both of these research projects and is a "silent co-author" in the presentation of the results; calling attention to the presence of the Murcielago-Hess fault in northern Costa Rica is a major contribution, although its value to jade research is as yet unknown. Carlos Balser's views also figure prominently in Soto's chapter.

Although preliminary, these geological data from the Atlantic Watershed are essential to broadening our data base and furthering efforts to resolve the disparities between the one-source and multisource models of prehistoric jade procurement.

These two chapters also demonstrate the differences between developed and developing countries' analytical capabilities. One of the reviewers of this work in manuscript, prior to its acceptance by the University of Utah Press, wished for data that were more comparable to those in Chapters 1 and 2; unfortunately the resources available to Harlow, Bishop, Sayre, and Mishara are not available to researchers in Costa Rica and other Latin American countries.

As discussed in Chapter 2, drilling a hole (even a small one) in an artifact for sample removal, or whole-sample irradiation of small objects are often inappropriate techniques for analysis. In Chapters 5 and 6 Brian Curtiss and Phoebe Hauff discuss new, nondestructive means for testing artifacts and geological samples, and for distinguishing true jade from social jade. Their insights into the complexities of analysis and identification also shed additional light on the one-source/multiple-source discussion. Of particular interest is the use of portable analytical equipment that can be transported to the research location, rather than engaging in complicated international requests to borrow objects.

1

Middle American Jade

Geologic and Petrologic Perspectives on Variability and Source

GEORGE E. HARLOW

Middle American jades can be various lithic types, but jadeite rock is the most important. The world's occurrences of jadeite rock (jadeitite) are found as inclusions in serpentinite bodies along major fault zones and are associated with albite rock and other diagnostic rock types. This mode of occurrence restricts the possible sources of Middle American jadeite jade to serpentinites along the Motagua Fault in central Guatemala. A study of the petrology and mineralogy of jadeitite from a 15 km zone of the Middle Motagua Valley of Guatemala (called Motagua-I source) shows strong mineralogical similarities with most jadeite artifacts; jadeite, omphacite, albite, and white mica are distinctive of the Motagua jadeitites and Middle American artifacts. Two emerald green jade varieties have been found that narrow the presently cited gap between Motagua-I rock and jade artifacts. Olmec blue and Costa Rican types are still the most problematic but are similar to known Motagua-I material. A new source, Motagua-II, and other, as yet unknown sources along the Motagua Valley may also be important.

Among lithic artifacts, some of the most interesting and intrinsically beautiful are of jade. Unfortunately, the term *jade* is a fuzzy one that complicates understanding what the material actually is. Most people know that it is some sort of tough rock, usually (but not always) green, that can be fashioned into artistic objects, often of unequaled intricacy. The materials that make up the jades turn out to be a variety of different rocks (typically composed substantially of a single mineral), the most important of which are termed jadeite and nephrite (see Table 1.1). There is an interesting history to the etymology of the terms *jade, jadeite,* and *nephrite* (see Foshag 1957) that hinges around the material that the Spanish conquistadors found being worn by the Aztecs and other mesoamerican natives. The jades of Middle America, here broadly defined as the whole of Mexico and Central America, are usually jadeite, but there is still some uncertainty about the diversity of rock types that constitute the social jades. However, equally important to the question "what is jade?" is

TABLE 1.1 Some Rocks Known as Jade

TRUE LAPIDARY JADES
Nephrite A massive rock consisting of felted, intergrown, fiberlike crystals of the minerals tremolite and actinolite, $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$, members of the amphibole family of minerals. It is the toughest known rock, the classic jade (*Yu*) of China, and unknown in Middle America.
Jade A rock composed mostly of the pyroxene mineral jadeite, $NaAlSi_2O_6$, known geologically as jadeite rock or jadeitite. In a pure state jadeite is white, but chemical substitution of iron yields green coloring. Emerald green color is due to substitution of chromium for aluminum. Jadeite jade is a tough dense rock, but it is not as durable as nephrite.
OTHER ROCKS TERMED "JADE"
Serpentine Serpentine rock (serpentinite) is composed of hydrous magnesium silicates; usually a poor jade substitute.
Bowenite Gem serpentine; translucent
Soapstone Rock form of talc; light to dark green or black and too soft to be good jade
Zoisite/clinozoisite Usually in rock form known as rodingite; it is the variety known as California jade.
Albitite Albite rock with green inclusions, genetically related to jadeitite, common among Maya jades
Cryptocrystalline quartz Chrysoprase, prase, plasma
Quartzites Fine-grained to microcrystalline quartz rock with green inclusions (fuchsite mica, garnierite, chrysocolla, etc.)
Ufindit/unameit?

