of a fluid element from the center of the sun; and M_r is the mass of solar material enclosed by this same radius. Consequently, large-scale convection should not occur in the solar interior. The solar model assumed in Eqs. 5 and 6 is for a nonrotating sun. Rotation would have some effect on the density profile; however, this is not expected to change the basic result, namely, that the buoyancy force is much larger than the pressure gradient. We conclude that solar models with rapidly rotating interiors are stable against large-scale convection caused by "Ekman pumping."

Conclusions regarding the rotation of the interior of the sun also must be consistent with the overall loss of angular momentum. The torque on the sun caused by magnetic forces (*8*) gives a time constant for an exponential decay of the rotation of about 7×10^9 years. If it is assumed that the sun was formed rotating at high velocities, the present magnetic torque is sufficient to slow an outer layer, thus leaving the interior in rapid rotation. However, a somewhat stronger magnetic field early in the life of the sun ($\approx$20 gauss instead of the present 3 gauss), would have been sufficient to slow the entire sun to the presently observed angular velocity. The magnetic history of the sun is not known. The work of Wilson (*9*) on stellar emissions indicates a higher level of activity early in the life of stars, which may imply stronger magnetic fields. However, it is not possible to measure stellar magnetic fields as small as 20 gauss; hence there is no direct evidence. We conclude that the existence of a rapidly rotating interior is in accord with the solar angular-momentum loss.

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Circum-Pacific Late Cenozoic Structural Rejuvenation: Implications for Sea Floor Spreading

Abstract. *The hypothesis of sea floor spreading and lithosphere plates seems to unify the origins of both oceanic ridges and volcanic arc-trench systems; therefore knowledge of well-known land areas should shed light upon sea floor tectonics. Impressive evidence of a major mid-Cenozoic discontinuity in the tectonic history of circum-Pacific land areas suggests a roughly synchronous change in sea floor development, more evidence for which may be anticipated in the future.*

The widely acclaimed hypothesis of sea floor spreading, and especially its latest refinement, the lithosphere plate hypothesis, appears to be one of those rare simplifying generalizations of knowledge that provide powerful new bases for formulating and rapidly testing questions about the earth. According to this "new global tectonics" we should expect closer worldwide relationships among continents and between the sea floors and continents than we had reason to suspect before (*1, 2*). All movements of lithosphere plates should be so interrelated that "no mid-oceanic ridge can be understood independently of the others" (*2*). If true, then students of continental structure and history should be in a position to shed considerable light upon less-known sea floor history; well-known land areas should provide tests or refinements of postulated spreading histories.

Geologists long have been impressed by a profound change in land-sea relations, sedimentation, biota, and structural disturbances near the middle of the Cenozoic era (about 25 to 30 million years ago). Recognition a century ago of such contrasts in Europe is reflected in the formal divisions of the Cenozoic, Neogene and Paleogene. Well-known major extinctions and beginnings of changes in geographic distributions among land animals and plants in mid-Cenozoic times were related to inception of profound topographic and climatic changes. In addition, prominent late Cenozoic structural disturbances have been recognized on most continents. These include the principal activity of Afro-Arabian and Baikal (Siberia) rift systems, the Victoria Land "horst" (Antarctica), Rhine graben—all with associated volcanoes—the Auvergne (France) volcanoes, and widespread elevation of mountains and plateaus (*3*).

Many circum-Pacific continental and island arc regions contain evidence of a mid-Cenozoic (about 25 million years ago) discontinuity in structural disturbances and sedimentation, which has been noted by several authors (*4, 5*). It appears that such a change was essentially universal around the Pacific, and therefore should be reflected in the sea floor if the "new global tectonics" is correct. A major stratigraphic discontinuity (unconformity) occurs widely around the Pacific margin beneath upper Cenozoic strata, and a great increase of volcanism during the past 25 to 30 million years is almost universal. In various areas severe faulting, uplift, and some metamorphism and formation of granitic masses (plutons) occurred as well. A few well-documented regions are summarized briefly below with reference citations to the most accessible literature.

Northeastern Honshu, Japan, shows a striking discordance of late Cenozoic (post-Oligocene) structural patterns with early Cenozoic ones. A prominent unconformity marks the base of Miocene strata, and great volcanic activity has characterized the past 25 million years; granitic plutons also formed (*4*). It is inferred that the Japanese trenches subsided rapidly during the latter interval as well.

Indonesia was relatively quiescent structurally in early Cenozoic time, but major mountain building commenced about 15 to 20 million years ago (late Miocene). As in Japan, granitic plutons formed, extensive faulting and folding occurred, and extreme volcanic activity commenced (*6*); simultaneously, the Java-Sumatra trench subsided profoundly. In the New Guinea-Solomon-Fiji Island belt, Miocene rocks rest unconformably upon older ones, and great volcanism has characterized the past 25 million years (*7, 8*). In southeastern New Guinea, a slight discordance between late Cenozoic and older structures is reported (*7*). Major volcanic activity commenced in New Zealand about 25 million years ago as the great Alpine transcurrent fault was reactivated (or possibly initiated). Up to 15 km of uplift occurred along that fault just in the past few million years (*9*).

