or elsewhere. Although a low metallic iron content of lunar material is indicated by both earth-based and Surveyor V data (*6*), the reducing conditions in the solar wind, to which the lunar surface is exposed, requires that most of the iron not be in the Fe^{+3} state. If the iron is all in the Fe^{+2} state, it is possible that radiation damage could create Fe^{+1} with an absorption maximum in the visible region of the spectrum. This species is thermally unstable and would be bleached when subjected to solar heating. However, if some Fe^{+3} is present, as is likely because of the reddish color of the moon, the presence of Fe^{+1} due to radiation damage is precluded because of the reaction

$$Fe^{+3} + Fe^{+1} \rightarrow 2Fe^{+2}$$

The most probable reaction if the powder contains the Fe^{+3}–Fe^{+2} couple is bleaching in the short wavelength side of the visible spectrum by solar ultraviolet, electrons, and protons through either or both of the following mechanisms

$$Fe^{+3} \rightarrow Fe^{+3} + \text{(trapped hole on adjacent oxygen)} + \text{(trapped electron color center)}$$

and

$$Fe^{+3} + e \rightarrow Fe^{+2}$$

where the electron in the last reaction is a photoelectron or secondary electron released elsewhere in the silicate lattice by radiation. However, if appreciable Fe^{+2} is present, which is most likely, the trapped hole reaction is unlikely because of the probable reaction

$$Fe^{+3} + \text{(trapped hole)} + Fe^{+2} \rightarrow 2Fe^{+3}$$

The only important reaction, then, of Fe^{+3} in the presence of Fe^{+2} would be the radiation-reduction of Fe^{+3} to Fe^{+2}. Because Fe^{+3} absorbs so strongly in the ultraviolet [band maximum in crystalline quartz at 2250 Å (tetrahedral coordination) (*7*); band maximum in topaz at 2350 Å (octahedral coordination) (*8*)] that the long wavelength tail of its absorption band extends well into the visible, a decrease in the Fe^{+3} content would cause the absorptivity to decrease; therefore, the transparency and reflectivity of the dust over most of the visible region of the spectrum would increase. A decrease in reflectivity in the red could also be expected in view of the increase of the Fe^{+2} band in the infrared [1.1 to 1.2 μ in acidic volcanic glass (*9*)]; however, this decrease would be minor, because of the large oscillator strength of Fe^{+3} compared to Fe^{+2}.

The discussion here is probably an oversimplification, as the smaller amounts of manganese and titanium present may also be important in these reactions. If any of the lunar surface is sialic in composition, which appears doubtful, the preceding discussion concerning iron would probably still apply. The exact mechanisms and centers involved as well as rate processes of the radiation-induced reactions must await detailed examination of lunar surface material (*10*).

The bleaching reactions that we discuss are generally reversible. Thus, when the lunar surface material is removed from sunlight (such as through burial by meteorite gardening) it will darken and, when reexposed, will slowly lighten. Because there were no discernible changes in the albedo of the throw-out from the Surveyor footpads over a period of several weeks, the time constant of the bleaching reaction must be of the order of more than a year. This rate is quite reasonable; for instance, it is well known that amethyst quartz will bleach after exposure to sunlight for several years.

Predictions of the bleaching hypothesis are as follows:

1) Surface-bleaching by photoreduction of Fe^{+3} would cause the material to become less red in color.

2) The lighter layer should be only a few particle-diameters thick.

3) If shielded for a long time from sunlight the layer should slowly darken.

4) Portions of surfaces of clods of soil which are permanently shadowed (as at high latitudes) should be darker than portions exposed to sunlight.

5) The lighter upper layer should have the same composition as the darker material. Within the large experimental errors of the Surveyor VII analyses (*5*) this prediction agrees with observations.

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10. In order to study possible chemical or physical differences between the lighter-colored top layer of lunar soil and the darker, underlying layers it is essential that the light material be as highly concentrated in a sample of soil as possible. Such concentration may be difficult because the lighter layer may be only a few particles thick. This difficulty could be circumvented by the following collection technique: if a flat piece of inert material, such as glass, were gently pressed against the lunar surface large numbers of small particles from the uppermost layers would stick to the glass because of surface-adhesive forces. Two pieces of glass could be used to pick up material and then placed with their contaminated faces together for storage and transport. A second, similar set of samples might be collected from subsurface material for comparison.