"where is the geological source or sources?" so that we can understand transportation routes and the social ramifications.

Jade type and geologic source are the focus of this chapter. In the early 1980s I began studying jadeite rock (jadeitite) and associated rocks, focusing on the occurrence in the Middle Motagua Valley of Guatemala. There are now sufficient data to understand some of the variability among these rocks (Harlow 1993). In addition, a number of artifacts have been studied with petrologic techniques in order to determine their mineralogy and chemical composition. Moreover, from the general study of jadeitite occurrences, significant geological constraints can be placed on the possible "deposits" of jadeitite (consider that only nine are known worldwide) to determine sources of Middle American jade. Consequently, geological and mineralogical evidence and criteria will be used as the basis of the discussion.

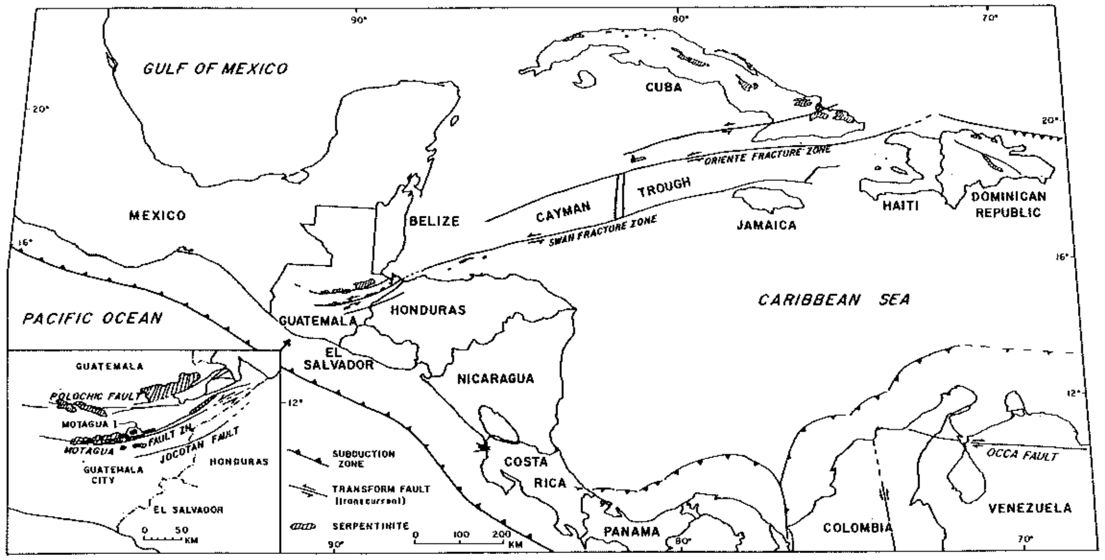
JADEITE SOURCE: ARCHAEOLOGICAL STUDIES AND GEOLOGIC CONTEXT

Jade and jadeite artifacts are distributed widely through Mexico, Central America, and the Caribbean region among many different early cultures. Consequently, the geographic area that people have examined in searching for jade sources constitutes the entire circumcaribbean region, with a focus on Central America and Mexico. However, only one source has been found and described.

Following an initial description by Foshag and Leslie (1955) of a sample of jadeite rock from Manzanal, Guatemala, in the Valley of the Río Motagua (Figures 1.1 and 1.2), McBirney, Aoki, and Bass (1967) further described the occurrence and geology of the jadeite rocks found along the Atlantic Highway near Manzanal. This has served as and still constitutes the primary description in the literature of jadeite rock from Mesoamerica. However, there are a few other unpublished or obscure works, including a Ph.D. thesis describing the San Agustín Acasaguastlan quadrangle (Bosc 1971); description of the occurrence of jadeitite and associated albite rocks (albitite) (Silva 1967, 1970); and an analytically limited (and thereby flawed) but insightful unpublished undergraduate thesis on Guatemalan jadeitites (Duncan 1986). None of these is a definitive study.

