the fraction of the mean summer insolation rather than as a usual equivalent latitude. Whereas the normal presentation may be more useful to a geologist thinking in terms of shifting zones of climate, that adopted by us is far more convenient for scientists thinking in terms of radiation balance.

Whereas the 65°N insolation curve has warm peaks at 11,000, 48,000, 82,000, and 127,000 years, when the precession effect is given more weight than is tilt effect the warm peak at 50,000 years ago is largely removed; those at 127,000, 82,000, and 11,000 years ago persist, and a new peak appears at 106,000 years ago. Our results clearly indicate that the last four high stands of the sea correspond closely in time to the last four prominent warm peaks in the modified curve of summer insolation.

If the "half-response time" for glacial melting is taken to be 3000 years (adopted by Broecker to explain the lag between the present high stand of the sea and the 11,000-year insolation maxima), the high stands associated with the last three insolation maxima should have occurred about 121,000, 100,000, and 76,000 years ago. Since the 6000-year lag time is of the same order of magnitude as the present uncertainty in the absolute ages, the existence of such lags cannot now be demonstrated by radiometric dating.

In addition to demonstrating a remarkable relation between sea level and insolation maxima, we can also show that the last two changes from oceanic cold to warm conditions (11,000 ± 1000 and 126,000 ± 6000 years ago) correspond to the two greatest insolation maxima during the last 140,000 years (that is, those 11,000 and 127,000 years ago). As indicated by results of both faunal (*17*) and $O^{18}:O^{16}$ (*16*) studies, these changes were abrupt (less than 3000 years from full-cold to full-warm); by contrast, the transitions from warm to cold (especially as shown by the oxygen-isotope data) were more gradual. As suggested by Broecker (*7*) these abrupt warmings may well reflect triggering of the ocean-atmosphere system from one mode of operation to another.

Thus, as pointed out by Emiliani and Geiss (*20*), absolute chronologies of climate change certainly support the hypothesis that changes in insolation are the cause of climatic oscillations. As both quantity and precision of our data on absolute age increase, the coincidences become more numerous and exact. Therefore the often-discredited hypothesis of Milankovitch (*21*) must be recognized as the number-one contender in the climatic sweepstakes.

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Pallasitic Meteorites: Implications Regarding the Deep Structure of Asteroids

Abstract. *Olivine compositions in pallasites exhibit a bimodal distribution and indicate a high degree of internal equilibrium. Cooling rates measured in the metal phases are uniform and consistently lower than those of most iron meteorites. These factors suggest that the pallasites were derived from few parent bodies, and that they crystallized in a highly insulated site—presumably the core of their parent body. Most iron meteorites were derived either from isolated areas closer to the surface or from other parent bodies.*

The pallasites consist of large single crystals of olivine within a metal matrix. They are transitional in composition between the major groups of meteorites: stones and irons. It has long been thought that the pallasites formed at the interface of a stony mantle and a metal core, although other models have been proposed (*1*). We investigated these models by measuring certain critical chemical and physical parameters of a large number of pallasites.

Olivine is the most abundant mineral and the only silicate found in the pallasites. Its composition in meteorites in general is of particular interest; for example, chondrites are classified partly on this basis (*2*). Using an ARL microprobe, we have determined the bulk compositions, compositional gradients, and intercrystalline variations of pallasitic olivine (*3*). At least four and as many as 16 distinct olivine crystals were measured for each pallasite; all crystals were homogeneous (with a variation of less than 2 percent of the amount of Fe present), and only six meteorites displayed compositional variations between olivine crystals. Of these six, only Glorieta Mountain had compositional differences greater than 5 percent in Fe.

In order to determine the maximum differences in composition between olivine crystals within a given pallasite, samples from the opposite ends of the largest available specimens (Albin, Brenham, and Mount Vernon) were measured; no differences in composition were detected.

The measured olivine compositions (mole percentage fayalite) for 38 pallasites (*4*) appear in Fig. 1; the compositional data may be interpreted as either a skewed population or a bimodal distribution, with 85 percent of the pallasites having olivine of $Fa_{12\pm1}$; the remainder, of $Fa_{18\pm2}$ (*5*). This distribution is similar to that found by x-ray diffraction and refractive-index techniques (*6*). The chondrites show a bimodal distribution of olivine compositions, with the gap at higher contents of fayalite (*7*).

In addition to the major elements we also determined the Ti, Ni, Mn, and Ca concentrations in olivine from selected pallasites. Titanium and Ni are in extremely low concentrations—approximately 20 parts per million (ppm)—considerably below those of terrestrial olivines. Manganese, on the other hand, is present at approximately the 2000-ppm level; the abundance thus does not greatly differ from that in terrestrial olivines. The low Ca content, roughly 50 ppm, is similar to that in some olivines from deep-seated terrestrial rocks and lower than that in others (*8*).