10 June 1968; revised 9 August 1968

Transform Faulting and Growth of the Gulf of California Since the Late Pliocene

Abstract. *Seismic-reflection and magnetic profiles over more than 6000 kilometers suggest that spreading of the sea floor on the East Pacific Rise, at the mouth of the Gulf of California, began to broaden a proto-gulf about 4 million years ago. Movement occurred, on transform faults, offsetting the rise and other centers of crustal growth within the gulf, and translated the end of the peninsula about 200 kilometers to the northwest. Thick pelagic sediments on the east flank of the rise indicate that there was a lapse of spreading by crustal growth between 4 and 10 million years ago.*

The Gulf of California is commonly believed to have formed by separation of the peninsula of Baja California from mainland Mexico; therefore this is a critical region for examination of hypotheses of spreading of the sea floor and continental drift. Evidence from our preliminary analyses of new geophysical data suggests that the present configuration of the gulf results from spreading of the sea floor by crustal growth beginning about 4 million years ago on the East Pacific Rise at the mouth of the gulf, and on other

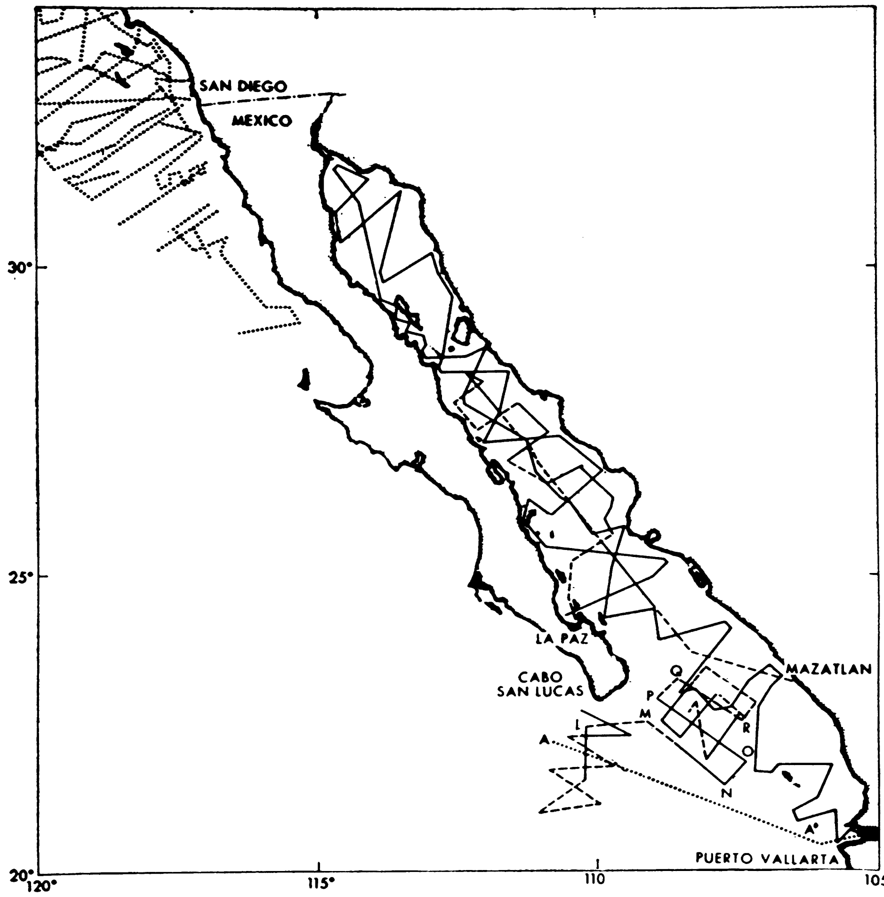

Fig. 1. Survey tracks in the Gulf of California and over the continental margin west of the peninsula. Both magnetic and reflection-profiling data were collected along tracks shown by solid lines; dashed lines show magnetic surveys only; dotted lines, reflection profiling only. Tracks off southern California are from earlier surveys. Positions of profiles in Fig. 2, A and B, are shown in the mouth of the gulf.

spreading centers, offset by faults, en echelon up the gulf (*1*).