On the practical side, a few visits to the jade workshops in Antigua and Guatemala City will provide one with enough information and observations to determine that there is an abundance of jadeite in the Motagua Valley, particularly near Manzanal, Uijo (alternatively spelled Ouijo and Huijo), Usumatlan, and La Palmilla, as Hammond and colleagues (1977) show. Moreover, until recently no hard evidence has come forth from geologists or archaeologists to prove another source of jadeitite somewhere else in the Motagua Valley. Mary Lou Ridinger (personal communication, 1989) of JADES, S.A. (Antigua, Guatemala), has located another source in the Motagua Valley of a jade similar in appearance to the dark varieties from Costa Rica. Complete data on this material are not yet available.

There have been several studies to determine whether or not the middle Motagua source is the one that supplied the rough material from which the various cultural jade artifacts were made (see Hammond et al. 1977; Bishop et al. 1985; and Chapter 2). The studies by Bishop and his colleagues are the most definitive in which instrumental neutron activation analysis (INAA) of whole rocks and artifacts is the primary analytical technique. INAA appears to be the technique of choice for the analysis of lithic artifacts by most archaeologists in spite of the lack of a persuasive rationale. The conclusion based on examining clusters of compositional data is that the Motagua Valley source is an important one but not the only one. In particular, artifacts that are of emerald green jade (two specific types labeled by Bishop as Chichén Green for some beads from the Cenote at Chichén Itzá and the other simply Emerald Green), a similar green called Maya Green, and the blue-green jades (both a light and dark type) of Costa Rica do not match up with their samples from the Motagua Valley. There are at least two possible reasons the conclusion may be invalid: (1) sampling from the area was inadequate or inappropriate for the analysis of this kind of material; and (2) there is another (other), unknown source (or sources).



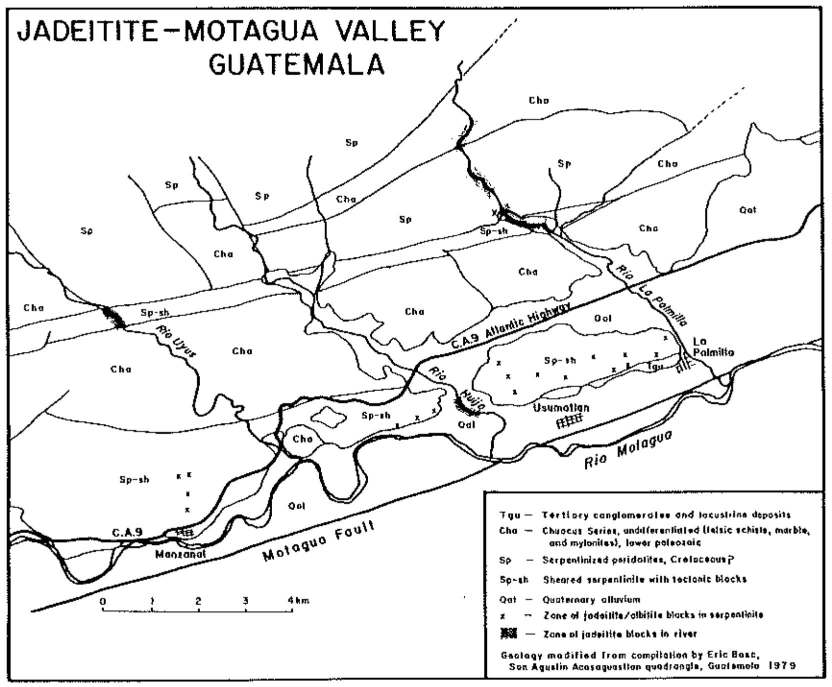


FIGURE 1.1 Tectonic map of Central America and the western Caribbean

FIGURE 1.2 Jadeitite/albitite-bearing region of the Middle Motagua Valley

I entered this arena sideways, from a geologic interest in the mineralogy and geologic origin of jadeite rock. This interest and the stimulation of a graduate student, E. Peter Olds, led to a study of jadeite rock in general and a field investigation of the Guatemalan occurrence in the summer of 1984, and more-recent visits in 1987. Results from this and subsequent work, as well as from the perspective of being a geologist, produced a number of questions and problems with the interpretations of the archaeologists' data. In order to understand the geologic perspective, one must understand something of the nature of jadeite rock.

