sized particles from the moon. Öpik (*12*) has pointed out that shock alone will not give high velocity to large particles. Although Öpik himself states that large particles can be given high velocities by the gas ball produced in an impact, it is interesting to note that most of the large crystalline fragments in the Apollo 11 sample fall in a narrow compositional range and are not shocked, as if they came from the local bedrock. The fines, on the other hand, are often strongly shocked and correspond to a much wider range of composition, including fragments that come, according to Wood *et al.* (*10*), from the highlands. It would seem that the gas propulsion process is relatively unimportant in impacts and that the main shock mechanism could either produce small particles at high speed or larger particles at low speed.

These two difficulties can both be solved if we assume that tektites are propelled from the moon not by impact but by volcanism, as suggested by Verbeek (*13*). Gas escaping into a vacuum reaches a limiting velocity V_{lim} given (*14*) by

$$V_{\mathrm{lim}} = (2c_pT)^{1/2}$$

where c_p is the specific heat at constant pressure and T is the absolute temperature. Thus, at the lunar magmatic temperature of 1200°C, V_{lim} is about 6.6 km sec^{-1} for hydrogen and 2.4 km sec^{-1} for water. Under the reducing conditions of the moon, hydrogen is a plausible gas. [Note that Kozyrev (*15*), working at 150 Å/mm, found a line at 4634 Å, near the strongest line of the blue portion of the spectrum of H_2, coming from Aristarchus (*16*).]

Note that, since particle size is a high inverse power of the velocity according to Opik, the above objection against lunar origin by impact applies with even greater force against a terrestrial origin by impact, because the velocities demanded are at least 50 percent higher in the terrestrial case.

The geochemical significance of a volcanic, as opposed to an impact, origin for the tektites lies in the fact that the materials erupted from a volcano will be expected to have differentiation ages that are nearly the same as the date of the eruption. This will be approximately true even for materials torn loose from the volcanic pile by a later eruption, since volcanism does not usually continue long at any one site. In addition, only acid volcanoes give rise to paroxysmal outbursts; the basaltic volcanoes generally produce gentler flows. The reason is believed to be connected with the viscosity of the magma; it would therefore be valid for the moon.

If tektites are really propelled by volcanism, the K-Ar clock on tektites was set not by impact but by volcanism. Volcanism is more plausible than impact because it is found impossible in the laboratory (*17*) to reset the K-Ar clock without volatilizing the rock. Laboratory treatment, like impact, involves times that are short compared with volcanic processes. The Rb/Sr ages can also be interpreted in terms of low ages of differentiation, if we are prepared to believe that the initial $^{87}Sr/^{86}Sr$ ratio (before the last stage of differentiation) was not near 0.700 but near 0.720.

Urey (*18*) has attacked the notion of a lunar origin for tektites on the ground that the tektites that missed the earth on the first pass would go into space. After a period of the order of 100,000 years, they would encounter the earth again; thus a worldwide distribution of tektites would be produced, which is contrary to fact. Urey's calculation neglects the focusing effect of the earth's gravitational field. In addition, a number of authors (*19*) have shown that tektites are rapidly destroyed in space either as a result of rotational bursting induced by solar radiation or as a result of impact by micrometeorites, and hence they do not return to the earth.

In conclusion, the glass of sample 12013 appears to be tektite glass by all the usual tests. Its constitution answers the arguments given by proponents of the terrestrial origin of tektites to the effect that only sedimentary processes can produce the typical tektite composition. There appears to be no sound reason not to say that tektites come from the moon.