The great compositional uniformity of individual olivine crystals and the lack of scatter between crystals indicate a high degree of internal equilibrium. The clustering of olivine compositions indicates a limited number of parent bodies. Their low Ni content, in marked contrast to that of terrestrial olivines, suggests that the olivine crystallized in equilibrium with metal; being highly siderophylic, the Ni entered the metal phase. The fact that the pallasites also seem to obey Prior's law (*6*) supports the contention that silicate crystallized in equilibrium with metal.

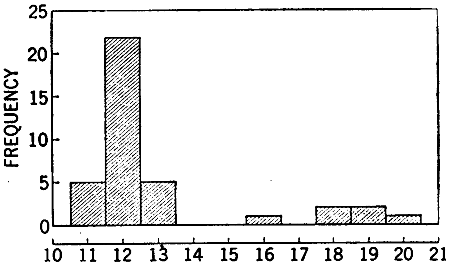

Fig. 1. Compositions of olivine in pallasites.

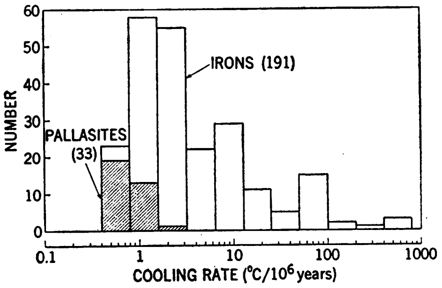

Fig. 2. Comparison of cooling rates of pallasites and iron meteorites.

The cooling rates of 33 pallasites (*3*), determined by the methods of Short and Goldstein (*9*), are shown in Figure 2; they indicate the thermal histories of the meteorites while they were at temperatures beween 700° and 350°C; they are uniformly low, ranging between 0.5° and $2°C/10^6$ years, with a median at $0.8°C/10^6$ years. The iron meteorites, on the other hand, have a wide range of cooling rates: from 0.4° to $500°C/10^6$ years, with a median at $3.5°C/10^6$ years (*10*). Only two irons (Butler and Laurens County) having cooling rates lower than the median rate of the pallasites, and only 25 percent have cooling rates of $2°C/10^6$ years or less, the maximum cooling rate of any pallasite.

Anders (*1*) has summarized the theories regarding the former location of pallasites within their parent body (or bodies). Our results permit evaluation of the several alternatives; these are that the pallasites represent: (i) the mantle-core boundary of the parent body; (ii) the contact zones of isolated metal pools surrounded by a silicate matrix, radially distributed within the parent body; (iii) the end product of a violent mixing of metallic and silicate fractions, perhaps near the mantle-core boundary; or (iv) the central part of the parent body.

Model (i), the most widely accepted theory, is based on an analogy with Earth. If one assumes no unusual thermal events, had the pallasites formed according to this model they would have been situated closer to the surface of the parent body than were the iron meteorites; consequently they would display cooling rates equal to or greater than do most of the iron meteorites; this they do not do. According to model (ii), the pallasites would have formed at varying depths; therefore we would expect a spread in both their cooling rates and olivine compositions; our results do not support this expectation. According to model (iii) we would expect the pallasites to display a range in olivine compositions and probably a range in cooling rates; that is, a lack of internal equilibrium. This model, too, is not consistent with our measurements.

A problem connected with the formation of the pallasites is that solid olivine (density, about 3.3 g/cm^3) must at one time have been suspended within metal that was probably molten

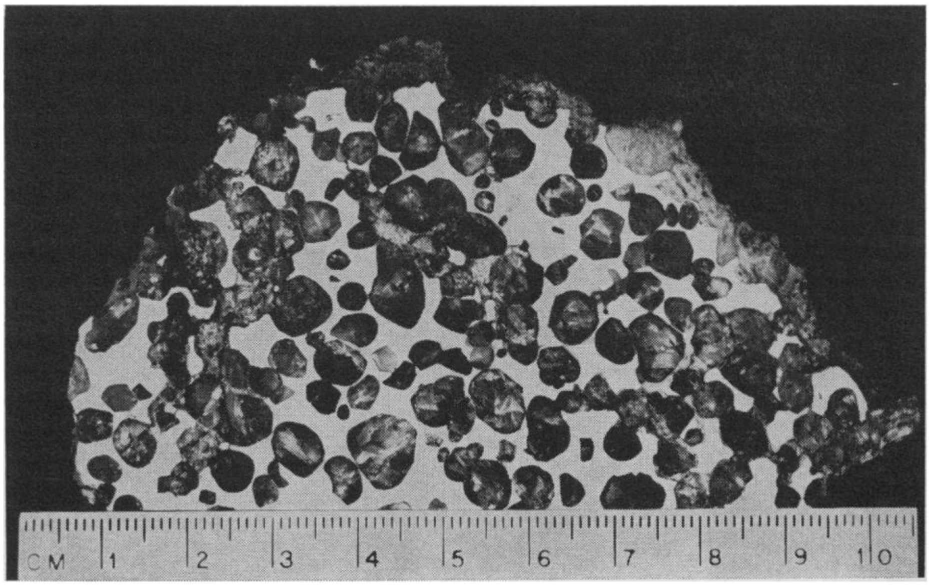

Fig. 3. Springwater pallasite, showing olivine crystals (dark) surrounded by and apparently suspended within Fe-Ni metal (light).