More than 8 years ago Menard and Heezen (*2*) suggested that the East Pacific Rise (a midocean ridge) extends to the North American continent at the mouth of the gulf, and that it reappears off northern California and Oregon. Strike-slip faults of the San Andreas system (*3*) extend from near the head of the gulf to Cape Mendocino off northern California. Earlier hypotheses on the origin of the gulf called both for tectonic effects of the rise (*4*) and for strike-slip faulting (*5*) to accomplish separation of the peninsula from the mainland.

Since Vine and Mathew's hypothesis relating patterns of magnetic anomalies to reversals of polarity in a spreading sea floor (*6*), several origins of the gulf have been suggested. Wilson (*7*) related the gulf rift to a single major dextral ridge-ridge transform fault extending from the East Pacific Rise at the mouth of the gulf to Gorda and Juan de Fuca ridges north of Cape Mendocino. From bathymetric surveys Menard (*8*) showed that the East Pacific Rise, south of the gulf, was broken by offsets along relatively small fracture zones, and that it probably turned eastward toward the mouth of the gulf. On this basis, together with the topography of the gulf, Vine (*9*) and Sykes

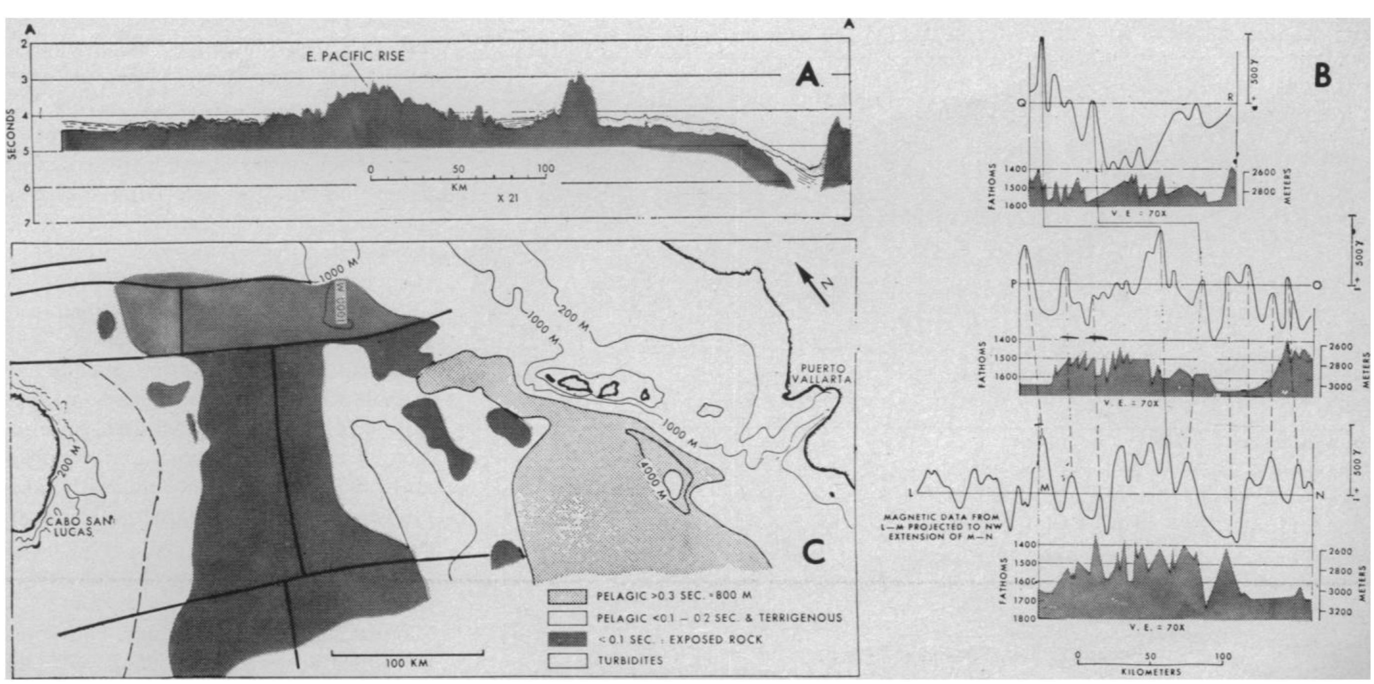

Fig. 2. (A) Line drawing of a seismic-reflection profile across the mouth of the Gulf of California; the East Pacific Rise is centered. Basement reflector is solid gray and pelagic sediments are hatched; stippled sections are probably turbidites. Unpatterned layered sediments underlying pelagics in the trench at the right are of unknown origin. Note the abrupt increase in thickness of pelagic sediments to the southeast of the seamount about 120 km from the axis of the East Pacific Rise. See Fig. 1 for location. (B) Magnetic and bathymetric profiles of the East Pacific Rise at the mouth of the gulf. See Fig. 1 for locations. (C) Areal distribution, and thickness of sediment types and exposed rock. Fracture zones and first major offset of the East Pacific Rise in the mouth of the gulf also are shown.

(*10*) (who added the evidence of earthquake epicenters) modified Wilson's hypothesis of a single transform fault to include a series of en echelon faults connecting spreading centers within the gulf. Normark and Curray (*11*) suggest that some of these faults are transcurrent where the spreading axes are forced westward away from the continental flank.

Three recent cruises by U.S.N.S. *Charles H. Davis* (AGOR-5) to the Gulf of California, the East Pacific Rise at its entrance, and the continental margin west of the peninsula have produced more than 6000 km of seismic-reflection, magnetic, and bathymetric profiles (Fig. 1).