Cenozoic structural and stratigraphic

discordance seems clearest in the Oregon-Washington region (Fig. 1), although evidence also is present throughout the entire North American Cordillera. Following late Mesozoic and early Cenozoic Cordilleran mountain building (from about 150 to 50 million years ago), there was a 10- or 15-million-year interval of relative structural quiescence. In late Cenozoic time (beginning about 20 or 25 million years ago), a new style of deformation characterized by wholesale fragmentation of the crust and accompanied by very widespread volcanism was imposed, and has continued to the present. Block faulting commenced in the basin and range region 25 or 30 million years ago, as did subsidence of the Snake River lava plain (*10*). Beginning about 10 or 15 million years ago, the Cascade volcanoes formed along a major north-south fracture zone that is markedly discordant with older Cordilleran structures (*11*). Small granitic plutons formed in Washington and southern British Columbia (Fig. 1). Extensive lava plateaus developed in Mexico and Central America, and in British Columbia as well (*12*). Miocene and Pliocene volcanism occurred in western California (*13*), and most intense (if not the first) transcurrent faulting of the San Andreas type formed the coast ranges from Baja California to southwestern Oregon (*14, 15*). The Gulf of California apparently began forming about 15 million years ago (late Miocene) by rifting of Baja California away from the Mexican mainland, presumably due to sea floor spreading from the East Pacific Rise (*16*). Simultaneously, the Rocky Mountain and Colorado Plateau regions suffered local igneous activity and en masse upwarping, which caused the cutting of many late Cenozoic river gorges. Late Cenozoic disturbances are so distinct from earlier patterns that they have been designated collectively the Cascadan orogeny (*15*).

The Andes Mountains of South America also show a dramatic late Cenozoic structural rejuvenation. In the past 30 million years they have been raised 5000 to 6000 m, and much thrust faulting has occurred (*12, 17*). Finally, majestic volcanic peaks were superimposed upon the upheaved and eroded older-rock complex, much as were the Cascade volcanoes in the north. Central America and the eastern Caribbean (Lesser Antilles) arc also experienced a late Cenozoic increase of volcanism (*12*).

The submarine Antarctic and East Pacific rises appear to have formed in Late Cretaceous or Early Cenozoic time

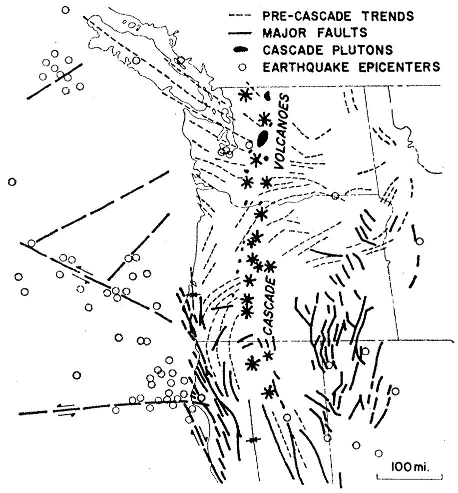

Fig. 1. Discordant tectonic patterns of the Pacific Northwest. Mesozoic through early Cenozoic pre-Cascade arcuate trends formed during the Cordilleran orogeny are transected by late Cenozoic Cascadan orogeny faulting and volcanism. Basin and range faulting appears in the southeast; Coast Range transcurrent faulting in the southwest. Note that inferred sea floor fractures do not conform closely to any onshore trends. [After (*15*); courtesy *J. Geophys. Res.*]

after the southwestern Pacific Darwin Rise (Mesozoic) had ceased to be active (*18*). But the East Pacific Rise has had a somewhat episodic history. Vine (*19*) deduced a 30° to 40° shift of spreading directions off western North America during Pliocene time. Ewing and Ewing (*20*) postulated a late Cenozoic quiescence followed by a new spreading cycle beginning about the same time (that is, about 10 million years ago) based upon discontinuity of sediment thicknesses between the rise axis and its flanks. Moore and Buffington (see *16*) inferred a similar spreading change in the Gulf of California. Such a postulated discontinuity of sea floor structural history is compatible with much-better-known late Cenozoic histories of circum-Pacific land areas where there is abundant evidence of Pliocene and Pleistocene acceleration of volcanism, faulting, and uplift (see, for example, *4, 6, 8, 9, 15, 21*).

