A PROTOTYPE FLUX-PLATE HEAT-FLOW SENSOR FOR VENUS SURFACE HEAT-FLOW DETERMINATIONS.

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Introduction: Venus is the most Earth-like planet in the Solar System in terms of size, and the densities of the two planets are almost identical when self-compression of the two planets is taken into account [1]. Venus is the closest planet to Earth, and the simplest interpretation of their similar densities is that their bulk compositions are almost identical. Models of the thermal evolution of Venus predict interior temperatures very similar to those indicated for the regions of Earth subject to solid-state convection [2, 3], but even global analyses of the coarse Pioneer Venus elevation data suggest Venus does not lose heat by the same primary heat loss mechanism as Earth, i.e., seafloor spreading [4]. The comparative paucity of impact craters on Venus has been interpreted as evidence for relatively recent resurfacing of the planet associated with widespread volcanic and tectonic activity [5]. The difference in the gross tectonic styles of Venus and Earth, and the origins of some of the enigmatic volcano-tectonic features on Venus, such as the coronae, appear to be intrinsically related to Venus heat loss mechanism(s) [6, 7]. An important parameter in understanding Venus geological evolution, therefore, is its present surface heat flow.

Venus Heat Flow: Assuming that Venus and Earth have similar concentrations of heat producing elements, the present steady-state mean surface heat flow of Venus has been calculated as 63 mW m^{-2} [8]. However, from the morphology and distribution of impact craters on Venus, and thermal arguments summarized by Turcotte [6], evidence suggests that Venus may not exhibit steady-state heat loss, but episodic heat loss with a time-scale of several hundred Ma [6]. As Venus is now several hundred Ma since its last episode of major heat loss, it is predicted to have a large average lithospheric thickness (~300 km) and below steady-state mean surface heat flow [6]. The fundamental test of these predictions is to measure Venus surface heat flow.

Measurement of Venus Surface Heat Flow: Heat-flow determinations typically have two components: measurement of the vertical thermal gradient, $\partial T/\partial z$, where T is temperature, z is depth, and the gradient is positive if temperatures increase downward; and measurement of thermal conductivity, K, in the rock or sediment in which the thermal gradient is measured. Conductive heat flow, q, is then given by:

$$q = K\, \partial T/\partial z$$

from Fourier's Law. In terrestrial land heat flow measurements the gradient is measured in a borehole 100 m or greater in depth, below the effects of convective groundwater heat transfer. In marine measurements the gradient is measured in the upper 5-10 m of sediment where the bottom temperature is stable.

Drilling a borehole on Venus would be impractical because of the high surface temperatures (~500^{o}C). Sediment is collected in sand dunes on the Venus surface [9], and these dunes may allow the penetration of heat flow probes, but they are unlikely to be attractive targets for other lander studies. Venera lander surface images indicate insufficient sediment at their landing site for penetrating probes, but they show flat rock surfaces around the landers.

An alternative heat-flow measuring device is the flux plate in which heat is measured flowing through a relatively thin "plate" by measuring the temperature difference across a layer of known, or calibrated thermal conductivity. The lower surface of the plate is placed in contact with the surface from which heat loss is to be measured, and heat loss from the upper surface of the plate is to the atmosphere. The areal dimensions of the plate are large with respect to its thickness so that edge effects are minimized. Similar flux plates are used in the laboratory divided-bar apparatus for measurement of rock thermal conductivities [10]. Flux plates are not suitable for terrestrial heat-flow determinations because surface temperature fluctuations prevent meaningful near-surface heat-flow measurements. However, the constant cloud cover and very dense atmosphere of Venus result in very stable surface temperatures. Globally averaged heating rates at the surface are only 0.001 K day^{-1} [11], a small fraction of surface heating rates on the Moon and Earth, and suitable conditions for use of a flux-plate for surface heat-flow determinations.

Prototype Flux-Plate Heat-Flow Sensor: Before the complications of survival in the hostile Venus' surface environment were tackled, a prototype flux-plate heat-flow sensor was built and tested for use under synthetic stable terrestrial surface conditions. The design parameters for this prototype were that it should operate on a conforming (sand) surface, with a small, self-contained power and recording system, capable of operating without servicing for at least several days. The precision and accuracy of the system should be < 5 mW m^{-2}.

