces new lithosphere at propagating seafloor spreading centers. Regionally high deviatoric tensile stresses associated with regional uplift provide a quantitatively plausible driving mechanism. Crack growth occurs when the stress concentration at the tip, characterized in elastic fracture mechanics by a stress intensity factor, exceeds some threshold value that is a function of the strength of the lithosphere. Propagation can be driven by excess gravity sliding stresses due to the shallow lithosphere near the hot spot, which is almost, but not quite, counterbalanced by the resisting stress intensity contribution due to the local tip depression. The spreading center propagation rate is limited by the viscosity of the asthenosphere flowing into the rift. The overlap/offset ratio of propagating and failing rifts tends to be ~ 1, close to the ratio at which the stress intensity factor is maximized (*see* **Mid-Ocean Ridge Tectonics, Volcanism and Geomorphology**).

Although many rifts appear to propagate in response to hot spot-related stresses, others appear to propagate because of stresses produced when changes in plate motion occur. A common mechanism in the Northeast Pacific producing such changes and propagation appears to be subduction-related stresses. This probably explains most of the massive reorganizations of the spreading geometry as the Pacific-Farallon ridge neared the Farallon-North America trench, although some propagation away from a hot spot has also occurred in the Juan de Fuca area. Propagation may be produced in many ways over a wide range of scales.

Discussion

Propagating rifts form new extensional plate boundaries and rearrange the geometries of old ones, with the numerous consequences already discussed. These include the formation of anomalous structural, bathymetric, and petrologic provinces; the formation of pseudofaults instead of fracture zones; and the transfer of lithosphere from one plate to another, as well as spreading center reorientations, jumps, and failed rifts.

Propagators that replace pre-existing spreading centers always seem to result in at least slight spreading center reorientation. Whether rifts propagate in response to changes in direction of seafloor spreading, or the spreading direction changes while the rift propagates, rift propagation is the primary mechanism by which many seafloor spreading systems have adjusted to changes in spreading direction. Spreading center jumps are a predictable consequence of rift propagation if there is a failing rift. The largest jumps sometimes involve transient microplate formation, geometrically similar to the broad overlap zone model of **Figure 1C** but on a much larger scale.

Rift Propagation on Other Scales

The pervasively deformed zone of transferred lithosphere is characteristic of propagating rift systems in which the offset of the axes ranges from a few kilometers to more than 100 km. Below this offset width, small propagators are sometimes called migrating overlapping spreading centers (*see* **Mid-Ocean Ridge Tectonics, Volcanism and Geomorphology**), the distinction being that this smaller scale reorganization takes place completely within the nonrigid plate boundary zone, before rigid plate tectonics begins, whereas propagators break through rigid lithosphere, thus reorganizing the plate boundary geometry.

Sometimes the overlap zones between propagating and failing rifts are on very large scales, e.g., the 120 × 120 km pervasively deformed overlap zone be-