Circum-Pacific land history would predict discovery of evidence of a discontinuity of spreading about 25 to 30 million years ago more profound than the 10-million-year-old one described above; however, little evidence of such has appeared so far. Recent comparisons of magnetic anomaly data from all of the major ocean basins suggest an impressive similarity of spreading histories (summarized in Heirtzler *et al.*, see *18*). The data also are interpreted to indicate a nearly continuous sea floor spreading cycle for at least the past 70 million years (since Late Cretaceous). Deep sea sediment–age distribution patterns also are said to support an essentially linear spreading rate, at least in the South Atlantic (*22*). But the magnitude of possible errors involved in the time scale established by LePichon and Heirtzler may be of such a size (*23*, p. 2114) that the postulated mid-Cenozoic discontinuity perhaps could be obscured. Nonetheless, in the Indian Ocean there is magnetic evidence of a possible Miocene spreading discontinuity that could correlate with well-known tectonic events on surrounding continents (*23*). In the North Atlantic there is similar evidence of a possible Oligocene-Miocene discontinuity (*24*). Lastly, a change of spreading direction, presumably dating from late Miocene time, is postulated along the Vema Fracture zone in the equatorial Atlantic (*25*). If the "new tectonics" is correct, then these scattered marine evidences may reflect the well-known onshore mid-Cenozoic tectonic discontinuity, and we may expect further evidence of this major event from the sea floor (*26*).

From the large body of available evidence, only briefly summarized above, it appears that modern volcanic arcs, and especially their associated deep trenches, may date only from mid-Cenozoic time. While there was earlier volcanism and deformation in most arcs, to be sure, there is little positive evidence that all *present* arcuate structures are simple continuations of older ones; in several cases cited above there is proven discordance. Moreover, older rocks around much of the Pacific margin tend to show structural styles and metamorphism different from late Cenozoic ones. Commonly assumed continuity of tectonic patterns through long times is more apparent than real. For example, it appears that the South Sandwich Arc between South America and Antarctica was formed in late Cenozoic time on juvenile oceanic crust some time after dismemberment of a former continuous Andean mountain belt (*27*). While it may seem radical to relegate most modern arc structures merely to the last 25 or 30 million years, it is the working hypothesis most consistent with available circum-Pacific evidence. Findings during the past decade have forced an episodic view of tectonic activity to replace older *wholly continuous* and *uniformly cyclic* views. The uniform extrapolation back in time of any process rate, either on land or on the sea floor, is almost certain to produce erroneous conclusions. LePichon (*2*) suggests that major lithosphere movements are episodic with a period of roughly 30 million years. He offers the intriguing speculation that this would be the time required to depress lithosphere slabs down along the "Gutenberg fault" (earthquake) zones to a depth of 800 km below volcanic arcs. Presumably the plates cannot be depressed further, so a modification of plate boundaries must occur to initiate a new episode of movements.

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DQ Herculis: Synchronous Photometry

Abstract. *Synchronous signal averaging, applied to the photometry of the steller system DQ Herculis in order to study the 71.1-second pulsations discovered by Walker in 1956, yields a light curve which is a pure sinusoid, within the accuracy of measurement. The binary period is increasing, probably as a result of mass lost from the system.*

The periodic variations in brightness discovered by Walker (*1*) in the old nova DQ Herculis (Nova Herculis 1934) have been studied with the technique of synchronous signal averaging first developed by Clark (*2*), in order to reduce the effects of the sporadic variations in light common to old novae and similar variables. Pulses of light from the star were counted in a 400-channel multiscaler which was carefully synchronized to the effective pulsation period (*3*) corrected for the motion of the earth in the direction of the object. The pulsation cycle was divided into 20 time segments, and 10 to 12 cycles were summed for each scan.

The light curve of the eclipsing binary system was simultaneously monitored by conventional pulse-counting techniques in order to relate each synchronous scan to the binary phase. Walker's finding that the pulsations disappear abruptly during eclipse was verified, and an estimate of the rate of disappearance was obtained: the pulsations disappear completely in one cycle, implying that the pulsating body is smaller than previously estimated and is almost certainly an extremely dense white dwarf.

A total of 35 scans, each containing the information from 10 to 12 pulsation cycles, was obtained during four nights in August 1968, on the 82-inch (208-cm) Struve reflector at McDonald Observatory. Each scan showed about the expected improvement in suppressing the sporadic "flickering," but each was still to some extent distorted by this effect. Twenty-two scans were selected, those made during eclipse and the few which were severely distorted were omitted. The ones selected were carefully aligned in phase and averaged. Figure 1 represents the best measure of the pulsation light curve which can be obtained from our data. The solid line is the best-fitting (in the sense of least squares) sine curve, with amplitude and phase selected by a two-variable differential corrector computer program. The fit is sufficiently good that any deviation from a pure sinusoid amounting to 10 percent or more would almost certainly have been detected. The power of this signal-averaging technique can best be appreciated when it is noted that the curve in Fig. 1 represents a variation of about 2 percent in the total light of this 14th-magnitude star.

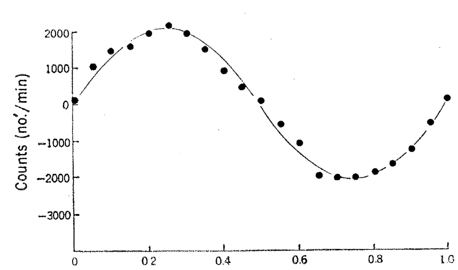

Fig. 1. Light curve obtained by synchronous signal averaging of the 71.1-second pulsations in DQ Herculis.