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28 April 1970

Geological History of the Western North Pacific

Abstract. *A considerable portion of the abyssal floor of the western North Pacific was already receiving pelagic sediment in late Jurassic time. Carbonate sediments were later replaced by abyssal clays as the basin deepened and bottom waters became more aggressive. The resulting facies boundary, which can be recognized on seismic profiles, is broadly transgressive; it ranges in age from mid-Cretaceous in the western Pacific to Oligocene in the central Pacific. Cherts are encountered at and below the major facies boundary and appear to have been formed by postdepositional processes.*

The greatest surprise that the geologic study of the oceans has provided in the last decade is the youth of the oceanic crust as compared with the age of the crust of the continents. Geological and geophysical evidences of many sorts (*1*) have suggested that the crust grows by the accretion of mantle-derived ultramafic rocks and basalt in the axial zone of the Mid-Oceanic Ridge to form there a "volcanic oceanic basement." As newly formed basement moves away from the axial zone to make room for new additions, it ages, subsides, and accumulates a cover of sediment. Deep-sea drilling (2) is obtaining direct evidence on the age, composition, and history of the ocean floor and of the processes that operate on and within it. We shall here be concerned with the observations made on board the *Glomar Challenger* during its drilling voyage from Hawaii to Guam (3) that relate to crustal genesis and changes in water depth.

In the Pacific Ocean, the East Pacific Ridge had generally been inferred to be the site of crustal accretion (4), and samples obtained by drilling between San Diego and Hawaii in general substantiated the suggested pattern, with the ocean crust becoming progressively older westward toward Hawaii (5) (Fig. 1). Although it had been presumed that the ocean crust continued to become progressively older west of Hawaii, the pattern of crustal growth could not be inferred from the scanty data available. Drilling between Hawaii and the Philippine Sea [see (3) and Table 1] thus provides the first evidence on pre-Tertiary Pacific crustal genesis. The main portion of the northwestern Pacific fits the general model of westwardly increasing crustal ages, whereas the Philippine Sea and the area of the Caroline Ridge do not, inasmuch as they appear to have a basaltic basement of Tertiary age.

Rocks as old as Cretaceous or Jurassic were reached at nine drill sites (Fig. 2, sites 45 to 51 and 59). In every case the cherty nature of the older sediments prevented penetration into the underlying basement. However, seismic reflection profiles, when examined in conjunction with our drilling data, suggest that the oldest sediments in the Shatsky Rise area are latest Jurassic and that elsewhere in this area the crust may be older. This region appears to be within the oldest part of the Pacific Ocean and is probably the largest remnant of Mesozoic ocean floor left in existence. It may well have been formed by the Mesozoic ancestor of the present East Pacific Ridge.

A simple westward extrapolation of these general age relations of the oceanic crust (Cenozoic in the eastern Pacific, late Cretaceous in the central Pacific, early Cretaceous to late Jurassic in the western Pacific) would call for even greater ages across the Mariana Trench in the Philippine Sea. Yet our drilling failed to confirm this view:

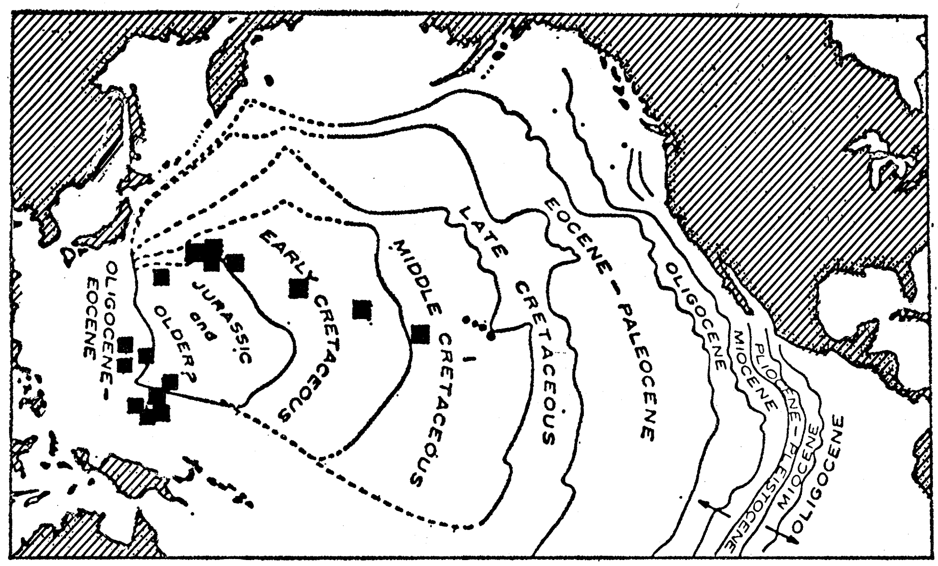

Fig. 1. Basement ages in the North Pacific and drill sites of leg 6 of *Glomar Challenger*.

