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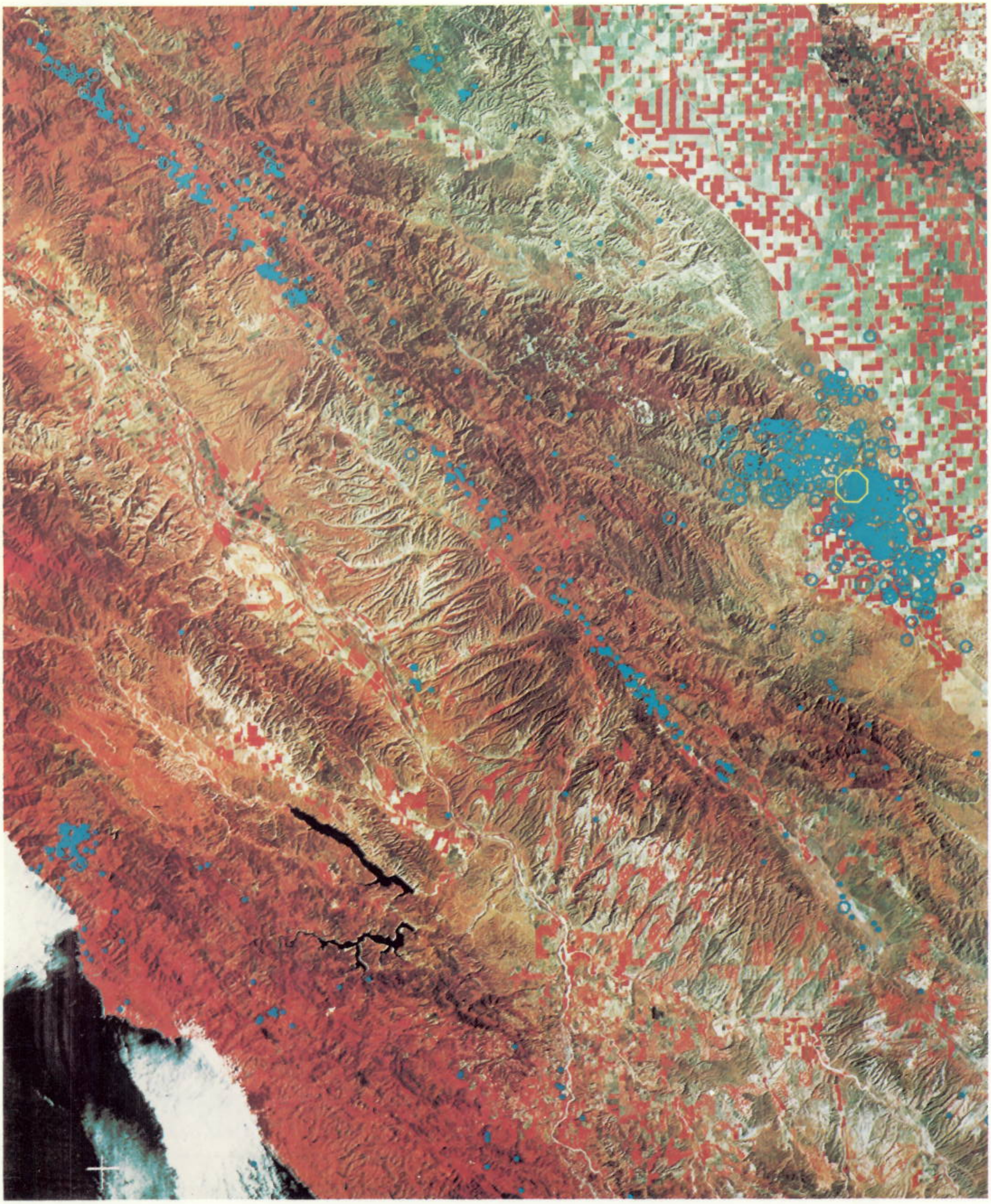

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The Weekly Newspaper of Geophysics

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Eos: The Greek goddess of dawn, representing for AGU the new light continually being shed by basic geophysical research on the understanding of our planet and its environment in space.

