5. R. Reilinger and J. Oliver, *Geology* **4**, 583 (1976); ———, L. Brown, A. Sanford, E. Balazs, *ibid.* **8**, 291 (1980).
6. J. R. Pelton and R. B. Smith, *Science* **206**, 1179 (1979).
7. K. Mogi, *Bull. Earthquake Res. Inst. Tokyo* **36**, 99 (1958); R. S. Fiske and W. T. Kinoshita, *Science* **165**, 341 (1969); J. H. Dieterich and R. W. Decker, *J. Geophys. Res.* **80**, 4094 (1975).
8. G. C. Taylor and W. A. Bryant, *Calif. Div. Mines Geol. Spec. Rep. 150* (1980), p. 49; M. M. Clark, J. C. Yount, P. R. Vaughan, R. L. Zepeda, *U.S. Geol. Surv. Misc. Field Invest. Map MF 1396*, in press.
9. J. C. Savage, M. Lisowski, W. H. Prescott, N. E. King, *Bull. Seismol. Soc. Am.* **71**, 465 (1981).
10. C. H. Cramer and T. R. Toppozada, *Calif. Div. Mines Geol. Spec. Rep. 150* (1980), p. 91.
11. We appreciate the cooperation of California Department of Transportation in the 1980 leveling and the assistance of R. O. Castle in the analysis of the 1932 and 1957 leveling data.

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Ancient Maya Mercury

Abstract. *Discovery of mercury in an ancient Maya offering at Lamanai, Belize, has stimulated examination of possible sources of the material in the Maya area. Two zones of cinnabar and native mercury deposits can be defined in the Maya highlands, and the presence of the native metal suggests that the ancient Maya collected rather than extracted the mercury from ore.*

Excavation of the ancient Maya site of Lamanai in northern Belize (Fig. 1) has revealed extensive evidence of a rich Postclassic and early historic occupation (A.D. 900 to 1675), as well as remains from an earlier period (600 B.C. to A.D. 900) (*1*). In 1980, offerings associated with stelae and other monuments were recovered; among these was the giant marker disc at the center of the lone ballcourt at the site. Raising of the disc, (1.5 m in diameter) revealed an offering in a lidded bowl; the vessel contained more than 100 g of crystalline hematite, mostly in powder form, and artifacts that included two miniature vessels, in one of which was approximately 19 g of cinnabar (HgS). The vessels and a number of objects of jade, shell, and pearl sat atop a pool of 9.7 cm^3 (131.9 g) of mercury (Fig. 2). Slip and shape characteristics of the container vessel and two fragmented dishes on which it rested fix the date of the offering and the ballcourt construction in the late 9th or early 10th century A.D.

The ballcourt offering is evidence of ceremonial activity at the central Maya lowland site of Lamanai at the end of the Classic period. Previously, mercury was known only from highland sites about 275 km to the south: Copán and nearby El Paraiso in Honduras (*2*); Quiriguá in Guatemala, some 45 km north of Copán (*3*); and Kaminaljuyú (*4*) and neighboring Lake Amatitlán (*5*), approximately 140 km west of Copán (Fig. 1). Thus the Lamanai discovery extends both the known geographic distribution and the time span of mercury use by the Maya. These aspects of the discovery prompted a review of data on possible sources of the metal.

Mercury usually occurs as cinnabar, and cinnabar was prized by the Maya as pigment, apparently because its color was symbolic of blood and blood sacrifice; it was included in offerings and elite burials, not infrequently in association with crystalline hematite (*6*, *7*). It has been assumed that the cinnabar found in lowland sites in Guatemala, Belize, and the Yucatán Peninsula came from the Maya highlands and was important in highland-lowland Maya trade (*6*). Most of the Yucatán Peninsula is mineralogically impoverished, but the Sierra Madre mountains of southern Mexico, Guatemala, and Honduras are geologically suitable for the occurrence of HgS deposits.