A key seismic-reflection profile, crossing the mouth of the gulf (Figs. 1 and 2A), clearly shows the East Pacific Rise as a well-defined bathymetric feature between peninsula and mainland. The northwest flank of the rise presents the classic picture of a growing midoceanic ridge, with no measurable sediment on the active crest and with pelagic sediments thickening with distance from the axis. The southeast flank presents quite a different picture, with a less-uniformly thickening accumulation of pelagic sediments that is largely covered by an undisturbed section of well-stratified sediments. These strata, underlying an abyssal plain, were probably deposited by turbidity currents. A seamount separates these probable turbidites from a line of abrupt increase in thickness of pelagic sediments that remain uniformly thick for about 100 km to the rim of Middle America Trench near the mainland. Beneath the draped, unstratified, pelagic sediments of the trench there are downwarped layered strata.

Three significant magnetic profiles were collected (Figs. 1 and 2B). On the two most southwesterly of the three, one can clearly see the central positive anomaly, which here appears as a rather ragged, low, broad feature, and the associated topographic rise. The anomalies can be correlated with reasonable assurance, and in the northern line there is a pronounced 80-km offset to the northwest.

On the basis of the width of the central magnetic anomaly and Cox, Doyle, and Dalrymple's dating of reversals (*12*), the spreading rate on each flank of this part of the rise is about 3 to 3.5 cm/year. At a distance of 100 km on the west flank, the age of the sea floor would thus be about 3.3 million years at a point where pelagic sediment is 0.1 second (about 80 m) thick (Fig. 2, A and C). This value gives a plausible rate of accumulation for the pelagics of 2.4 cm/1000 years. In contrast, the thick, wide band of pelagic sediment on the east flank of the rise, starting about 120 km from the crest (Fig. 2, A and C), would, if the same rate of accumulation is assumed, required 10 million years for deposition.

Because of the abruptness of the change in thickness of the pelagics, we interpret this value to mean that a period of quiescence, lasting at least 6 million years, prevailed before the present cycle of spreading commenced. During an earlier active period, before deposition of the overlying pelagics, the eastward translation may have downbowed the now-buried, prominently layered strata of the trench.

In addition to the undisturbed sediments on the east flank of the rise (Fig. 2, A and C), other sections of probable turbidites have been mapped in the north end of Middle America Trench (*13*). On the basis of the apparently anomalous occurrence of these undisturbed sediments on the southeast side of the spreading cell, we suggest that, with resumption of crustal formation, the axis migrated westward.