THE GEOLOGIC/TECTONIC CONSTRAINTS ON THE JADE SOURCE

Jadeite is a sodium aluminum silicate mineral ($NaAlSi_2O_6$) in the pyroxene family (mostly common rock-forming minerals) but is unusual in that its density is much greater than that of other sodium aluminum silicates, 3.24 g/cm^3 versus about 2.7. Experimental synthesis has shown that jadeite should form under geologic conditions of unusually high pressure and low temperature, regimes that are rarely preserved in the geologic record. Jadeite rock, or jadeitite, is a very rare rock composed of more than about 90 percent jadeite and is conspicuously heavy or dense (> 3.0 g/cc in an unaltered state). It occurs in only a handful of places, including the Moguong area of northern Burma (the source of Chinese and most commercial jadeite jade [Chhibber 1934]); the Omi-Kotaki district and nearby areas in Japan (Iwao 1953; Chihara 1971); the Kamuikotan Gorge area, Hokkaido, Japan (Takayama 1986); Oosa-cho, Okayama, Japan (Kobayashi et al. 1987); San Benito County, California (Coleman 1961); the Pay-Yer massif, Polar Urals (Morkovkina 1960); the Borus Mountains, West Sayan (Dobretsov 1963, 1984); the northern Near-Balkhash region (Dobretsov and Ponomareva 1965); and along the Motagua Valley in Guatemala (Foshag and Leslie 1955; McBirney et al. 1967; Hammond et al. 1977; Duncan 1986) (see Figure 1.3). Jadeite rock, when found in situ, is always associated with serpentinite, a green rock composed primarily of serpentine minerals (serpentine is a family of hydrated magnesium silicates). Serpentinite commonly forms from the interaction of water and olivine-rich rocks, called ultramafic rocks, that are typical of the earth's upper mantle. Jadeitites are interpreted as being produced by a fluid-dominated chemical modification of a preexisting rock (a process called metasomatism) and/or fluid transport and recrystallization of the preexisting rock's components. This process occurs at relatively high pressures and low temperatures relative to average conditions in the earth's crust (the subduction regimes where ocean crust descends into the mantle produce these conditions). The fluid involved in jadeitite formation appears to be the same as or similar to the fluid involved in serpentinization. Jadeitites are usually a part of a larger suite of unusual rock types besides serpentinite, including albitites, blueschists, and altered eclogites, that are helpful in interpreting jadeitite petrology and in recognizing or predicting