Contents

Cover. Central California earthquakes during 1983 on an enhanced Landsat 1 image, showing the May 2, 1983, $M_s = 6.7$ Coalinga main shock (yellow) amid its $M>3$ aftershocks (blue circles). California earthquakes, seismic sources, and premonitory deformation are among the topics to be discussed at the 1984 AGU Fall Meeting in San Francisco, Calif., December 3–7 (see meeting information and abstracts of papers to be presented at the meeting in this issue). In the cover image, the creeping section of the San Andreas fault is lit up by $M>1.5$ shocks (blue dots). (R. A. Kerr reports on J. Eaton's analysis of pre- and post-Coalinga earthquake seismicity in *Science, 222*, p. 916, 1983.) The aftershocks are located beneath Anticline Ridge, one of many Plio-Pleistocene anticlines that separate the Coast Ranges (red-brown) from the San Joaquin Valley (red and white squares). The ridge uplifted 0.5 m during the earthquake, and the Pleasant Valley Syncline (located just west of the Ridge) dropped 0.25 m, unaccompanied by surface rupture. The resemblance between the earthquake deformation and the geological structure suggests that the fold was built by repeated subsurface thrust earthquakes (see R. S. Stein and G. C. P. King, *Science, 224*, pp. 869–872, 1984). For more information, see news item on p. 794. (Photo courtesy of Ross S. Stein, U. S. Geological Survey, Menlo Park, Calif.)

News

Coalinga's Caveat

No one had foreseen that a shock as large as M_S 6.7 could strike at the eastern edge of the California Coast Ranges near the town of Coalinga. No faults of any age cut the gently folded sediments at the earthquake focus, and equally astonishing, no ground breakage accompanied the earthquake. A month would pass before surface rupture did occur, in a sequence of large aftershocks (see cover: large blue circles west of the yellow main shock) on a minor adjacent fault.

The May 2, 1983, earthquake, which caused $31 million in damage and took one life, alerted the seismological community to the earthquake potential of active folds. Leveling surveys demonstrated that Anticline Ridge (whose fold axis plunges southeast through the main shock) uplifted 0.5 m during the event, while adjacent Pleasant Valley (see cover: red and white squares immediately southwest of the aftershocks) subsided half that amount. The surface deformation is best explained by a fault that slipped over a depth of 4–12 km but does not reach the surface. Identification of earthquake risk has proceeded almost exclusively on the premise that faults capable of generating large shocks must extend to the surface. Surface faults that do not cut young deposits are not deemed active, even if the faults displace older beds at greater depth. At Coalinga, on the other hand, the fault, the seismic slip, and the aftershocks are confined to deeper and therefore older strata. The fault is invisible on seismic reflection profiles, but it is indisputably active. The surface fold which built Anticline Ridge appears to have formed as a consequence of repeated slip events at depth. From the pattern of earthquake deformation, R. Stein and G. King have argued that many folds mask subsurface thrust faults and that these folds may largely deform elastically in jumps, rather than through steady and aseismic ductile deformation. In retrospect, a number of large thrust earthquakes over the last 30 years have uplifted anticlines, dropped synclines, and produced little or no ground rupture, such as the 1964 M_S 7.5 Niigata shock in Japan. Thus, despite the paucity of bounding faults, the folded eastern margin of the California Coast Ranges must now be regarded as a possible target for large thrust events. The uplift rate of the folds should guide judgments of relative activity. Ominously, the Kettleman Hills anticline, which abuts the Coalinga aftershocks to the southeast, is rising at twice the rate of Anticline Ridge. (These processes will be discussed at the AGU Fall Meeting in the Tectonophysics session entitled "Mechanics of Large-Scale Faulting and Earthquakes," scheduled for Friday morning, December 7; see abstracts in this issue for more information.)

