lunar equator, or an angular displacement of less than 0.005 arc second as seen by an earthbound observer (about 10 percent of the minimum resolution capability of the largest conventional telescopes).

The only observations presently available that are capable of resolving such small displacements of the moon are the series of laser range measures obtained at the McDonald Observatory since the Apollo 11 landing in July 1969 (*14*). We recognized the interest inherent in the possible existence of free librations in 1974, and since that time one of us has undertaken a series of investigations to deduce them from the laser observations (*15*). The techniques required for such a study are too complex to be treated here (*16*), but they have been conducted with several different models of the forced librations and several lunar ephemerides, including those of our own construction. There is considerable inherent difficulty in determining modes A_2 and A_3 with these data; for A_2, the correlations with other parameters having periods close to the sidereal month are enormous, requiring 24 years for good separation; for A_3, the observations cover only 10 percent of a period and thus this parameter can easily be confused with secular variations in other parameters. It appears that the best test of the dynamical consistency rests with the amplitude A_1 of the free libration in longitude; over the past 3 years, with different models, the value given by the laser data has remained essentially constant at about 1.8 arc seconds, which corresponds very closely with the theoretical value for the Bruno event if one adopts an impact energy law midway between the two extremes cited above.

Discussion. Hartung's interpretation of the Canterbury chronicle has been challenged by Nininger and Huss (*17*), who prefer to believe that the event was a meteor entering the earth's atmosphere along the line of sight between Canterbury and the moon. Their claim that the ejecta from a lunar impact would not be visible (citing the naked-eye invisibility of large craters) seems specious since one may imagine a considerably different albedo for a dust cloud than for low-contrast surface features. The reference to the coldness along the ejecta trajectory is also irrelevant. On the other hand, their interpretation requires that the already-improbable trajectory enter the earth's atmosphere at nearly grazing incidence, and atmospheric drag should surely cause a curvature of the path, easily discernible in the line of sight against such a well-defined background object as the 1.6-day-old lunar crescent. Considering that we are dealing with an exceptional event, Hartung's interpretation seems at worst no less believable than that of Nininger and Huss.

From the point of view of the free librations, it is evident that the Bruno impact is very convenient. We have already cited Peale on the values imaginable in the absence of recent stimulation. The results of the laser analyses are only explicable by a recent impact. Thus, as stated by Kovalevsky (*18*), "It could be an interesting challenge to lunar geologists to try to find a very recent crater." Convenience is not an a priori reason for rejection. The laser value of A_1 and the Hartung hypothesis are supportive of one another.

We will be the first to admit that the calculations outlined above do not prove the Hartung hypothesis. What we have done is to show that such an impact would have been observable and that the only modern observations that are capable of revealing the dynamical vestiges of such an event provide a compatible result. Neither the required ejecta trajectories nor the determinations of free librations cited here can be used to refute Hartung's interpretation, which has thus passed a considerable test. Neither can these results be sufficient to confirm it. Perhaps this question can be resolved, or at least narrowed, by the chemical analyses of soil samples returned by Luna 24.

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19. We are very grateful to J. B. Hartung for his cooperation on technical matters, to the Lunar Science Institute for assistance in locating the crater photograph used here, and to the U.S. National Space Science Data Center for providing copies of it for our use. J.D.M. was on partial leave in 1976 and 1977 from the Department of Astronomy and McDonald Observatory, University of Texas, Austin.
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Mid-Recent Human Occupation and Resource Exploitation in the Bismarck Archipelago

Abstract. *Human settlement of the Bismarck Archipelago occurred by 6000 to 7500 years ago. Early inhabitants of New Ireland drew on widely dispersed stone sources, including obsidian from Talasea (New Britain), whereas those after about 3000 years ago used either stone from more local sources or obsidian from Lou Island (Admiralty Islands group) or Talasea. The dates and resource changes support a gradualist model of Melanesian settlement.*