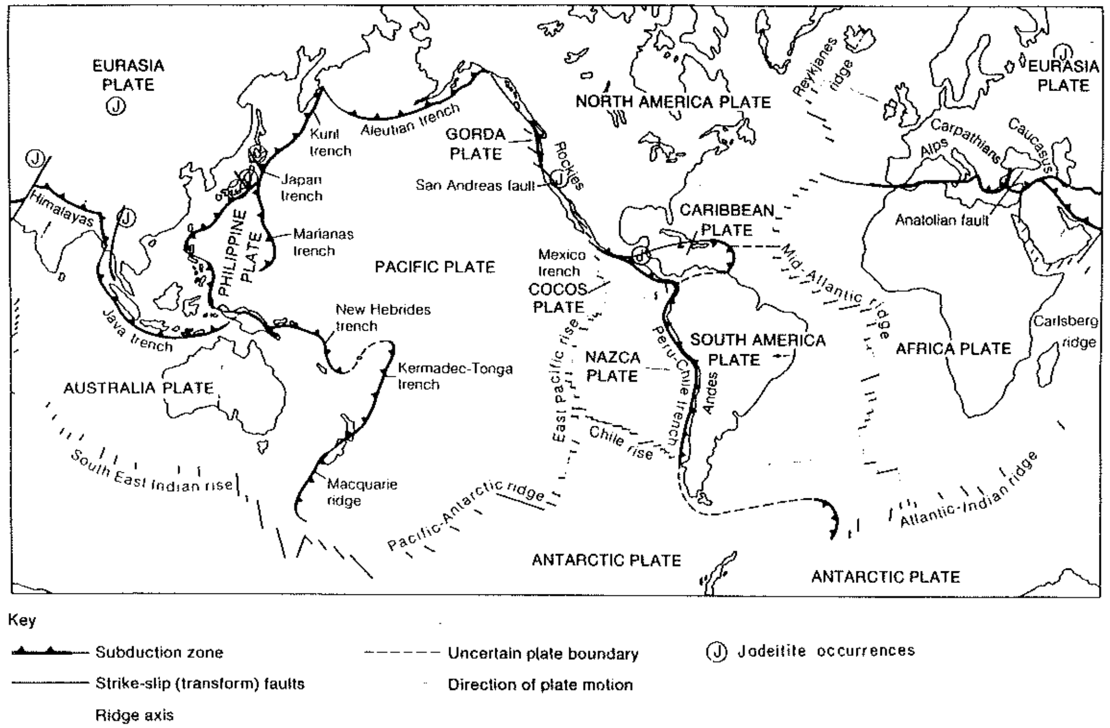


FIGURE 1.3 Simplified tectonic map of the world showing jadeitite occurrences

its presence. Thus, one can look for this rock suite as a signature of potential jadeitite terrain.

Another significant feature is that jadeite-bearing serpentinites are closely associated with large and possibly active fault zones that are major crustal boundaries (e.g., the San Andreas Fault) and involve mostly horizontal motion. There is more-specific criteria along with the faulting, but for the purposes here it serves as an important Occam's razor. Finally, most jadeite rocks occur in relatively young geologic terrain, Cretaceous age or younger (less than 100 million years).

These facts strongly suggest a genetic relationship between plate tectonics (the grand paradigm of the movements of and in the earth's crust) and the formation and surface appearance of jadeite rock. This subject is presently being investigated and is beyond the scope of this chapter (Harlow 1993). However, more to the point of sourcing jadeite jade, one can use tectonic maps (ones that show crustal dynamics, including both faults and serpentinites) and geologic maps of the Middle American region to see which locations have the appropriate signature for finding jadeite rock (whether or not it has been found).

POTENTIAL JADEITE ROCK SOURCES IN MIDDLE AMERICA

The Motagua Valley of central Guatemala follows the Motagua Fault Zone, the extension of a large active fault system with potentially hundreds of miles of lateral offset and certainly an active history over millions of years. This fault zone appears to be continuous with the Swan Fracture Zone, a transform fault, that cuts the Caribbean Sea floor and is the boundary between the North American and Caribbean plates of the earth's crust. In the Motagua Valley the zone of several parallel faults is the boundary in Central America between the Maya or Yucatán crustal block to the north and Chortis block to the south (see, e.g., Wadge and Burke 1983; Anderson and Schmidt 1983; or Weyl 1980 for details). This is one of the major fault zones in the region for locating jadeite. There are other possibilities to the north (the Chixoy-Polochic Fault in the Chixoy and Polochic valleys) and south (the Jocotán-Chamelecón Fault), but in looking at serpentinites in these regions, mainly to the north, no one has found a high-pressure signature (blueschists and eclogites), jadeite-bearing rock, or the associated albitites. Generally, the style of metamorphism and tectonic emplacement has not yielded the appropriate conditions for these other ultramafic belts.

Following the tectonic model of where to find jadeite rock, one should look along the Motagua Fault Zone for "young" tectonized serpentinite (highly deformed by faulting) with inclusions of signature rock types. The known Guatemalan source (Motagua-I) is shown on the map (see Figure 1.1), totally consistent with the model. Other sources might be expected along the Motagua Valley. Indeed, McBirney (1963) reported jadeite pebbles approximately 70 km to the west, and Mary Lou Ridinger (personal communication, 1989) has located dark jadeitic material in a streambed an unknown distance from Motagua-I; the new, mysterious locality is referred to here as Motagua-II. Following the Swan Fracture Zone east, one finds small bodies of serpentinite near Roatan in the Bay Islands of Honduras (McBirney and Bass 1969); again a possibility worth investigating, but there is no evidence of jade. Jumping to the comparable Oriente Fracture Zone, one might expect to find jadeite-bearing rocks in southern Cuba or on Hispaniola. In fact, jadeite-bearing rocks have recently been described from the Dominican Republic (Grenville Draper and Sorena Sorensen, personal communication, 1989), but no jadelike jadeite rocks have been noted so far. The only other significant faults with lateral motion are located in Venezuela and Colombia (Occa, Bocono, and El Pilar faults). Again, jadeite-bearing rocks, but no jade, have been found in Venezuela (Morgan 1967). An important corollary observation is that whereas there are minor serpentinites in southern Mexico (Puebla and maybe Chiapas) and northwestern Costa Rica (Cabo Santa Elena), as pointed out by Foshag (1957), they do not have the appropriate associations. They are not associated with major active faults and do not contain rocks with a similar level of metamorphism and metasomatism; in particular, no jadeite rocks or ones associated with jadeitites (e.g., albitites or blueschists) have ever been discovered associated with these serpentinites. Thus, based on a geologic interpretation, the prospect of Mexican or Costa Rican sources is extremely poor. This insight is not entirely new; Foshag (1957) noted some of the same problems.