at two sites (sites 53 and 54) volcanic ash lay unconformably on a basaltic complex of lava flows, one of which (site 53) contained interbedded, baked pelagic limestones of Oligocene or early Miocene age. The sequence is very much like the one exposed in Guam and Saipan (6). When taken in context with earlier seismic work (7), these findings suggest that the Philippine Sea has a rough basaltic basement of Cenozoic age, which may represent

Table 1. Summary of deep-sea drilling sites in western North Pacific.

Site	Water depth (m)	Latitude (N)	Longitude	Total depth
44	1478	19°18.5′	169°00.0′W	76 m in middle Eocene chert in carbonate ooze
45	5508	24°15.9′	178°30.5′W	105 m in chert(?) and lithified ash in Upper Cretaceous (Cenomanian) chalk and limestone
46	5769	27°53.8′	171°26.3′E	9 m in Cretaceous chert and ash in "red clay"
47	2689	32°26.9′	157°42.7′E	129 m in Upper Cretaceous (Maestrichtian) chert in carbonate ooze
48	2619	32°24.5′	158°01.3′E	84 m in Upper Cretaceous (Maestrichtian) chert in carbonate ooze
49	4282	32°24.1′	156°35.0′E	20 m in Upper Jurassic (Tithonian) to Lower Cretaceous (Neocomian) chert in carbonate ooze
50	4487	32°24.2′	156°36.0′E	45 m in Upper Jurassic (Tithonian) in carbonate ooze
51	5981	33°28.5′	153°24.3′E	132 m in Upper Cretaceous (Cenomanian) chert in carbonate ooze
52	5744	27°46.3′	147°07.8′E	69 m in Mesozoic (probably Cretaceous) ash in "red clay"
53	4629	18°02.0′	141°11.5′E	201 m in upper Oligocene or lower Miocene basalt and limestone
54	4990	15°36.6′	140°18.1′E	294 m in pre-middle Miocene basalt
55	2850	09°18.1′	142°32.9′E	131 m in upper Oligocene chalk
56	2508	08°22.4′	143°33.6′E	270 m in upper Oligocene on basalt (?)
57	3300	80°40.9′	143°32.0′E	335 m in pre-upper Oligocene diabasic basalt
58	4503 4486	09°14.1′	144°25.1′E	173 m in pre-lower Miocene basalt
59	5554 5547	11°46.8′	147°34.9′E	135 m in Cretaceous chert in "red clay"
60	3717	13°40.0′	145°41.9′E	348 m in lower Miocene volcanic ash

the basaltic carapace over a coeval ultramafic crust.

At this time we consider as less likely the alternative that in this region an earlier crust, continental or oceanic, was mantled by extensive mafic volcanism. Several models may be postulated. In one, the East Pacific Ridge may be envisioned as having extended around the northern and western margins of the Pacific basin and thus as having given rise to young crust west of the old oceanic area discussed above. The abrupt contact of young and old sea floor along the Mariana Trench can be explained by crustal swallowing in the trench. In this model, we must allow for the disappearance of the "East Pacific Ridge" from the northern and western sides of the Pacific Ocean in late Cenozoic time. An alternative model postulates areas of crustal growth separate and distinct from the Mid-Oceanic Ridge system; such a local center of growth may have been located within, or on the margin of, the Philippine Sea and may still be active. A third possibility is that oceanic crust may be made by processes other than crustal accretion in specific belts, perhaps by massive ultramafic-mafic invasion of older crust. The data presently available to us do not permit a resolution of this problem. In any case, the association of young crust with an island arc and trench system that appears to have been in existence since Eocene times or longer suggests that current concepts of the mechanics of island arcs are too simple (*8*).