(density, about 8 g/cm^3) (Fig. 3). This great difference in density would normally have produced a complete physical separation of olivine and metal (*11*); such a separation is, with the possible exception of portions of Brenham and Glorieta Mountain, unobserved within the pallasites. Within the center of a parent body [model (iv)], gravitational separation would be minimized; moreover, according to model (iv) we would expect uniform and consistently low cooling rates as well as uniform olivine compositions; such features are in fact observed. Thus we feel that, despite unresolved problems connected with the energetics of core formation, our data indicate that the pallasites came from the central part of their parent body (or bodies) (*12*).

It is not known with certainty which if any of the iron meteorites formed in the same parent body as did the pallasites. If some of the irons formed within this body we can place some boundary conditions on their former locations: Iron meteorites having cooling rates as low as those of the pallasites could have occurred within or near the core; thus it is possible that a few iron meteorites occurred centrally to the pallasites. However, the bulk of the iron meteorites, having much faster cooling rates, must have been situated closer to the surface than were the pallasites. Furthermore, the faster cooling rates of many irons that may have formed in the same parent body as did the pallasites can best be explained if iron bodies were "suspended" in the mantle. Thus they would have been physically and thermally insulated from the pallasitic core by appreciable thicknesses of intervening silicates.

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Utah Jet: A Vitrinite with Aberrant Properties

Abstract. *The gem-grade jet found in Upper Cretaceous rocks of the Jet Basin, Wayne County, Utah, has been shown to be a vitrinitic, high-volatile B bituminous coal with aberrant chemical constitution. The residual structure is entirely that of taxodiaceous conifer wood. The abnormally high volatile content (62 percent) and low reflectance (0.25 percent) of Utah jet compared with other vitrinites of similar rank is produced by the unusual derivatives of cellulose and lignin of which the woody structure is composed.*

Jet is a lustrous, tough, firmly compact variety of coal that breaks with a glassy, conchoidal fracture, takes a high polish, and, compared with other coals, is rather free of shrinkage cracks (Fig. 1A). It is also remarkably stable on exposure to air—that is, it checks and weathers very little even on prolonged exposure. From prehistoric times it has been cut, polished, and used as a gemstone for both decorative and magical purposes. The classic locality is Whitby, Yorkshire, England, and vicinity, where jetified logs and smaller pieces of jet occur in lower Lias (Jurassic) carbonaceous shales (*1*). Toward the end of the past century, over a thousand persons were employed in the production of jet jewelry in Whitby, but the vogue passed, and the industry is practically extinct today. Gem-grade jet is known also from other parts of the world—Spain, for example (*2*). Although there are numerous references to jet in the literature, its petrologic nature has never been satisfactorily explained.

A variety of coal material similar in properties to Whitby jet occurs in Upper Cretaceous rocks of the Jet Basin, Wayne County, Utah. It was mined commercially for gem jet from 1919 to 1925. One of us (R.W.K.) did reconnaissance field work for the Utah Geological and Mineralogical Survey in the Jet Basin in 1964 and collected samples for analysis. The samples were collected in the SE ¼ of Sec. 22, T30S, R10E, Wayne County.

Jet Basin is a steep-walled valley located nearly on the Wayne-Garfield county line, southeastern central Utah. The basin lies on the northeast flank of Table Mountain, one of the laccolithic bodies of the Henry Mountains. Jet Basin is the breached nose of an anticlinal fold that plunges to the north (*3*). The steep southern walls of this basin are composed of gray to black, montmorillonitic marine shales of the Tununk shale member of the Mancos formation of late Cretaceous age. These shales overlie pinkish-gray sandstone and conglomerate of the Dakota sandstone.

Jet occurs discontinously in an irregular layer of carbonaceous shale, 6 to 10 feet (20 to 32 m) thick, that crops out about 15 feet stratigraphically above the Tununk-Dakota contact. The layer becomes discontinuous on the southwest and west sides of Jet Basin; in this area petrified wood occurs instead of jet. The carbonaceous shale in which the jet occurs is subjacent to a thin, dark gray limestone containing numerous fossil mollusks (*Gryphaea newberryi*).

The external morphology of large pieces of jet that have been eroded from the shale resembles that of weathered logs. Jet occurs, *in situ*, in irregu-