Some have suggested that jadeite-bearing serpentinites might be buried under a mantle of volcanic debris from the volcanic cordillera of Central America, overlooked in the mapping of the geology but popping up as erosional remnants in elusive drainage systems found by the ancient inhabitants. Whereas this does sound plausible, there is a severe problem in the geologic preservation of jadeitite. Jadeite is unstable at typical geologic conditions of water saturation, low pressure, and temperatures experienced near the surface such as underneath a warm, "wet" volcanic cover. Here jadeite chemically reacts to form analcime ($NaAlSi_2O_6H_2O$), or albite if silica is present. In fact there is an abundance of blue and green albitites in the region of the Motagua Valley where jadeitite is found. These albitites are produced by the breakdown of jadeitite during ascent from depth to the earth's surface. So, even in ideal circumstances the jadeitites are at risk of never reaching the surface intact. Consequently, the chance of finding true jadeite from beneath the volcanic cover is very unlikely; albitite or its alteration product would be the prime possibility if the scenario were possible. In fact, few albitites are found anywhere, nothing being brought to light that would fill the bill. Consequently, the requirements of the model—exposed serpentinite and faulting—appear to be rigorous.

So if the Motagua Valley looks like the only recognizable source, why has the INAA analysis not shown that the emerald green and blue-green jades have an affinity with the jadeitites from the Motagua Valley? I suggest that there is now good evidence that all the jadeite jade did come from the Motagua Valley. One must look at the jade artifacts and jadeite rocks, understanding something of their petrology, to be comfortable with this interpretation.

JADEITITE AND JADE: VARIABILITY AND SAMPLING

One of the principal arguments for alternative sources is that certain trace elements that were measured by INAA in groups of artifacts were not matched by samples recovered from the Motagua Valley (Bishop et al. 1985; and Chapter 2). This suggests several problems. First, the samples were looked at as homogeneous material, like obsidian or possibly chert, rather than as the somewhat heterogeneous rocks that they are. Second, the archaeological analysis was limited by a lack of diverse and numerous rock samples. For example, researchers did not find any emerald green jadeite rocks in the Motagua Valley, but they did not conclude that there are not any in this area. A third possibility is that there are other locations along the Motagua, such as Motagua-II, that have not yet been studied.

With respect to the first problem, lithic materials such as obsidian and even chert form by processes that sample a large chemical reservoir that is relatively well mixed, providing a stable range of compositions over a large amount of material. Jadeitite, on the other hand, is formed as a chemical alteration of a potentially diverse suite of rocks, involving the chemical heterogeneity of the source and the vagaries of chemical infiltration, reaction, and alteration. Although jadeitites are composed primarily of jadeite with some other characteristic minerals such as albite or white mica, a large number of minerals can be found in many jadeitites as a result of different amounts of jadeitization and subsequent alteration. Each mineral has its own chemical signature, often accounting for the bulk of certain trace elements and having some degree of variability. Consequently, as composites, different jadeitite blocks are not likely to cluster into narrow or highly restricted zones in plots of a multidimensional chemical space. Moreover, most jadeites show the effects of shearing and deformation caused by the adjacent and genetically important fault(s), which can and did mechanically mix adjacent rocks. Thus, one must study jadeitites and artifacts as the somewhat nasty rocks they are and use the appropriate petrographic techniques to establish the basic facts. This is not to say that the INAA clustering analysis does not have its place and interpretive value, but rather that one has to understand the complexity of the problem to apply the technique properly.