Yet another surprise was provided outside the trenches on the northern flank of the Caroline Ridge (sites 55 to 58). Here Oligocene sediments rest on basalt. Unlike the mountainous basaltic basement of the Philippine Sea and the Mid-Oceanic Ridge, these basalts have a smooth, flat surface, displaced by simple step faults. Surfaces of this character underlie the sediments over large parts of the Atlantic and Pacific oceans and have been referred to as horizon B or B′ (*9*).

Our drilling has shown that such surfaces can occur on top of oceanic-volcanic complexes. Whether these basalts overlie coeval ultramafic rocks and represent true juvenile crust, or whether they mantle an older crust with its superimposed sediments in the manner of the continental plateau basalts, remains to be determined. This Caroline Ridge province abuts the Philippine Sea along the southern side of the Mariana Trench and abuts the old Pacific crust along a major east-trending fracture zone.

The areas drilled were so remote from the major land masses that terrigenous influence on sedimentation was slight. The sediments are either of pelagic type or are dominated by volcanic material—chiefly pumice ash and tuffaceous silt in varying grades of alteration to clays and zeolites. Volcanic components can be deposited at any depth. The pelagic sediments, on the other hand, are strongly influenced by the carbonate compensation depth, which in the Pacific Ocean's lower and middle latitudes lies today at about 4000 m (*10*). The shallower pelagic sediments are generally dominated by the calcareous skeletal elements of planktonic plants (Coccolithophyceae) and, to a lesser extent, Protozoa—a state that has existed at least since development of this calcareous plankton in Jurassic time. On deeper bottoms, the greater solubility of carbonate at lower temperatures and higher pressures results in the destruction of most of these minute calcareous particles either during settling or, more likely, on the sea floor, and the sediment is an insoluble or less soluble residue, generally the "red clay" (actually brown) of oceanographic literature. The boundary is not, of course, a sharp and invariable one, and the statistics of carbonate distribution relative to depth are further complicated by another factor: carbonate sediments can be, and are commonly, laid down and preserved at greater depths when brought in en masse. Thus carbonates are commonly deposited on deep abyssal plains and in trenches, where carbonate-producing banks and continental shelves give rise