Another surprise which the Coalinga earthquake had in store was its proximity to the soon-to-rupture Parkfield segment of the San Andreas. Abundant evidence advanced by W. Bakun, A. Lindh, S. Nishenko, K. Sieh, and L. Sykes had implicated this 30-km-long section of the San Andreas fault (southwest to due south of the Coalinga main shock) as coming due to rupture in a moderate shock before the end of the decade. Parkfield marks the transition from the creeping and seismically active to locked and currently aseismic sections of the San Andreas (these phenomena will be considered at the AGU Fall Meeting in the Seismology special session entitled "California Tectonics," on Tuesday, December 4). The thrust fault beneath Anticline Ridge strikes parallel to the San Andreas, not east-west, as would be expected if the strain field there was dominated by shear parallel to the San Andreas. Compression axes of the main shock and larger aftershocks all point southwest, normal to the San Andreas. In 1978, B. Minster and T. Jordan resolved a 5-mm/yr component of plate motion normal to the San Andreas fault in the Coast Ranges. B. Page and D. Engebretson recently found that this departure from purely strike slip motion began abruptly 2–5 m.y. ago, coincident with and probably responsible for the major episode of compression and folding that created the California Coast Ranges. In fact, before the change in motion the entire region visible in the cover image had been planed flat. It thus seems likely that thrust and reverse faults in the Coast Ranges accommodate the interplate compression, leaving the San Andreas to pick up the much greater transform motion. Interestingly, the process that has given rise to the hidden earthquake hazard has also provided ideal traps for hydrocarbon accumulation. Oil now flows from most of the San Joaquin Valley margin folds; pumping began on Anticline Ridge in 1898.

Did the Coalinga earthquake advance or retard the time before the next Parkfield earthquake? The Parkfield segment of the San Andreas fault jumped ahead (in a right-lateral sense) during the Coalinga earthquake, consistent with a small predicted increase in failure stress, but began to creep backward for the ensuing year. This behavior, recorded on creepmeters (wires stretched across the fault), has successfully evaded all explanation. A burst of small shocks located well into the locked section of the San Andreas fault occurred 2 days after the Coalinga event (lower right corner of the cover image). However, no simultaneous or subsequent change in strain could be detected anywhere along the fault zone, and the shocks did not persist. Parkfield remains closely watched. (A more detailed treatment of this subject will be given at the Fall Meeting in the Geodesy session entitled "The Design of Geodetic Networks and the Detection of Premonitory Deformation," on Monday afternoon.)

The most tenacious question about Coalinga is which way does the fault dip, toward the Coast Ranges or toward the San Joaquin Valley (the red and white squares in the cover image)? Virtually all but the smallest aftershocks are located deeper than 7 km in what at first appeared to be a cloud but is now resolved by J. Eaton, P. Reasenberg, and D. Eberhart-Phillips into an X-shaped pattern in cross section. This result and the two nodal planes of the main shock leave both steeply northeast dipping reverse faulting or gently southwest dipping thrusting in contention.

Editorial

Student Memberships

More than 2,500 AGU members—roughly one-sixth of the total membership—are student members. Furthermore, student membership is growing at a faster rate than the total AGU membership. To date, however, students have had little direct input into how the Union is run. In order to encourage students to suggest how the Union could better serve their needs, AGU sponsored a students booth at the 1984 Spring Meeting in Cincinnati. More than one-third of the students attending the meeting stopped to talk to AGU officers at the booth.

While all of these students felt that AGU was generally doing a good job, several suggestions were made repeatedly. Some of these, such as giving students book discounts, can be implemented relatively easily. Others will require committee and Council action. To initiate this process, the suggestions received have been referred to the Education and Human Resources Committee for consideration. Included are suggestions that AGU:

- Provide a continuing mechanism for students to make their views known.
- Have some "student only" activities at the national meetings.
- Arrange for low-cost student housing at meetings.
- Establish a program to give non-grant/contract students minimal money to travel to the meetings.
- Be more active as a job broker.
- Give students special book discounts.
- Sponsor contests for the best student paper presented in each Section at the two national meetings and announce the winners in *Eos*.
- Organize a lecture series for students similar in concept to the Sigma Xi series.
- Consider exam dates when scheduling meetings.

Comments on any of these suggestions or any additional ideas would be appreciated and should be forwarded to AGU, Member Programs Division, 2000 Florida Ave., N. W., Washington, DC 20009 (telephone: 202-462-6903).