Balof is a small overhang in uplifted corralline limestone, situated about 1 km inland of the east coast of New Ireland and 90 km south of Kavieng (Fig. 1). Six square meters were excavated (*1*); the maximum depth of occupation deposit was 80 cm. There was little visible stratigraphic differentiation, except for recent disturbances in the top 20 cm. Our interpretation is that human treading and scuffing, along with a slow rate of deposit accumulation, has destroyed many formerly visible features. Scattered charcoal fragments found 17 to 23 cm below the surface dated to 1540 ± 270 years ago (GaK 2437: half-life, 5730 years); 550 g of food-bone remains found 58 to 85 cm below the surface dated to ≥ 6800 ± 410 years ago [NSW 95: half-life (corrected), 5730 years]. The dates conform to the hypothesis of steady site accumulation, and the

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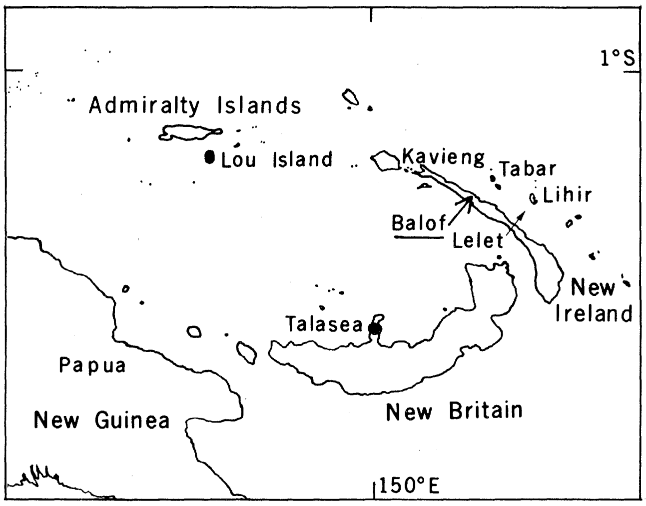

Fig. 1. Map of Bismarck Archipelago showing site excavated (underlined), obsidian sources (circles), and other places referred to in text.

Table 1. Percentage of total artifact stone identified as to type and probable source. Stone that could not be identified or for which the source was not known is not included in this table.

Source	Artifact stone (percent) at levels:							
	1	2	3	4	5	6	7	8
Talasea and Lou Is. (obsidian)	5.9	44.0	8.4	1.7	2.1	2.5	4.5	
Probably New Britain (black and colored cherts and chalcedonies)						9.6	8.0	7.4
Tabar or Lihir Is. (flow basalt)			0.3	0.9				
West coast or south part of New Ireland (microdiorite, dolerite)	16.4		3.9	69.4	9.8	10.2	21.8	30.7
Lelet Plateau (lithic tuff, laterite, ochre)	4.4		0.9	0.8	5.3	5.4	7.5	7.7
Limestone plateau (local) (fine-grained sedimentary rocks)		44.0		9.0	1.2	9.3	9.4	1.4
Total weight (g)	14.0	5.2	6.8	76.6	18.1	125.1	232.9	160.1

younger is consistent with dates associated with similar cultural material from elsewhere on New Ireland (*2*). They also confirm the absence of major site disturbances.

Stone tools and waste chips occurred throughout the deposit. Stone other than obsidian was flaked casually, and attention was given only to certain edges. This pattern is similar to that widely found in mainland New Guinea (*3*). The obsidian, except for some from the lowest levels, was flaked with a bipolar technique (*4*). This technique occurs frequently on stone from Lapita sites dating to the first millennium B.C. (*5*). It is not otherwise frequent in prehistoric Melanesian sites.

The known sources (*6*) of exotic stone are listed in Table 1. We draw attention to the occurrence in levels 6 to 8 of cherts and chalcedonies of probable New Britain origin. These are not found more recently. In the same levels, there are higher percentages of material from the west coast or southern part of the island and from the central Lelet Plateau; overall, there are larger amounts of stone in those levels. These results combine to suggest that earlier inhabitants drew stone from a wider variety of sources, both on- and off-island, than later people.