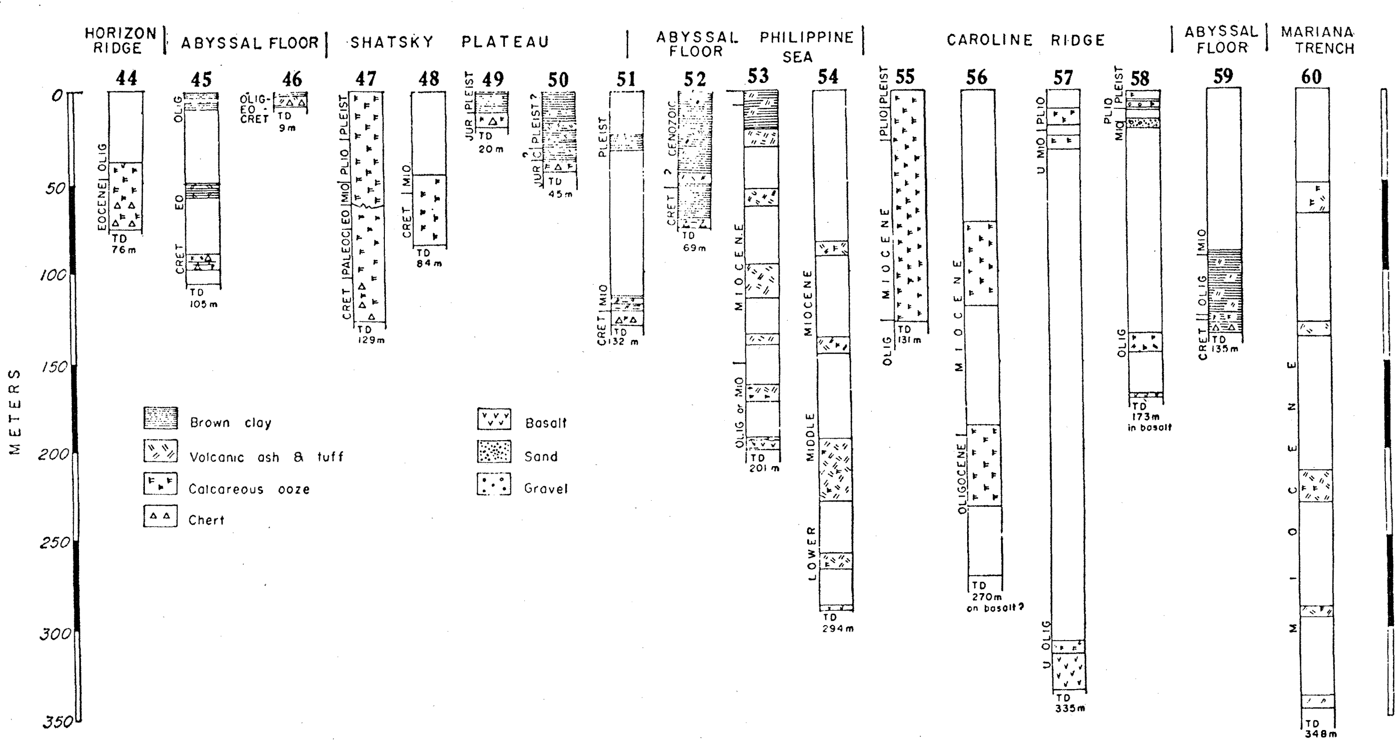

Fig. 2. Logs of holes drilled in the Western North Pacific. *TD*, total depth.

to massive episodes of transport and resedimentation by turbidity currents, mud flows, and possibly other means. Such resedimented carbonates, abundantly encountered on legs 1 and 4 in the western Atlantic, were found only at one site in the western Pacific (site 58).

The sediments encountered near the ocean floor strongly reflect the present compensation depth (Fig. 3). All seven sites drilled at water depths less than 4000 m yielded calcareous sediments throughout. Of the ten sites drilled in water over 4000 m deep, eight show brown clay in the upper part of the sedimentary sequence; of the remaining two, one did not recover sediment near the surface, and the other (site 58) is the only site that showed evidence of massive transport of carbonates and other material from nearby island areas.

Of these ten sites now located in water more than 4000 m deep, three sites yielded only brown clay, which may or may not be underlain by calcareous sediments, and five sites yielded both brown clay and calcareous sediments. Four of these sites show a distinct lower carbonate sequence and upper brown clay sequence, and one (site 59) yielded traces of Paleogene carbonate interbedded between older (Cretaceous) and younger brown clays, which suggests either a turbidite influx or a brief fluctuation back and forth across the compensation depth.

Thus not one of the sites shows, as part of its history, a clear-cut change from below compensation depth to above; that is, none shows an apparent shoaling. Four sites, however, began above and ended below it, recording an apparent deepening of the overlying water mass; all the sites may, in fact, have undergone such deepening in their history.

Such apparent deepening could reflect either a marked depression of the carbonate compensation depth or an actual deepening of the ocean above the respective site. At sites 49 and 50, the compensation depth was crossed in mid-Cretaceous time; at sites 45 and 51, in the late Cretaceous; and at site 53, in the Miocene or Pliocene. Response to an ocean-wide gradual change in the compensation depth would have provided a consistent relationship between the present water depth of the drill sites and the time at which they dropped below the carbonate compensation depth. Since such a relationship was not observed, we must conclude that the main factor recorded has been subsidence of the sea floor relative to sea level. This subsidence may be related to the lateral movements of the sea floor away from sites of crustal accretion. We do not eliminate the possibility of fluctuations in compensation depth, but we conclude that such changes played a minor and modifying role at most.