L. H. Meredith
General Secretary, 1980–1984

The leveling data favor the reverse fault, but interpretations of oil well logs have convinced industry analysts that a nearly flat-lying ramp thrust is the culprit. The Japanese have had equally rough going in trying to settle on the dip of the Niigata fault. In either case, active fold belts throughout the world now seem a little less safe and sound than they had before.

This news item was written by Ross S. Stein *at the U.S. Geological Survey, Menlo Park, Calif.*

Military Nuclear Waste Disposal

A National Research Council (NRC) panel has endorsed a plan for a proposed underground military nuclear waste disposal facility located on a site near Carlsbad, N. M. The Department of Energy (DOE) asked NRC to evaluate the geologic suitability of the site.

The NRC panel, chaired by Frank L. Parker of Vanderbilt University, concluded in its final report that "the important issues about the geology of the site have been resolved. . ." Those issues include the purity and volume of salt, the absence of brine pockets at the repository horizon in the areas excavated, the absence of breccia pipes and of toxic gases, and the nearly horizontal bedding of the salt. Thick underground salt beds have long been considered prime candidates for nuclear waste repositories. The existence of salt beds is believed to indicate long-term stability. In addition, the salt is flexible and will seal cracks and discontinuities over time.

The panel noted, however, that questions outside the scope of its study, concerning the hydrology of the site and specific engineering design of the facility, will need to be addressed before any large-scale disposal takes place.

The facility, called the Waste Isolation Pilot Plant (WIPP), is being constructed by DOE specifically for permanent storage of military- and research-generated transuranic nuclear wastes. Transuranic wastes are radioactive materials containing atoms heavier than uranium and are generated during the production of nuclear weapons and the operation of nuclear reactors. Processed and packaged radioactive waste will be lowered into the facility through a mine shaft. The storage facility is also designed for experimental emplacement and removal of a small quantity of high-level defense waste. However, no permanent storage of high-level waste is planned at this time.

Completion of the physical plant at the facility is scheduled for December 1987, but DOE says that construction is running ahead of schedule and may be completed up to a year earlier. In any event, testing, equipment checkout, and training programs will be geared to opening up the facility for the first emplacement of wastes by October 1988. The facility is expected to have a 25-year operating life. Estimated capacity is nearly 170,000 cubic m of transuranic wastes. According to DOE, 5,000–6,000 cubic m of transuranic wastes are created in the United States each year.—*DWR*

Rings of Uranus

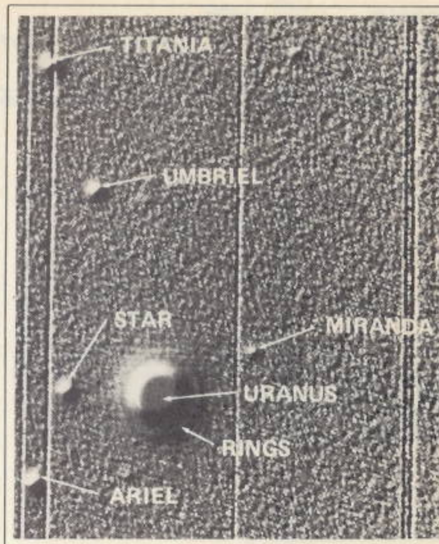

Fig. 1. Computer-enhanced photograph of Uranus' collective ring system. The three-dimensional effect is a result of computer processing. The heavy vertical lines are caused by defects in detector equipment (photo courtesy of NASA).

Using sophisticated computer enhancement techniques, two astronomers have been able to clearly "photograph" the rings of Uranus (Figure 1). The photographs show that the rings are made of particles that are perhaps the darkest found in the solar system. Creating clear images of the rings is a feat that has proved extremely difficult in the past because the rings are darker than charcoal and are very close to the much-brighter Uranus.

The astronomers, Bradford A. Smith of the University of Arizona and Richard J. Terrile of the National Aeronautics and Space Administration's (NASA) Jet Propulsion Laboratory (JPL), used a camera equipped with a charge-coupled device (CCD) to record the image at the Carnegie Institution's Las Companas Observatory in the Andes mountains in Chile.

