wind shear. Since the interaction reduces Ri below ¼ over regions of the order of $(z_u - z_l)$ in vertical extent, it could cause turbulence to grow into patches of this thickness. The parameters that influence the interaction include the amplitude and horizontal wave number of the IGW, the initial background wind shear near the critical level, and the intensity of the ambient turbulence. The presence of a moderate intensity of ambient turbulence tends to prevent the catastrophic buildup in the mean wind shear that might cause severe CAT.

What has been described is undoubtedly not the only cause of CAT, but it does demonstrate that the interaction of IGW's with vertical wind shear can lead to the production of turbulence. The irregular occurrence of critical levels in apparently stable regions of the atmosphere is consistent with the observed patchy and intermittent nature of CAT. Although the interaction mechanism has been described here in relation to the lower stratosphere (for which observational data were available) the basic phenomenon is not expected to be restricted to this region. Furthermore, since salinity (and thus density) varies with depth in the ocean, IGW's exist there, and a similar mechanism for causing turbulence is likely to occur. A straightforward extension of the present theory could include the multichromatic IGW's that exist in a real atmosphere. The theory presented here appears worthy of experimental studies of its validity.

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Obsidian Trade Routes in the Mayan Area

Abstract. *Obsidian from two sources in highland Guatemala has been found at 23 sites of the Classic Mayan civilization, mainly in the nonvolcanic lowlands to the north. The distribution, together with trade routes suggested by topography and documentary sources, suggests efficient waterborne transport and competition between sources for the lowland market.*

Trace-element analysis of obsidians has been used recently in both the Middle East and Mesoamerica as a method of documenting prehistoric trade (*1*). Studies have been based on a large number of determinations, and a fairly accurate picture of the temporal and spatial limits of the distribution of any one source has been elucidated. In the Mayan area centered on Guatemala and the Yucatán only a few determinations have so far been reported for the Classic Mayan civilization of the 3rd to 9th centuries A.D., but these preliminary results can be used to construct a model explaining the distribution of obsidians in the Mayan area which may be tested by further analyses.

The Mayan area is divided into three parts: a southern highland zone, a central lowland with tropical rain-forest vegetation, and a northern lowland with tropical scrub vegetation. The highlands are volcanic and possess a number of known obsidian sources; the lowlands have a sedimentary limestone geology (except for the horst of the Maya Mountains) and lack obsidian. The contrasting geology and relief of the highlands and lowlands results in different ranges of environmental niches and available resources, and trade in a variety of commodities between the two zones in prehistoric times has been demonstrated (*2*, pp. 124–158).

Two major sources of obsidian exploited by the Classic Maya have been identified in the highlands (Fig. 1). One is at El Chayal, 20 km northeast of Guatemala City; the other is some 50 km to the southeast at Ixtepeque-Papalhuapa, near the modern town and Classic site of Asunción Mita, the southernmost major center of the lowland-based civilization.

Analysis by x-ray fluorescence has shown that obsidians from these two sources can be characterized and differentiated, especially on the basis of their ratio of Fe to Mn and Ti to Ba, the presence or absence of Sr and Ba, and, to some extent, the relative amounts of Zr, Sr, and Rb, although this has a high noise level (*3*).

On the basis of such analyses of obsidians from 23 Classic period sites, it is possible to attribute the obsidian to either the El Chayal or the Ixtepeque source (Fig. 1). El Chayal obsidian is found in the highlands to the west of the source, and in the lowlands in the Usumacinta River Basin, in northeastern Petén and the Belize Valley, and in the Toledo District of southern Belize (British Honduras). Ixtepeque obsidian is found east and north of the source (except for one sample of undated obsidian from Kaminaljuyú) along the Caribbean coast of Belize, in northeastern Petén and the Belize Valley, and in northern Yucatán.

The pattern of distribution of both sources is thus elongated northward from the source, from the volcanic highlands into the nonvolcanic lowlands where obsidian was desired for both utilitarian and ritual purposes. Lowland products were clearly sent in the other direction in exchange for obsidian and other highland goods. The exact routes involved in this trade have not been established, but evidence derived from topography, ethnohistory, and ethnography supplies a number of possibilities. Topography suggests that trade routes followed the river valleys: the Río Negro and the Río de la Pasión flow directly down to the lowlands, converging to form the Usumacinta; the Río Motagua flows northeast to the Caribbean, and the Río Grande, the Belize River, the Río Hondo, and the Sarstoon River flow from Petén east to the Caribbean.

Transport on these routes would be by porter to the head of navigation and then downstream by canoe to the sea. In Spanish documents of the early colonial period a number of overland routes are mentioned: from Chetumal Bay across the Yucatán to Uxmal and the sites around the Puuc Hills; from Ascension Bay on the coast of Quintana Roo northwest to Chichén Itzá; and from the Toledo District of southern Belize southwest, up into the highlands around Cajabón and Cobán, by way of the upper basins of the Sarstoon and Cajabón rivers (*2*, pp. 134–135). The use of this latter route within living memory for the cacao trade has been documented (*4*).

The coincidence of the trade routes which are topographically likely or historically attested with the archeological distribution of obsidians is striking, and suggests that El Chayal obsidian reached the lowlands by inland routes through the Usumacinta and Sarstoon basins, while Ixtepeque obsidian was taken down the Río Motagua and north up the Caribbean coast and then brought inland, upriver or on overland routes.