Without trace-element analyses of HgS from a wide range of highland and lowland sites, it is not possible to identify specific sources with any degree of certainty. Fuson (*8*) proposed a source in the Mexican state of Chiapas for cinnabar traded to the Maya lowlands, but there is neither archeological nor direct geological support for the suggestion. There are, however, HgS deposits in the Early Cretaceous Todos Santos Formation of Guatemala near Nahualá, Department of Sololá, and Zunil, Department of Quetzaltenango (*9*), both west-northwest of Lake Atitlán. Native mercury appears to have been collected in Quetzaltenango (*10*) and in the area of San Miguel Acatán, Department of Huehuetenango (*11*) (Fig. 1). A second zone of HgS occurs in

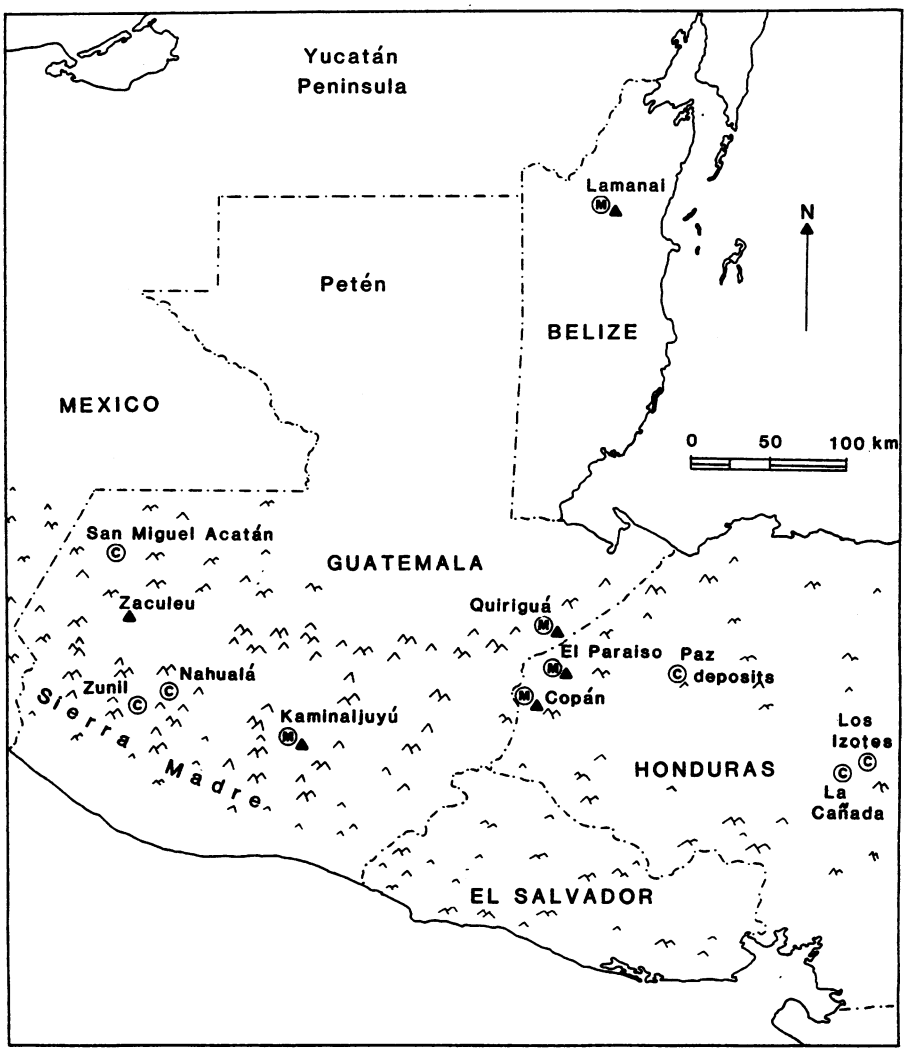

Fig. 1. Map of Maya Area. *C*, HgS and native mercury sources; ▲, archeological sites; and *M*, archeological sites yielding mercury.

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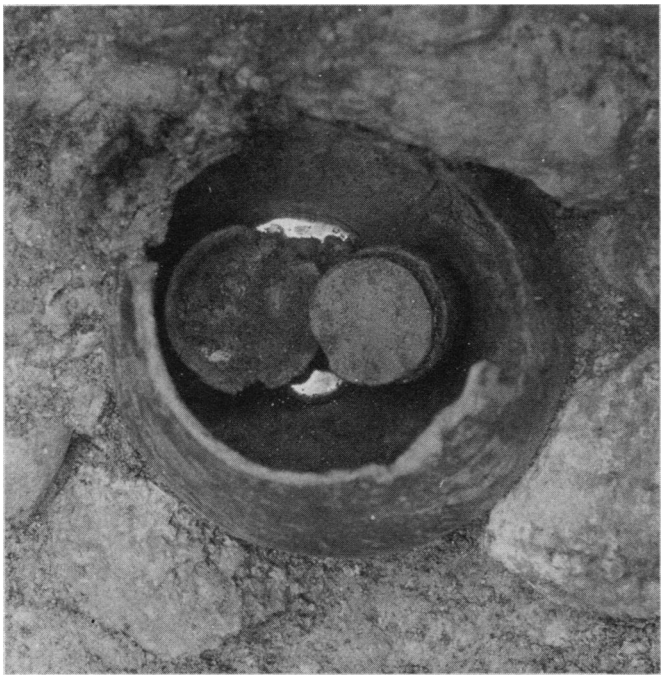