NASA says that the new photograph is an important piece of information that will help scientists to prepare for the Voyager 2 mission, which will give researchers their first opportunity to view Uranus close up in January 1986.

Analysis using the new photograph shows that the rings reflect only about 2% of the sunlight falling on them, leading scientists to believe that the rings could be the darkest material found in the solar system. As to the composition of the rings, the new information leads the researchers to two possibilities: First, that the rings are made up of material from the outer solar system; evidence from meteorites and observations of asteroids tend to support this. Second, the rings actually could be frozen methane. Methane ice, which is normally bright, can be darkened by radiation. The rings were discovered in 1977. The widest of the nine known rings has an average width of roughly 50 km.

The Oceanography Report

H.M.S. CHALLENGER UNDER SAIL, 1874.

The focal point for physical, chemical, geological, and biological oceanographers.

Editor: David A. Brooks, Department of Oceanography, Texas A&M University, College Station, TX 77843 (telephone: 409-845-5527).

Episodic Volcanism and Evolutionary Crises

John Campsie, G. Leonard Johnson, Janet E. Jones, and James E. Rich

It has long been recognized that the fossil record is characterized by a number of major extinction episodes, but the cause of these remains a controversy. Among the many suggested factors, a correlation with major rifting events has often been postulated [e.g., *Hallam*, 1984; *Valentine and Moores*, 1970], and we feel that the implication of this deserves much greater attention. The widespread volcanism, both submarine and subaerial, associated with such mega-tectonic events with energy much greater than 10^{30} ergs, offers a natural explanation for several of the features that have been linked with extinction crises. The occurrence of widespread submarine volcanism is likely to have been especially important in promoting massive marine extinctions through chemical and biologic mechanisms. Of the numerous extinction events cited in the literature, there are five major episodes for which there is widespread agreement, and several minor ones (Figure 1). Significantly, each of these can be correlated with an important volcanic event, and the correlation is especially strong for the three more recent major crises for which data is available (Table 1). These are the ones occurring at the ends of the Permian, Triassic, and Cretaceous periods.

The Permian event coincides with the initial major rifting of the supercontinent Pangaea (7) (numbers in parentheses are keyed to Table 1 and Figure 1) and possible initial rifting of west and east Gondwanaland [*Craddock*, 1982]. This extinction event is especially noted for the replacement of brachiopods by clams. Paleozoic brachiopods, which dominated offshore habitats, were profoundly affected and never recovered. Clams, which were largely restricted to nearshore environments, after a brief interruption exhibited normal trends of diversification [*Gould and Calloway*, 1980]. The late Triassic extinction (6) coincides with initial rifting of both North America and northwest Australia [*Craddock*, 1982]. The associated mass extinction had widespread effects on marine fauna. It is estimated that nearly half the existing bivalve genera and nearly all the species failed to survive. Species of the deep neretic group were the most susceptible [*Hallam*, 1981; *Laws*, 1982]. The major extinction event at the end of the Cretaceous (3) occurred at the time of the opening of the Labrador Sea [*Srivastava*, 1978] and was concurrent with extensive global plate reorientations. This event affected virtually every ecological group but the most profoundly affected were the marine organisms which suffered 70% extinction including 90% of the plankton [*Russell*, 1979].

Each of these events is characterized by massive marine extinctions. Moreover, in each case the effects were most noticeable in the ocean [*Shimansky and Soloviev*, 1982]. This immediately suggests that while a number of mechanisms may have been operative in causing the extinctions, the most fundamental were oceanic in origin.

The process of ocean crust formation has remained unchanged for several hundred million years and is independent of the ocean studied [*Lewis*, 1983]. As plates fracture and move apart, mantle-derived basaltic melts are erupted and form new oceanic crust [*Campsie et al.*, 1984]. The initial rifting process is characterized by extensive volcanism both subaerial and subaqueous [*Hinz*, 1981; *Mutter et al.*, 1982].