Figure 1 shows the basic design of the prototype flux-plate heat-flow sensor and the dimensions and design details are given in the figure caption. A test surface was constructed through which a variable heat flow could be passed into a fixed temperature atmosphere, and diagrammatic details of this system are shown in Figure 2, with details of the systems given in the figure caption.

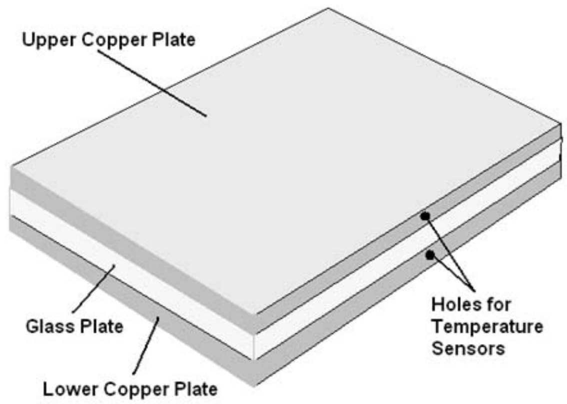

Figure 1. Perspective view of prototype flux-plate heat-flow sensor for Venus heat-flow determinations. The prototype unit was 128 mm in length, 100 mm wide, and ~16 mm thick, consisting of an ~4 mm window glass plate sandwiched between two ~6 mm copper plates. The glass was loosely bonded to the copper with thin layers of commercial semiconductor heat sink grease. The holes for temperature sensors were ~30 mm deep and Chromega/Alomega® (type K) thermocouples were used for temperature measurements to measure the differential temperature across the glass plate. The thermocouples were seated with heat sink grease.

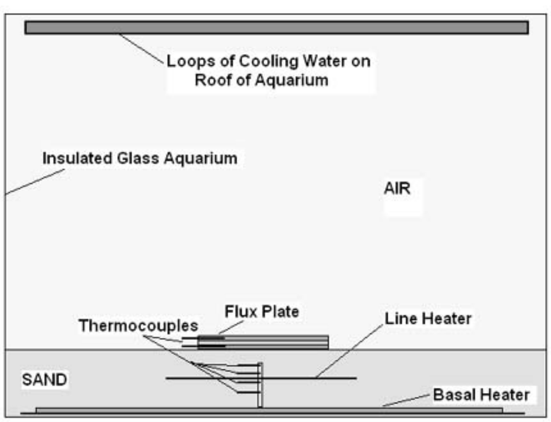

Figure 2. Diagrammatic cross section of flux-plate heat-flow sensor test system. The system was housed in a 400 mm long by 200 mm wide by 250 deep glass aquarium insulated on all surfaces by 25 mm thick Styrofoam insulation. Approximately 65 mm of medium grained sand was heated at the base by a nichrome wire heater below a 3 mm steel plate to spread the heat. Vertical temperatures in the sand were measures at four 10 mm vertical intervals to a precision of 0.01^{o}C using Chromega/Alomega® thermocouples on a balsa wood frame. A nichrome line-heater source with a Chro-mega/Alomega® thermocouple (instantaneous line source [10]) was used to measure the sand thermal conductivity. The air was maintained at a constant cool temperature by circulating cooled water from a constant temperature bath through loops of clear plastic tubing on the roof of the aquarium. Thermocouple temperatures were monitored on a PC using 16-bit A to D converters.

Test Results: The test system was run with thermal gradients in the sand ranging from approximately 10 to 100 mK m^{-1} ($\equiv$ ^{o}C km^{-1}). The temperature difference across the flux-plate responded linearly to changes in the sand thermal gradient to $\pm$ 3% over this range. Using the thermal conductivity of the sand determined from the line heater, the thermal gradient values will be converted into heat flow values and the flux-plate calibrated for heat flow from the test system.

Future Tests: A search is being made for a cave or abandoned mine with stable air temperature in a region where the heat flow is reasonably well determined. We plan to deploy the flux-plate heat-flow sensor in such a site using a portable commercial thermocouple data logging system (Hobo® data logger, manufactured by the Onset computer Corp.) to compare the flux-plate determined heat flow with the regional heat flow value. On Venus a segmented flux plate would be used to conform to the Venus surface.

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