Fig. 2. Lamanai ballcourt offering in situ, showing miniature vessels atop a pool of mercury.

the lithologically similar Late Cretaceous Metapán Formation of western Honduras, including the Los Izotes and La Cañada mines near the village of Jalaca, and the Paz deposits, just west of Lake Yojoa (Fig. 1); the first two of these deposits include native mercury in small amounts (*12*).

The distribution of HgS and native mercury deposits in the Maya highlands suggests that there may have been two centers from which one or both materials were traded in pre-Columbian times. There is no firm evidence of prehistoric extraction of cinnabar in either of the source zones, although the fact that La Cañada was mined in the Colonial period (*12*) suggests that the deposit may have been known before the Spanish arrived. The proximity of the Honduran deposits to Copán, El Paraiso, and Quiriguá suggests that the mercury of the southern highlands was obtained locally rather than through long-distance trade. The mercury found at Kaminaljuyú, which is within 80 km of the Lake Atitlán cinnabar sources and about 200 km from San Miguel Acatán, is likely to be of northern highlands origin. Zaculeu, the only extensively excavated site within the northern cinnabar-mercury zone, yielded no mercury (*13*); this may represent sampling error, or it may indicate that the metal was rare even within a source area.

Trade routes from the northern highlands to the Petén and thence to other parts of the lowlands have been proposed (*14*), and there is also archeological evidence for trade along the Caribbean coast of the Yucatán Peninsula that could have brought mercury to Lamanai from Honduran sources. Because the Lamanai metal is in the elemental state, analysis to identify one or the other of the two highland zones as the source is probably not possible; on grounds of proximity, the Honduran deposits are a likely source, and the metal could have been transported by way of Copán or neighboring centers.

Although it is not possible to determine whether the mercury at Lamanai and other ancient Maya sites represents collection of the native metal or extraction from ore, it is worth considering whether recovery of mercury from ore was technologically feasible for the Maya. Fuson (*8*), in proposing Maya use of mercury in compasses, discounts the possibility of collection of native metal, as does Brown (*15*), in discussing the Lake Amatitlán finds. Roasting of HgS at 580°C or higher temperatures results in sublimation, and reaction of the HgS vapors with oxygen produces SO_2 and mercury permitting recovery of the metal in some form of condenser. Temperatures well in excess of 580°C are achieved in open pottery firing of the sort generally thought to have been practiced by the ancient Maya (*16*), and open-fire roasting of HgS in a closed container would have produced the conditions necessary for sublimation. Since most HgS contains approximately 86.2 percent mercury by weight, the amount of ore required to produce the Lamanai metal would probably not have exceeded 150 to 200 g, a quantity easily manageable in a simple pottery vessel of the sort used by the Maya for cooking.

In an uncontrolled mercury extraction process there is a high probability of incomplete oxidation of the sulfur in a closed container, with resultant formation of synthetic cinnabar. Loss of the mercury through vessel failure, other problems in handling, as well as the small amount of mercury produced by each roasting of HgS, would probably have made extraction impractical were it not for the ritual importance of the metal. Although extraction of mercury from HgS was clearly possible for the Maya, this means of obtaining the metal is likely to have had limited appeal since native mercury was present in both the northern and the southern HgS deposits.

The alternative possibilities for obtaining mercury—extraction or collection—suggest historical concomitants of considerable significance. If extraction of the metal was practiced by the Maya, archeological evidence on the extent of HgS distribution in ancient settlements might make it reasonable to expect more mercury than has been discovered, unless all of the occurrences were of nearly identical date. The total amount of mercury discovered thus far is approximately 70 cm^3 (952 g), an amount that represents roughly 1106 g of cinnabar. The occurrences span a period of 400 years or more, from about A.D. 500 or earlier at Kaminaljuyú (*17*) to about A.D. 900 at Lamanai. The absence of other occurrences of mercury in the extensive archeological record for this period points to the rarity of the metal and lends support to the argument against extraction of mercury by the Maya.