Chemical data of strata pertaining to the end of the Cretaceous extinctions reveal anomalies in the abundances of iridium (Ir) and other metals [*Orth et al.*, 1982]. It is currently popular to interpret these in terms of a catastrophic meteoritic impact [e.g., *Lucke and Turekian*, 1983; *Alvarez et al.*, 1982; *Rampino and Sothers*, 1984; *Alvarez and Muller*, 1984; *Bohor et al.*, 1984]. However, we feel that these anomalies indicate the importance and pervasiveness of large-scale chemical deposits associated with the widespread volcanic activity—both submarine and subaerial—of that time. *Wenzel et al.* [1981] argue persuasively after more detailed studies that the Ir anomaly at the Cretaceous-Tertiary in the Gubbio deposits in Italy is the result of subaerial volcanism. These conclusions are from circumstantial evidence; direct measurement of high Ir enrichment in the plume from Kilauea [*Zoller et al.*, 1983] provides undisputed evidence that Ir anomalies can be the result of volcanism which in the case of Kilauea suggests it may be a result of mantle-derived magmas associated with the Hawaii hot spot. The presence or absence of Ir in volcanic emissions may relate to the properties of the mantle material from which they are derived. It is reasonable to suppose that youthful mantle material [*Campsie et al.*, 1984] is rich in volatiles, thus enabling Ir to be expelled in the form of IrF_6 (iridium hexafluoride), while older material depleted in volatiles would not show the same effect. A natural explanation is thereby provided for the presence of Ir in some volcanic events but not all.

There are two obvious routes by which volcanic activity could influence evolution—chemical and biological—and both of these exert their impact at the oceanic level. Effluents from submarine hot springs are typically depleted in magnesium (Mg) and sulphates (SO_4), but highly enriched in alkali, sulphur, and metals (i.e., cadmium (Cd), lead (Pb), etc.) known to be toxic [*Edmond et al.*, 1982; *Rise Project Group*, 1980; *Emery et al.*, 1969]. Over half of the existing ocean floor is covered by a metalliferous sediment component derived from hydrothermal vent systems. Such sediments extend over 2000 km to the west of the East Pacific Rise reflecting the shadow zone of the effluent plume which has been well mapped by the anomalous concentration of helium (He) in the water column [*Lupton and Craig*, 1981]. Vanadium (V) and iron (Fe) enriched sediments covering approximately half of the Indian Ocean have been used to map the extent of suspected hydrothermal activity [*Bostrom and Fisher*, 1971]. Fe distribution patterns show distinct maxima on active ridges. The interpretation of the Ir anomalies is consistent with this picture of widespread metalliferous deposits and is supported by the finding of increased Ir concentration in ocean sediments taken by the Deep Sea Drilling Project [*Asaro et al.*, 1982; *Officer and Drake*, 1983]. Osmium (Os) 187/186 ratios could also be interpreted as being the result of volcanic activity although *Lucke and Turekian* [1983] favor the meteoritic hypothesis.

The effect on marine life of a substantial chemical input is difficult to assess [*Cloud*, 1959]. However, the level of chemical input is related to the intensity of hydrothermal activ-

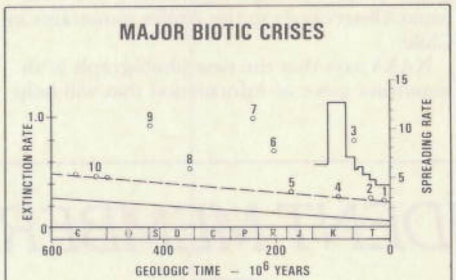

Figure 1. The relative magnitude of the extinction rate for significant Phanerozoic marine mass extinction episodes. The solid line in the figure represents the overall decline in the mean background extinction rate [*Raup and Sepkoski*, 1982]. The dashed line is the upper boundary of general data scatter. The circles are plotted to a relative scale depicting the magnitude of the extinction event. The numbers are keyed to the description in Table 1. The histogram is a sum of Atlantic and Pacific half spreading rates after *Force* [1984]. Extinction data is compiled from a variety of sources [*Newell*, 1967; *Flessa and Imbrie*, 1973; *Fisher and Arthur*, 1977; *Sepkoski*, 1982; and *Raup and Sepkoski*, 1984].