Forty-five samples of obsidian from all levels, except level 8 in which none was found, have been analyzed by the technique of prompt nuclear analysis (*7*). This nondestructive technique is especially suitable for specimens weighing less than 1 g, like most of these. All obsidian from the lower levels comes from the Talasea source on the central north coast of New Britain (*8*) (Fig. 1); some material from levels 5 and above, with an extrapolated date of about 3000 years ago to the present, is from the Lou Island source in the Admiralty Islands group (Table 2). It is probably significant that, whereas 600 km of coastal travel are required to move obsidian from Talasea to Balof, a direct voyage of more than 150 km as well as coastal travel is required to transport Lou Island obsidian there.

Two important conclusions derive from the above data. (i) Although preceramic settlement has been inferred (*9, 10*) for the larger islands of western Melanesia this has not previously been documented. Evidence of human settlement for at least 2000 years, and probably longer, before the earliest radiocarbon dates associated with pottery in Melanesia (*10*), along with evidence of wide-ranging resource exploitation, supports a gradualist model of island Melanesian settlement (*10*) rather than an abrupt settlement by pottery-making horticulturalists (*11*). (ii) As a consequence of the above, it now appears likely that the wide-ranging cultural phenomenon of Lapita pottery manufacture and the long-distance movement of obsidian (*12*) grew out of already existing conditions and that its development had a considerable effect on associated cultures on the larger islands of Melanesia.

Table 2. Number of pieces of obsidian identified as coming from the two available sources at Talasea and Lou Island for each level of Balof site. Level 3 is dated by GaK 2437, levels 7 and 8 by NSW 95.

Level	Number of pieces	
	Talasea	Lou Island
1	2	1
2	1	4
3	4	11
4	2	3
5	4	1
6	4	
7	8	
8		

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12 September 1977

Residential Natural Gas Consumption: Evidence That Conservation Efforts to Date Have Failed

Abstract. *A new short-term natural gas consumption model is developed, tested against American Gas Association sales data, and applied to the question of the effectiveness of conservation efforts. The results indicate that unit residential gas-heating sales per heating degree-day have remained constant in four major gas-consuming regions during the period 1974 to 1976 and that heating sales have not been affected by the recent sharp changes in price.*

The sum of the average heating degree-day values for a particular period times the number of heating customers in the area of interest has been used for many years by heating and gas service company engineers as an accurate index of fuel consumption for space heating. Hu (*1*) developed such a linear model for use by the American Gas Association (AGA) in estimating annual residential heating sales for each state. In the engineering estimates it is assumed that the heating degree-day elasticity (E) for space heating fuel consumption is unity (*2*).

On the other hand, nationwide studies of residential natural gas use based on econometric models indicate that E lies between 0.45 and 0.71. A recent analysis of 1970 data by use of a linear model gives E values of 0.71 for space-heating use and 0.40 for total residential use (*3*). A comprehensive study of the entire period 1970 to 1975 by use of a log-normal model gives E values of 0.45 for space-heating use and 0.345 for total residential use (*4*). Similarly, log-normal analyses of all residential fuel use in 1971 yield E values of 0.64 for space-heating use and 0.496 for total residential use (*5*).

Fuel use predictions based on the engineering and the econometric models can differ enormously, and such predictions are crucial to energy planning, conservation, and policy decisions (*5*). In view of the current need to manage our energy resources carefully, it is important that such major differences be resolved so that reliable information will be available for use at every management level.

In this report, we develop and test a simple linear model that appears to reconcile the results of the engineering and the econometric models, demonstrates that E values are currently close to 1.0 for space-heating use and 0.7 for total residential use, and provides indices that may be used to evaluate the effects of price change and conservation efforts on residential consumption of natural gas.