If the easier but more time-consuming activity of collection provided mercury for the Maya, then the archeological metal is likely to reflect a painstaking process that spanned a long period, given the apparent absence of large quantities of the native metal in the area. Long-term collection would presumably have given the mercury even greater value than that conferred on the metal by its physical qualities, particularly its reflectivity, and by its association with cinnabar. The distribution of archeological occurrences suggests that most of what was almost certainly a small and precious hoard of the metal was retained for use in centers not far removed from the areas of collection, a fact that lends significance to the mercury at Lamanai beyond the extension of spatial and temporal distribution of the rare metal.

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References and Notes

1. D. M. Pendergast, *J. Field Archaeol.* **8**, 29 (1981).
2. A. P. Maudslay, in *Biologia Centrali-Americana* (1889–1902), p. 20.
3. W. Ashmore, E. M. Schortman, R. J. Sharer, *The Quirigua Project, 1979 Report* (Univ. of Pennsylvania Press, Philadelphia, 1979), p. 6.
4. A. V. Kidder *et al.*, *Carnegie Inst. Washington Publ. No. 561* (1946), p. 144.
5. S. F. de Borhegyi, *Sci. Am.* **200**, 100 (March 1959).
6. J. E. S. Thompson, *Maya History and Religion* (Univ. of Oklahoma Press, Norman, 1970), p. 143.
7. See D. M. Pendergast [*Excavations at Altun Ha, Belize, 1964–1970* (Royal Ontario Museum, Toronto, 1979), vol. 1, pp. 61–63] for an example of HgS use in an elite burial.
8. R. H. Fuson, *Ann. Assoc. Am. Geogr.* **59**, 509 (1969).
9. A. O. Shepard, in *Carnegie Inst. Washington Publ. No. 561* (1946), p. 272.
10. Anonymous, *Maya Res.* **2**, 400 (1935).
11. C. Samayoa Chinchilla, *The Emerald Serpent* (Falcon's Wing Press, Indian Hills, Colo., 1957), pp. 153–154.
12. R. S. Roberts and E. M. Irving, *U.S. Geol. Surv. Bull. No. 1034* (1957), p. 169.
13. R. B. Woodbury and A. S. Trik, *The Ruins of Zaculeu, Guatemala* (United Fruit Co., Boston, 1953), pp. 262–265.
14. R. E. W. Adams, in *New World Archaeological Foundation Paper No. 40*, T. A. Lee, Jr. and C. Navarrete, Eds. (Brigham Young Univ. Press, Provo, 1978), pp. 27–35.
15. K. L. Brown, in *Teotihuacan and Kaminaljuyu: A Study in Prehistoric Culture Contact*, W. T. Sanders and J. W. Michels, Eds. (Pennsylvania State Univ. Press, University Park, 1977), p. 278.
16. A. O. Shepard, *Carnegie Inst. Washington Publ. No. 609* (1961), p. 28.
17. A. V. Kidder, J. D. Jennings, E. M. Shook, *Carnegie Inst. Washington Publ. No. 561* (1946), p. 246.

18. I thank W. Ashmore for calling my attention to early Maya mercury discoveries and J. O. Mandarino for data on cinnabar. Lamanai excavations funded by Royal Ontario Museum research budget and principal grants from Social Sciences and Humanities Research Council of Canada and R. M. Ivey Foundation.

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Mus poschiavinus Y Chromosome in the C57BL/6J Murine Genome Causes Sex Reversal

Abstract. *When the Y chromosome from* Mus poschiavinus *(Y^{POS}) is transferred onto the C57BL/6J genome, XY individuals develop as females with two ovaries, or as hermaphrodites. No XY individual develops normal testes. Although C57BL/6J-Y^{POS} XY females are rarely fertile, most hermaphrodites with normal male genitalia sire offspring. Thus, the* Mus poschiavinus *Y chromosome carries a form of the Y-linked testis-determining locus different from that present in the C57BL/6J inbred strain. This gene interacts abnormally with autosomal or X-linked testis-determining loci of the C57BL/6J genome to prevent normal testicular differentiation. Divergence of the Y-linked testis-determining gene may be involved in mammalian speciation.*

In mammals, the presence of a Y chromosome (XY, XYY, XXY) causes the undifferentiated gonad to develop as a testis. Individuals lacking a Y chromosome (XX, XO) develop ovaries. The simplest explanation for this is that one or more Y-linked genes are involved in testis determination, and in their functional absence, the uncommitted gonad develops as an ovary (*1*). Not surprisingly, exceptions to this hypothesis have been reported.