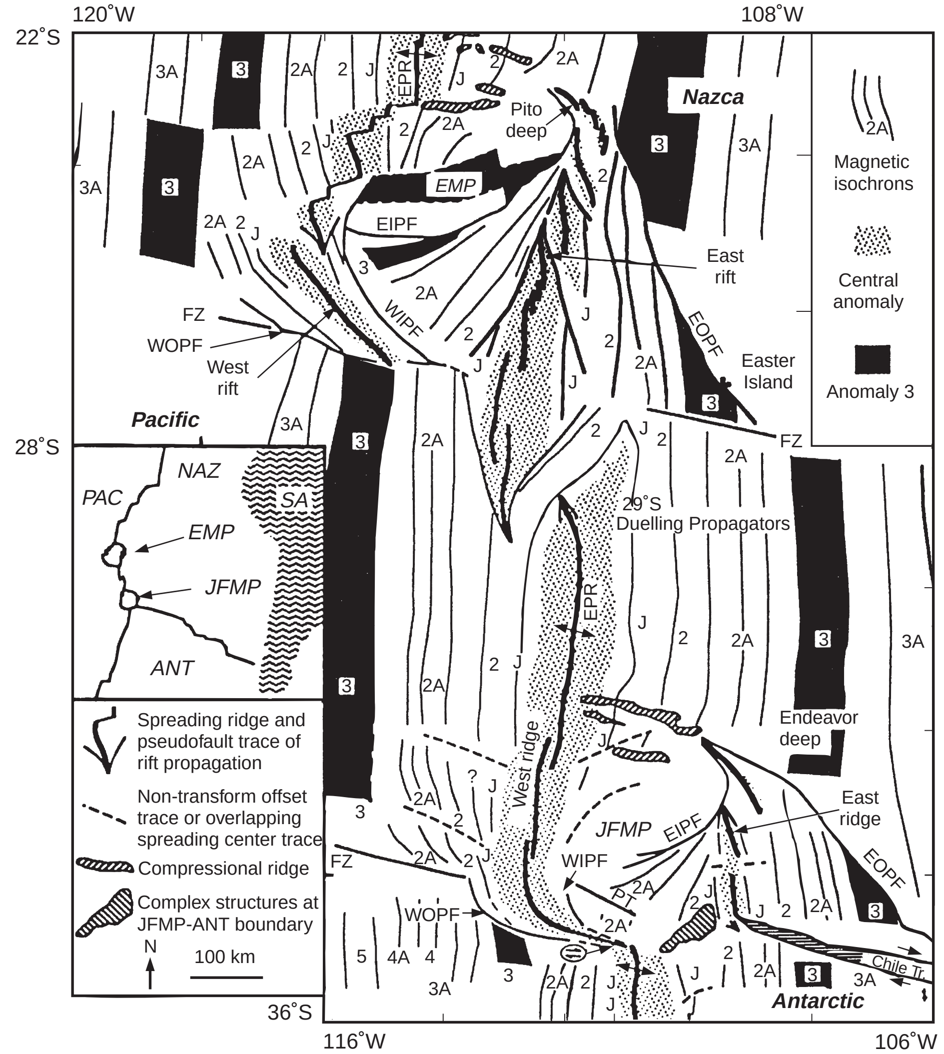

Figure 4 Tectonic boundaries, magnetic isochrons, and structures of Easter (EMP) and Juan Fernandez (JFMP) microplates. EPR, East Pacific Rise; FZ, fracture zone; WOPF, WIPF, EIPF, and EOPF are western outer and inner, and eastern inner and outer, pseudofaults, respectively. (Reproduced with permission from Bird and Naar, 1994.)

tween the giant duelling propagators southwest of Easter Island (**Figure 4**). Interestingly, both the Easter microplate just to the north and Juan Fernandez microplate just to the south of this area show evidence for pervasively deformed cores. This is interpreted as evidence for a two-stage evolution, with the deformed core formed during an early rift propagation stage, before later evolution as rapid rotation of a mostly rigid microplate about a pole near the center of the microplate. This suggests that large-scale propagation or duelling propagation could sometimes initiate microplate formation. If an overlap zone becomes too big and strong to deform by pervasive bookshelf faulting, it could instead accommodate the boundary plate motion shear stresses by beginning to rotate as a separate microplate.

Microplates

Microplates are small, mostly rigid areas of lithosphere, located at major plate boundaries but rotating as more or less independent plates. Although small microplates can form in many tectonic settings, and are common in broad continental deformation zones, this article addresses only the type formed along mid-ocean ridges. The two main subtypes – those formed at triple junctions and those formed along ridges away from triple junctions – share many similarities, and plate boundary reorganization by rift propagation is important in both settings. Although it was once thought that stable growing microplates could eventually grow into major oceanic plates, it now appears that these are transient phenomena resulting from rift propagation on such a large scale that the overlap zone eventually begins to rotate between dual active spreading centers. The best studied oceanic microplates are the Easter microplate along the Pacific-Nazca ridge, and the Juan Fernandez microplate at the Pacific-Nazca-Antarctica triple junction. Despite their different tectonic settings, they show many striking similarities (**Figure 4**).

Geometry

The scales of the Easter (~ 500 km diameter) and the Juan Fernandez (~ 400 km diameter) microplates are similar. The eastern and western boundaries of both microplates are active spreading centers, propagating north and south respectively. Both microplates began forming about 5 million years ago, and both East rifts have been propagating into roughly 3 million-year-old Nazca lithosphere. Extremely deep axial valleys occur at their tips, ~ 6000 m at Pito Deep at the northeastern Easter microplate boundary, and ~ 5000 m at Endeavor Deep at the northeastern Juan Fernandez microplate boundary. The northern and southern boundaries are complicated deformation zones, with zones of shear, extension, and significant areas of compression.