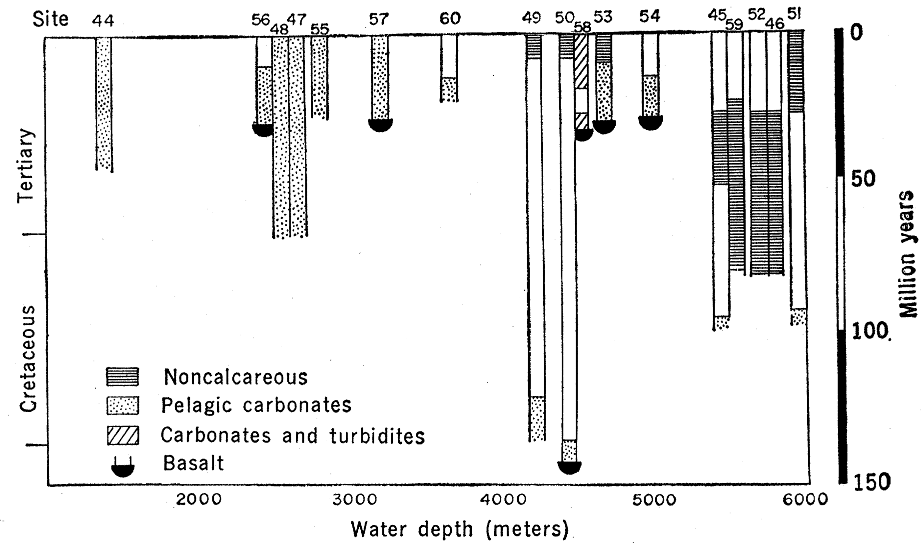

Fig. 3. Distribution of calcareous and noncalcareous sediments with age and water depth in the western North Pacific.

Chert or flint is a common sedimentary rock, which is formed mainly within sediments after burial. Its time of formation and mode of origin are surrounded by much uncertainty. The main source of silica for chert in marine sediments is probably the opaline skeletons of organisms such as diatoms, Radiolaria, and sponges. Chert has been the most serious single obstacle to deep-sea drilling. The best drilling bits available destroy themselves on less than a meter of chert because of the lack of control on bit weight inherent in an unstable drilling platform and the slow rotary speeds imposed by a long unsupported drill string subject to oscillations.

We encountered chert in two main forms: as vitreous "flints" in chalky sediments and as impure turbid beds in sequences of brown clay, which commonly contained fossil relicts or radiolarian skeletons.

Opaline skeletons and chert were found to be mutually exclusive. Skeletal opal was commonly abundant in sediments extending back to the Oligocene but is rare in older beds. A trace of chert was found in the Oligocene of site 44, where the Eocene contains massive cherts that stopped penetration, and Cretaceous and Jurassic sediments were found to contain chert wherever encountered.

This pattern of distribution suggests alternative explanations. The growth of chert, at the expense of opaline silica, may proceed exceedingly slowly on the ocean floor, possibly with some built-in delay mechanism (organic matter) that keeps the opal intact for the first 25 million years; in this case, the Oligocene cherts are growing at the present time and Miocene chert will grow in the future. Alternatively, there was a different environment of diagenesis on the sea floor in the Mesozoic and early Cenozoic, which permitted chert to form quickly but then inhibited its growth from the Oligocene onward.