In wood lemmings, some XY individuals develop functional ovaries (*2*). This sex reversal is caused by an X-linked gene that overrides the Y-linked testis-determining gene (*3*). The gene "polled" in goats is an example of an autosomal mutation that, in the homozygous state, causes development of testicular tissue in the XX individual (*4*). What seems clear from these examples is that there are autosomal and X-linked genes involved in primary sex (gonad) determination. This conclusion does not conflict with the hypothesis that a Y-linked locus is responsible for testis induction if we envision that the Y-linked gene is the first gene (or one of the first) that functions in the series of genetic events necessary for testis development.

We report the discovery that the transfer of the Y chromosome from the mouse species *Mus poschiavinus* (*5*) to the genome of the C57BL/6J inbred strain causes disruption of the normal testis determination process and results in partial or complete sex reversal of XY individuals. We hypothesize that the Y-linked testis-determining locus carried by *M. poschiavinus* is significantly different from that carried on the Y chromosome of C57BL/6J and functions abnormally when present in the C57BL/6J genome.

While we were transferring onto the inbred mouse strain C57BL/6J a triethylenemelamine-induced α-thalassemia (*6*) that had occurred in a male from the inbred strain designated POS A [see (*7*) for origin of POS A], we noticed that two males sired an excess of female offspring. The N3 backcross generation male produced 69 females and 28 males; the N4 backcross generation male sired 19 females and 2 males. Their common N2 ancestor had sired 22 females and 11 males. Closer inspection of a number of adult offspring from the N3 and N4 generation males revealed that many sons were true hermaphrodites (both ovarian and testicular tissue were present) and that some daughters, although morphologically normal females, were chromosomally XY (*8, 9*). Because the N3 and N4 backcross generation males were related and produced XY hermaphrodites and XY females, we suspected both carried a mutation that interfered with primary sex determination.

Inheritance of the hypothesized mutation was determined as follows. The N3 backcross generation male, number 1643, was mated to several C57BL/6J females. Offspring were classified at weaning as females if they had normal-appearing external female genitalia, including mammae-associated pigment, or as males if they had normal external male genitalia. Offspring were classified as abnormal if they had ambiguous genitalia (for example, hypospadias, an underdeveloped scrotal sac, or an enlarged clitoris), with or without mammae-associated pigment, or if they had normal male genitalia and mammae-associated pigment. The chromosome constitution (*8, 9*) of a number of the females was ascertained. Some offspring were autopsied as adults, the type and condition of their internal sex organs were noted, and their gonads were histologically analyzed. Male 1643 sired 31 female, 17 male, and 11 abnormal offspring (Table 1). Of the 11 females karyotyped, 9 were XX and 2 were XY. These results rule out autosomal recessive or X-linked inheritance of the mutation because XY females and hermaphrodites were produced by male 1643 when he was mated to unrelated females.

To determine whether the mutation was inherited as an autosomal dominant or Y-linked locus, we mated 14 sons and 9 XX daughters of male 1643 and 4 XX daughters of a son of male 1643 known to carry the mutation (number 08 in Table 1) to mice of the C57BL/6J strain. None of the 13 XX females produced externally abnormal XY individuals, and the sex ratio of the progeny was 1:1 (77 females and 80 males), suggesting that they did not carry the mutation. Ten sons produced XY females or morphologically abnormal offspring, or both, indicating that all ten males carried the mutation (Table 1). Three other males were shown indirectly to carry the mutation: male 06 proved on autopsy to be a hermaphrodite, and sons from males 10 and 13 produced XY female offspring when mated to a C57BL/6J female. Another male, number 03, died after siring one litter of nine females, none of which was karyotyped. Because the probability of a normal male siring nine daughters and no sons is highly unlikely ($P = .002$), male 03 probably carried the mutation. In ad-

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