Both the Easter and Juan Fernandez microplates have large (~ 100 km × 200 km) complex pervasively deformed cores, which could have formed by bookshelf faulting in overlap zones during an initial large-scale propagating rift stage of evolution. The abyssal hill fabric and magnetic anomalies of the younger seafloor also show a later stage of growth as independent microplates, by rift propagation and seafloor spreading on dual active spreading centers, with deformation during this microplate stage concentrated along the plate boundaries and resulting from the microplate rotation. At present, both microplates are rotating clockwise very rapidly about poles near the microplate centers, spinning like roller-bearings caught between the major bounding plates. The Easter microplate rotation velocity is about 15° per million years and the Juan Fernandez velocity is about 9° per million years.

This roller-bearing analogy has been quantified in an idealized edge-driven model of microplate kinematics (**Figure 5**). If microplate rotation is indeed driven by shear between the microplate and surrounding major plates, the rotation velocity (in radians) is $2u/d$, where $2u$ is the major plate relative velocity, and d is the microplate diameter. This follows because the total spreading on the microplate boundaries must be what the major plate motion would be if the microplate did not exist. The rotation (Euler) poles describing the motion of the microplate relative to the major plates will lie on the microplate boundaries, at the farthest extensions of the rifts, which must lengthen to stay at the Euler poles because of the microplate rotation.

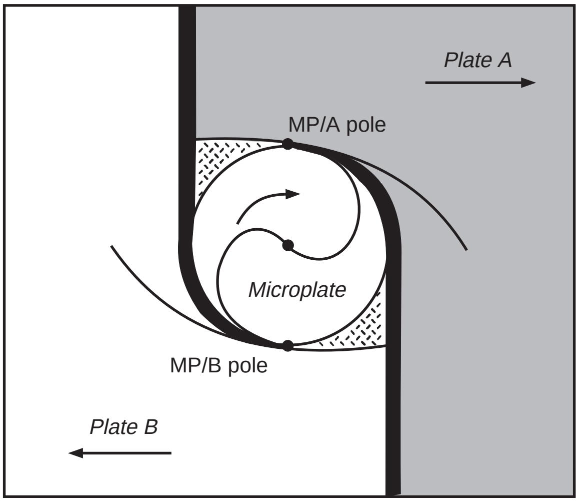

Figure 5 Roller-bearing model of microplates based on a simple, concentrically rotating bearing. The microplate is approximated by a circular plate (white) which is caught between two major plates A and B. The main contacts between microplate and major plates are also the positions of the relative rotation poles (dots). Dark shading shows major spreading centers, overlapping about the microplate. Cross-hatched corners are areas of compression. Medium curved lines are predicted pseudofaults, and arrows show relative motions. This schematic model assumes growth from an infinitesimal point to a present circular shape – the model can be extended to take account of growth from a finite width, eccentric motions, and growth of the microplate. (Reproduced with permission from Searle *et al.*, 1993.)

Evolution

This idealized geometry requires a circular microplate shape, yet also requires seafloor spreading on the dual active ridges, which must constantly change this shape. The more the microplate grows, the more deformation must occur as it rotates, and the less successful the rigid plate model will be. Although it would appear that this inevitable plate growth would soon invalidate the model, numerous episodes of rift propagation helping to maintain the necessary geometry are observed to have occurred at the Easter and Juan Fernandez microplates. These propagators all propagated on the microplate interior side of the failing rifts, thus transferring microplate lithosphere to the major plates, shaving the new microplate growth at the edges and maintaining a circular enough shape for the edge-driven model to be very successful. Although instantaneous spreading rates may be symmetric, time-averaged accration is highly asymmetric, much faster on the major plates than the microplates because of the lithosphere transferred by rift propagation. Nevertheless, some deformation is clearly occurring along the northern boundaries of both microplates, forming large compressional ridges.

According to the edge-driven model, a microplate may stop rotating if one of the bounding ridge axes propagates through to the opposite spreading boundary, eliminating coupling to one of the bounding plates. Dual spreading would no longer occur, spreading would continue on only one bounding ridge, and 10^6–$10^7\,\text{km}^3$ of microplate lithosphere would accrete to one of the neighboring major plates. There is evidence in the older seafloor record that this has happened many times before along the ancestral East Pacific Rise.