These patterns have several interesting features. First, the greater the proportion of the route covered by water, the further the obsidian is distributed; the route from Cobán to southern Belize is a foot trail all the way, whereas that from Asunción Mita to Chichén Itzá is more than 80 percent by water. This finding suggests that canoe-transport was more economical over long distances because of the larger load that could be carried. Second, the distribution or "market" areas of the two sources are largely complementary, overlapping only at and near Tikal and in southeastern Petén; this finding suggests that the two sources were being exploited contemporaneously during the Classic period and that there was competition between the two sources for the lowland market, a situation that is well documented in other cultures (*5*).

Third, the expansion of the Chol-Chorti Maya tribes southward as far as Asunción Mita (*2*, p. 86), would have given them control of the Ixtepeque obsidian source, and this may then have been an important factor in the distribution pattern of the material.

These hypotheses can be tested and either amplified or discarded on the basis of further analyses: additional data should, for example, enable us to document changes through time in the relative importance of the sources and the different routes, and to link this variation with the changing demand for obsidian as population and power waxed and waned at different sites across the Mayan lowlands. One test of this model is the accuracy of predictions based on it: if the model is true, then obsidian from an Usumacinta Basin site, for example, Palenque, should come from El Chayal; that from a Motagua Basin site, for example, Quiriguá, should come from Ixtepeque; and obsidian from sites in southern Belize such as Lubaantún, and in northeastern Petén, such as Yaxhà, should come from both. The model presented here is a skeletal one: it will be interesting to see whether the flesh fits the bones.

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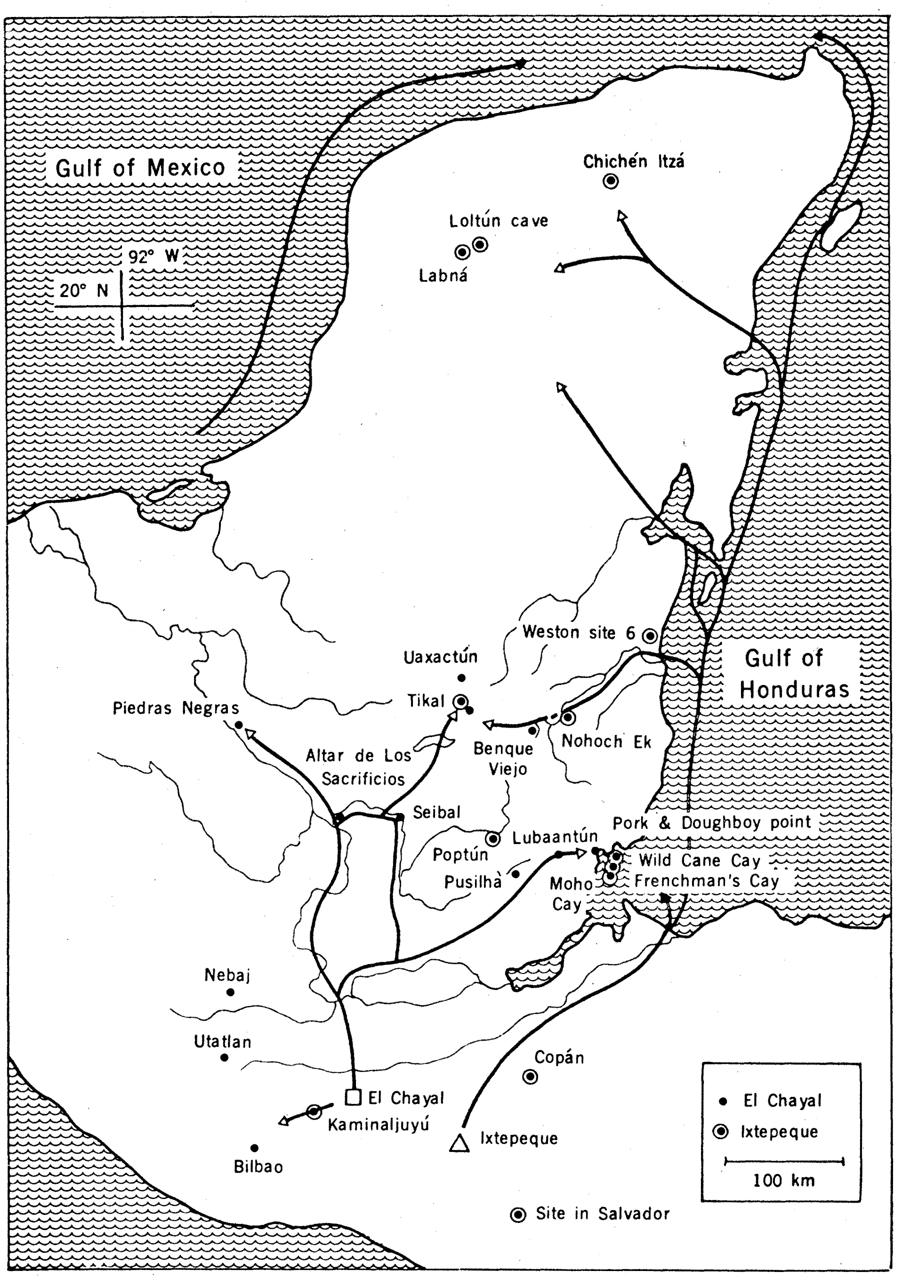

Fig. 1. Archeological distribution of El Chayal and Ixtepeque obsidians and probable major trade routes in the Mayan area.

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