Testing the model. According to the simplest linear model, within a state i the quarterly residential natural gas sales are given by

$$s_i = jc_i + kh_iz_i \qquad (1)$$

in which c_i and h_i are the number of *total residential* and *residential heating* customers, respectively; z_i is the sum of

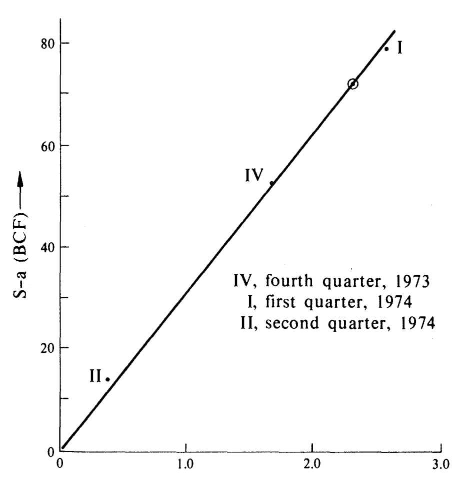

Fig. 1. Temperature dependence of natural gas sales in the state of Missouri, 1973–1974 heating season. The data are aggregated by quarter; a is fixed sales, 37.5 billion cubic feet (*BCF*) per quarter; S is total sales in all sectors. The following values were used: (1973-IV) S, 90.25; $S - a$, 52.75; $\bar{z}$, 1.67; (1974-I) S, 116.6; $S - a$, 79.1; $\bar{z}$, 2.50; (1974-II) S, 36.9 (8-week period only); $S - a$, 13.8; $\bar{z}$, 0.37; (⊙) $S - a$, 72.8; $\bar{z}$, 2.305. For the three quarters, the total $S - a$ = 145.6; total $\bar{z}$ = 4.61. (⊙) Sum of the sales ($S - a$) and sum of the degree-days plotted at half their values. The straight line defines the average ($S - a$) sales per degree-day. Departures from this line indicate seasonal differences from the annual norm.

population-weighted heating degree-days for the quarter; and j and k are parameters to be determined. We thought that a simple linear model could adequately describe and predict quarterly sales within a state because of our earlier experience with data for Missouri (*6*). In the course of developing a state model, we acquired daily gas sendout data for the heating season 1973 to 1974 directly from the utility firms serving Missouri. Whether the data are displayed weekly (*6*) or quarterly as in Fig. 1, the relationship between degree-days and sales values is linear.

The accuracy of prediction of the linear model can be tested by comparing reported sales with predicted sales calculated by using values of j and k derived from base period equations—that is, two simultaneous equations like Eq. 1 in which the subscripts i denote known customer sales—and degree-day data for the two quarters preceding the one under test.

Such testing would be possible if quarterly data for natural gas sales were available by state. Unfortunately, sales information is available in general only by census division (*7*). Therefore, to test the simple linear model, we modified it so that it predicts sales values for multistate census divisions. We chose a form that resembles Eq. 1 and is simply related to it

$$S = jC + kH\bar{z} \qquad (2)$$

in which S is the regional quarterly sales; C and H are, respectively, the number of *total residential* and *residential heating* customers in the region; and $\bar{z}$ is the regional weighted mean number of accumulated heating degree-days in the quarter, defined by

$$H\bar{z} \equiv \sum_i h_iz_i \qquad (3)$$

A second important modification of Eq. 1 was necessary. Experience in comparing predicted sales with sales reported by the AGA suggested that $\bar{z}$ is a function of a sales reporting lag. To use the AGA sales data as given, we defined a lag parameter, x, which shifts $\bar{z}$ so that it corresponds to the mean number of degree-days in the lagged reporting period. This leads to

$$H\bar{z}(x) \equiv x \sum_i h_i\Delta z_i + \sum_i h_iz_i' \qquad (4)$$

or

$$H\bar{z}(x) \equiv Ax + B \qquad (5)$$

where A and B represent the summed quantities, z_i' is the number of heating degree-days in the 3-month period lagging the calendar quarter by 1 month,

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