Causes of Microplate Formation

The occurrence of large, pervasively deformed cores in both microplates, probably formed during early propagating rift stages of evolution, suggests that these oceanic microplates may have originated as giant propagator or duelling propagator systems which formed overlap zones so big that their mechanical behavior had to change. This propagation could have been normal rift propagation, or from another documented type where a new propagator appears to start from near the center of a long transform fault, perhaps on a small intra-transform spreading center.

Both microplates appear to have originated at large left-stepping offsets of the East Pacific Rise. All large right-stepping offsets along the Pacific-Nazca spreading center are transform faults, while all large left-stepping offsets are microplates or the possible duelling propagator proto-microplate between the Easter and Juan Fernandez microplates (**Figure 6**). The Galapagos microplate at the Pacific-Cocos-Nazca triple junction also fits this pattern. This suggests that a recent clockwise change in Pacific-Nazca plate motion could have been an important factor triggering the formation of these microplates, although the right-stepping Wilkes transform also shows evidence for previous boundary reorganization, and the smaller scale 21°S duelling propagators are also right-stepping.

The dominant East rift of the Easter microplate, the dominant West rift of the Juan Fernandez microplate, and the dominant West rift of the duelling propagators between the microplates, are all propagating away from the Easter mantle plume (or the intersection of this plume with the ridge axis), suggesting that microplate formation as well as rift propagation can be driven by plume-related forces.

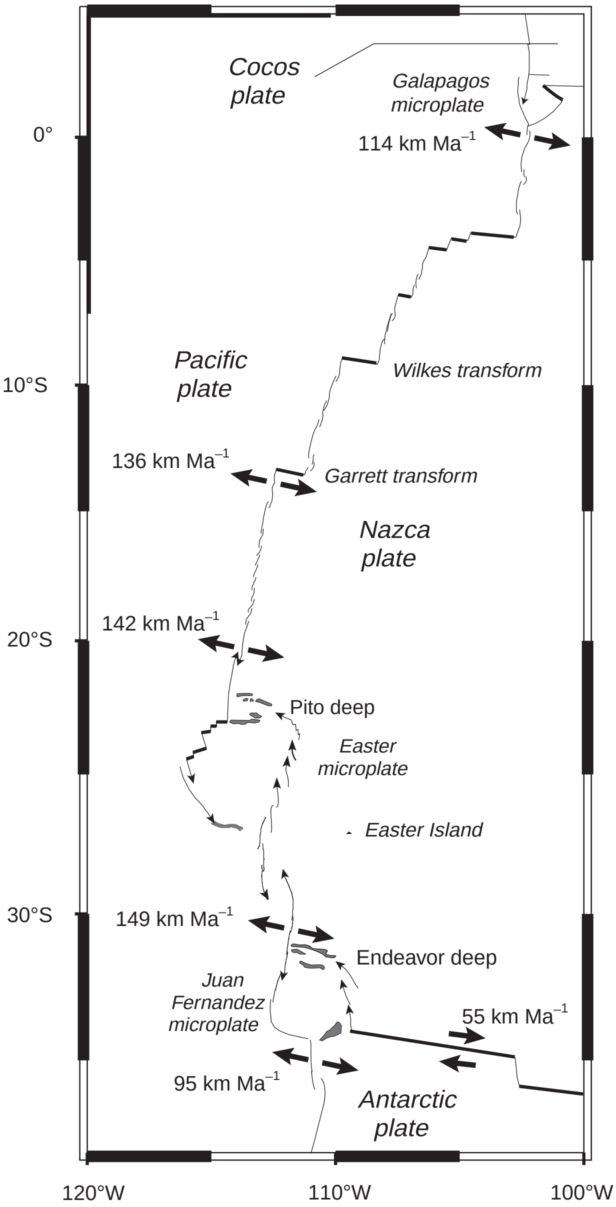

Figure 6 Plate tectonic geometry and relative plate motions along the southern East Pacific Rise. Light lines are ridges, those with arrows are propagating. Heavy straight lines are transform faults. (Adapted with permission from Hey *et al.*, 1995.)