Very striking, rectangular, bathymetric lineations are associated with the offset of the rise along the southernmost fault. On the basis of this association and positions of the earthquake epicenters we have inferred a series of spreading axes normal to the major fault lineaments extending en echelon through

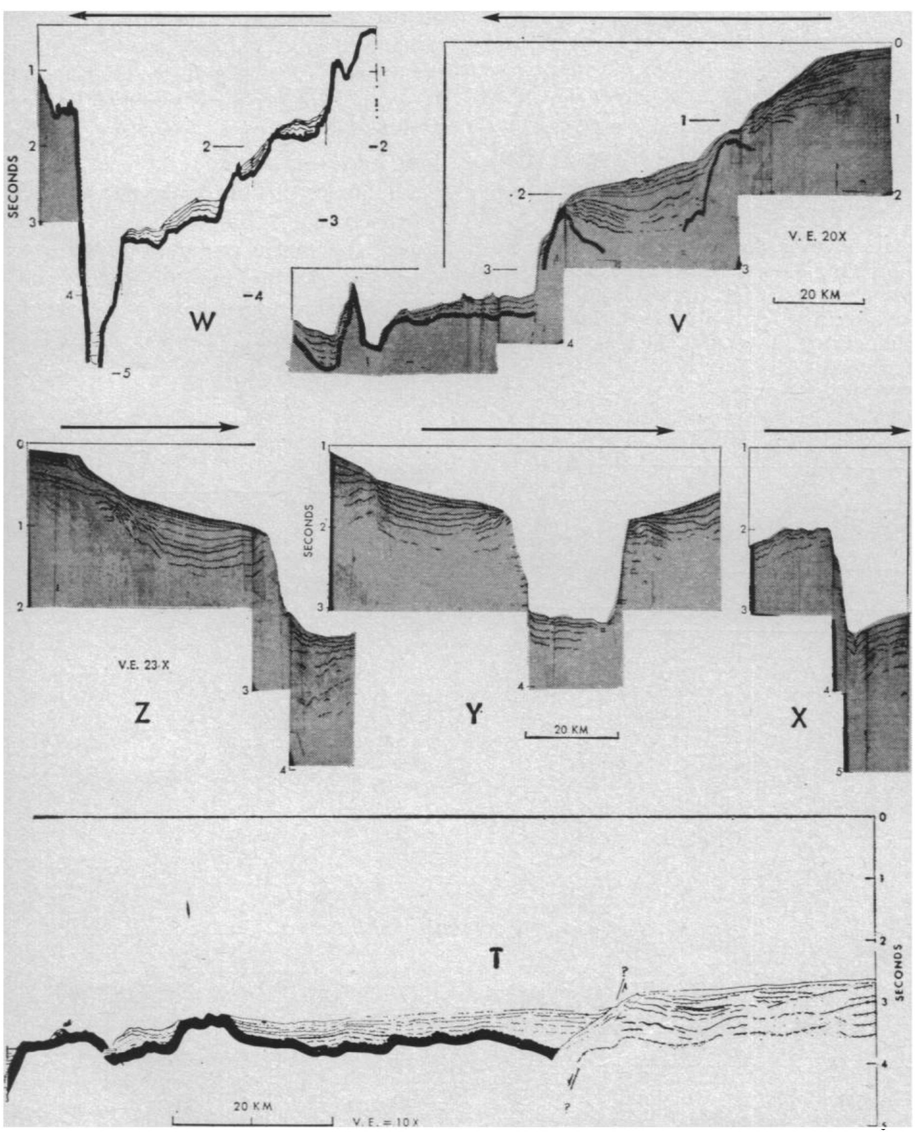

Fig. 3. Reflection profiles *V, W, X, Y,* and *Z* crossing fracture zones within the Gulf of California. Profile *T* crosses a transpeninsular fault under the Pacific west of the peninsula. Arrows match those of Fig. 4 and give positions and directions of the profiles; heavy black line, basement reflector.

the gulf. The earthquake epicenters show a remarkable parallelism with the fracture zones that form the prominent bathymetric and structural lineations.