Seismic reflection profiles from the abyssal Pacific characteristically record an upper layer with few internal reflecting horizons (*9*). This upper "transparent" unit generally overlies a sequence of closely spaced, highly reflective interfaces, collectively referred to as the "opaque layer," which in turn overlies a so-called "lower transparent layer." This latter member lies on a highly reflective lowermost reflector, which is generally accepted as the oceanic crust. Before drilling commenced, the thin beds of the "opaque layer" were assumed to be turbidites possibly derived from a hypothetical nearby elevation for which the name Darwin Rise was proposed (*11*). Our results suggest that the opaque layer is not a clastic sequence but, instead, an alternating sequence of pelagic ooze and chert. The only clastics encountered were found in the Caroline area overlying Neogene basalt. Thus, the Darwin Rise faces abandonment as a useful working hypothesis. The sequence of layers described above was initially assumed to be time stratigraphic (*9*). The drilling results indicate that the boundary between the "upper transparent layer" and the "opaque layer" is broadly transgressive, ranging from Oligocene south of the Hawaiian Islands to mid-Cretaceous east of the Mariana-Bonin arcs.

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3. The *Glomar Challenger* has completed five legs of its drilling cruise in the Atlantic Ocean and five legs in the Pacific. The drilling reported here was accomplished on leg 6, Hawaii to Guam, from 11 June to 5 August 1969. A total of 125 cores with an aggregate length of 684 m were recovered from 17 drill sites.
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29 January 1970

Jupiter: His Limb Darkening and the Magnitude of His Internal Energy Source

Abstract. *The most accurate infrared photometric observations (8 to 14 microns) to date of the average limb darkening of Jupiter have been combined with the most refined deduction of jovian model atmospheres in which flux constancy has been closely maintained in the upper regime of radiative equilibrium and a much more accurate approximation of the 10- and 16-micron vibration-rotation bands of ammonia has been incorporated. The theoretically predicted emergent specific intensity has been multiplied by the spectral response function and folded (mathematically convolved—intersmeared) with the spatial response function of the atmosphere-telescope-photometer combination. The resulting comparison indicates that Jupiter is radiating from three to four times as much power as the planet is receiving from the sun.*

In the next decade it is likely that spacecraft missions will be launched to all of the remaining known planets of the solar system (*1*). Jupiter, the most gigantic member of this group of celestial bodies, has been a source of profound enigmas (*2*). One of the most significant of these has been the suggestion that he may be radiating energy at a rate that is greater than that at which he is receiving energy from the sun. For example, by making bolometric observations of the jovian reflected sunlight, Taylor (*3*) deduced that the jovian effective temperature (that of a blackbody of equivalent bolometric luminosity), if Jupiter's only source of energy is the sun, should be 105°K. He compared this with the brightness temperature at 8 to 14 μ (that of a blackbody of equivalent surface brightness or specific intensity in the same wavelength range) of 128°K and suggested that Jupiter was radiating two to four times as much energy as he was receiving from the sun. Unfortunately, the 8- to 14-μ band pass contains a very small fraction of the jovian thermal spectrum, and, although brightness temperatures at other wavelengths have also been higher than 105°K by varying amounts, the collection of such measurements cannot be synthesized into a bolometric result because of the absence of measurement over significant wavelengths where extraterrestrial radiation is blocked by the earth's atmosphere. Direct bolometric observations made from high-flying aircraft have yielded an effective temperature of 134°K (*4*). However, the absolute calibration of such measurements is difficult and the proper correction for residual absorption in the earth's atmosphere is especially uncertain. The suggestion of the jovian power excess is thus confirmed, although the question of its magnitude invites further discussion.

One approach to the problem of the total luminosity of Jupiter is through the predictions of a model atmosphere for which the true effective temperature is a characteristic parameter. We have approached this problem in terms of a comparison between observed limb darkening in the 8- to 14-μ band pass and the theoretically predicted brightness distribution.

The basic theoretical approach to the determination of the model atmospheres has been described (*5*). In general, it is assumed that the lower regime of the model is convective and that radiative equilibrium prevails in the region above the level at which ammonia condenses. In the models hydrostatic equilibrium is assumed. The source of continuous opacity to thermal radiation lies in the pressure-induced translational and translational-rotational interactions in molecular hydrogen and hydrogen-helium mixtures (*6*). Although the ammonia band absorption is a rather insignificant contributor to the mean opacity (hence to the tem-