Earth's fastest active seafloor spreading occurs in this area, and every major mid-ocean ridge segment presently spreading faster than 142 km per million years is reorganizing by duelling propagators or microplates (**Figure 6**). The combination of thin lithosphere produced at these 'superfast' seafloor spreading rates, as well as the unusually hot asthenosphere produced by the Easter mantle plume, would reduce the forces resisting propagation and thus make these plate boundary reorganizations easier, perhaps explaining their common occurrence in this area.

Summary

Rift propagation on scales ranging from overlapping spreading centers with a few kilometers offset up to several hundreds of kilometers at microplate tectonic scales, and indeed all the way up to several thousands of kilometers at continental rifting scales, appears to be the primary mechanism by which Earth's accretional plate boundary geometry is reorganized.

Although conceptually simple, the propagating rift hypothesis has important implications for plate tectonic evolution. It explains the existence of several classes of structures, including pseudofaults, failed rifts, and zones of transferred lithosphere, that are oblique to ridges and transform faults and thus previously seemed incompatible with plate tectonic theory. These are all quantitatively predictable consequences of rift propagation. It explains why passive continental margins are not parallel to the oldest seafloor isochrons, but instead are pseudofaults, bounding lithosphere created on propagating spreading centers and indicating the direction of the continental breakup propagators. It explains the large-scale reorganization of many seafloor spreading systems, including both the origination and termination of many fracture zones, as well as the formation of some transient microplates which appear to be the modern analogs of large-scale spreading center jumps. This hypothesis provides a mechanistic explanation for the way in which many (if not all) spreading center jumps occur and why they occur in systematic patterns. It explains how spreading centers reorient when the direction of seafloor spreading changes, and the origin of large areas of petrologically diverse seafloor, including the major abyssal ferrobasalt provinces. The common occurrence of rift propagation over a wide range of spreading rates and tectonic environments indicates that it represents an efficient mechanism of adjustment of extensional plate boundaries to the forces driving plate motions.

See also

Mid-ocean Ridge Geochemistry and Petrology. Mid-ocean Ridge Tectonics, Volcanism and Geomorphology.

Further Reading

Bird RT and Naar DF (1994) Intratransform origins of mid-ocean ridge microplates. *Geology* 22: 987–990.

Hey RN, Naar DF, Kleinrock MC *et al.* (1985) Microplate tectonics along a superfast seafloor spreading system near Easter Island. *Nature* 317: 320–325.

Hey RN, Sinton JM and Duennebier FK (1989) Propagating rifts and spreading centers. In: Winterer EL, Hussong DM and Decker RW (eds) *Decade of North American Geology: The Eastern Pacific Ocean and Hawaii*, pp. 161–176. Boulder, CO: Geological Society of America.

Hey RN, Johnson PD, Martinez F *et al.* (1995) Plate boundary reorganization at a large-offset, rapidly propagating rift. *Nature* 378: 167–170.

Kleinrock MC and Hey RN (1989) Migrating transform zone and lithospheric transfer at the Galapagos 95.5°W propagator. *Journal of Geophysical Research* 94: 13859–13878.

Larson RL, Searle MC, Kleinrock MC *et al.* (1992) Roller-bearing tectonic evolution of the Juan Fernandez microplate. *Nature* 356: 517–576.

Naar DF and Hey RN (1991) Tectonic evolution of the Easter microplate. *Journal of Geophysical Research* 96: 7961–7993.

Phipps Morgan J and Parmentier EM (1985) Causes and rate limiting mechanisms of ridge propagation: a fraction mechanics model. *Journal of Geophysical Research* 90: 8603–8612.

Schouten H, Klitgord KD and Gallo DG (1993) Edge-driven microplate kinematics. *Journal of Geophysical Research* 98: 6689–6701.

Searle RC, Bird RT, Rusby RI and Naar DF (1993) The development of two oceanic microplates: Easter and Juan Fernandez microplates, East Pacific Rise. *Journal of the Geological Society* 150: 965–976.

PROTOZOA, PLANKTONIC FORAMINIFERA

R. Schiebel and **C. Hemleben**, Tübingen University, Tübingen, Germany

doi:10.1006/rwos.2001.0192

Introduction

Planktonic foraminifers are single celled organisms (protozoans) sheltered by a test (shell) made of calcite, with an average test diameter of 0.25 mm. They