Profiler records, crossing the two southernmost offsets (Fig. 3, *V* and *W*), emphasize the faulted nature of the bathymetric lineations. To the east of the fault bordering the southernmost offset, the Mexican mainland margin is made up of a thick section of sediments within which there is a prominent unconformity, with probably Tertiary sediments forming much of the section. West of the fault, beneath the actively spreading section, only very thin sediments cover a basement reflector (Fig. 3, *V*).

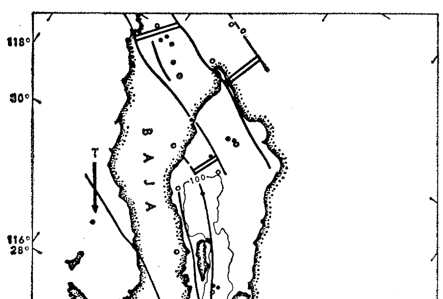

Fig. 4. Bathymetric chart of the Gulf of California. Positions of fracture zones (solid black lines) are based on reflection profiles. The crest of the East Pacific Rise, based on magnetic and seismic-reflection profiles at the mouth of the gulf, is hatched. Proposed positions of spreading centers are shown by double black lines; epicenters (*14*), by open (Gutenberg and Richter) and by solid circles (Sykes). Positions and directions of reflection profiles of Fig. 3 are shown by solid arrows.

Farther up the gulf, seismic-reflection profiles again give positive verification of the faulted nature of the basin flanks. The section of profile *X* (Figs. 3 and 4) shows faulting on the south side of a spreading cell, and profile *Y* (Figs. 3 and 4) shows a rifted trough defined by the bordering fracture zones. The latter profile also indicates that the next fracture zone, well up the slope, projects into the section as a distorted zone. Profile *Z* (Figs. 3 and 4) crosses the mainland continental terrace to its abrupt termination at a major eastern boundary lineation; again the structure indicates that the next-northeastern fracture zone may be projected into the section.

Two major faults that can be seen crossing the peninsula are the previously documented Agua Blanca fault (*15*) and, to the south, a fault newly verified by Fyfe (*16*); between them lies most of the granite pluton of the peninsula. The Agua Blanca, in particular, is known for its recent dextral movements and, by our placement of spreading axes, would be a transform fault.

Additional verification of the transpeninsular nature of the recently defined fault to the south is shown by the reflection profile *T* (Fig. 4) on the west side of the peninsula. Fyfe found that the onshore fault turned more to the west before heading out to sea. Projected on this course it coincides neatly (Fig. 3) with the major structural discontinuity seen in the reflection record.

On the basis of an axial growth rate of 3 cm/year and the distance of 120 km from the present crest of the ridge to the 1000-fathom (1830-m) isobath off the tip of the peninsula, the present cycle of spreading began about 4 million years ago. Because the spreading cell is believed to have migrated to the west, translation of the peninsula, from near the west edge of the thick pelagic sediments to its present location, occurred at a doubled rate of about 6 cm/year. Therefore, from about 4 to 10 million years ago, during Late Mionene and Pliocene time, a proto-Gulf of California existed. The earlier period of spreading of the sea floor, which is now buried by the thick pelagic sediments, also would have required about 4 million years if the peninsula was originally situated next to the mainland, south of Puerto Vallarta, and moved to its Late Miocene or Early Pliocene position at a rate comparable to that of the present cycle. The presence of relatively thick, probably Tertiary sediments on the mainland continental margin of Mexico (Figs. 3 and 4: *V*, *Y*, and *Z*) complements the idea of existence of a Late Miocene–Pliocene gulf, and is additional evidence of the existence of a regional lapse in spreading of the sea floor during much of Pliocene time.

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17. Sponsored by NAVSHIPS under SR 104 03 01 (Task 0539).

28 June 1968

Taste-Modifying Protein from Miracle Fruit

Abstract. *The active principle of miracle fruit* (Synsepalum dulcificum) *is a basic glycoprotein with a probable molecular weight of 44,000. Application of the protein to the tongue modifies the taste so that one tastes sour substances as sweet.*

A native shrub (*Synsepalum dulcificum*) in tropical West Africa yields a small, red berry that, once its pulp is chewed, causes sour substances to taste sweet. Local people often use it to make their stale and acidulated maize bread more palatable and to give sweetness