With respect to sampling, the rocks are so diverse that many samples are required; and with respect to the emerald green jade problem, such jadeite does exist at Motagua I, though its presence was only recently documented (Harlow and Olds 1987). The entire subject of emerald green jadeite stimulated the study of jadeite and led to the search in Middle America; we expected to find it in the Motagua Valley.

Emerald green jade is well known from the deposits in Burma as Imperial jade; however, the source of the emerald green color was poorly documented in the geologic literature. Pure jadeite is colorless, but small amounts of chromium replacing aluminum will produce a very strong emerald green coloring (the same replacement occurs in the mineral beryl to produce the green variety, emerald). The geochemical problem with this substitution is that chromium is generally not found in geologic systems rich in sodium and aluminum; they have very different affinities. The admixture of geochemically dissimilar elements is carried out by the tectonics (motion along the fault). Chromium is abundant in the mineral chromite (iron chromium oxide), which occurs as grains and often minable pod-shaped concentrations in ultramafic rocks, those same rocks that alter to form serpentinite. Apparently the movement along the fault occasionally mixes some chromite into the jadeite bodies in the serpentinite, a fluid-promoted reaction occurs, and the rare mineral kosmochlor (up until recently also called ureyite—sodium chromium silicate [$NaCrSi_2O_6$]—is formed [see Harlow and Olds 1987]). Any amount of kosmochlor can mix with jadeite in the solid state; only minor amounts yield vivid emerald green jadeitic pyroxene. Because the same basic set of geologic and tectonic conditions are found among the known jadeite-rock localities, it seemed reasonable to expect to find some emerald green jadeite rocks at the Guatemalan occurrence.

This reasoning led to an examination of the kosmochlor content of jadeite in Middle American artifacts, and a search for emerald green rocks, perhaps associated with chromite, among the jadeite rocks of the Motagua Valley in Guatemala. The investigations led to the discovery of special characteristics of the emerald green rocks and artifacts as well as to consistent similarities among jade artifacts and Guatemalan jadeite rocks.

Analysis of the emerald green rock fragments found at La Palmilla, Guatemala (about 12 km east of Manzanal), shows them to be chromian omphacite (omphacite is a pyroxene that is roughly half jadeite and half diopside, $CaMgSi_2O_6$ [Figure 1.4]; it is relatively common as a late-stage mineral in the Guatemalan jadeite rocks). The chromian omphacite coexists with chromite, albite, and chlorite (clinochlore) (see Table 1.2). Several lithic samples from caches in workshop excavations from Guaytán Castillo (Walters 1982), about 23 km from La Palmilla, show the same characteristics of pyroxene composition (see Figure 1.4) and mineralogy. By comparison, all but one of about five artifacts that have been examined in the electron microprobe show this same kind of chromian omphacite rather than chromian jadeite. This type of dark emerald green material appears to be the Emerald Green jade (Bishop et al. 1985) that previously could not be matched with Guatemalan rocks.

One Olmec bead (Xalitla, Guerrero, Mexico; Mineral Sciences NMNH 106891) that was studied is mostly jadeite and white mica (phengitic muscovite) with two small areas of kosmochlor and chromian jadeite surrounding chromite fragments. Other samples show good emerald green color with only minor amounts of kosmochlor in the jadeitic pyroxene. This is probably the Chichén Green kind of material that is similar to samples found near and in Río La Palmilla, except that the latter samples do not contain chromite. These rare Guatemalan samples seem to manifest emerald green color primarily in thin veins cutting pale green jadeitite. With these findings, some of the sourcing dilemmas seem to be resolved (or at least addressed). Now, what do the general characteristics of Guatemalan jadeite rocks and their related lithologies provide as connections to Middle American jades as a whole?

The jadeite artifacts, like the jadeitite, are rocks, assemblages of several minerals, though mostly jadeite. Compared to other rocks, they are not greatly homogeneous—the grain size of the constituent minerals varies substantially, as do the relative abundances of the minerals. However, the individual minerals and their compositions are limited and reasonably diagnostic. In fact, under this kind of scrutiny one can sort most jadeite rock among the various known geologic sources. The jadeitites and related rocks in the Middle Motagua Valley have their own characteristics and are generally recognizable.

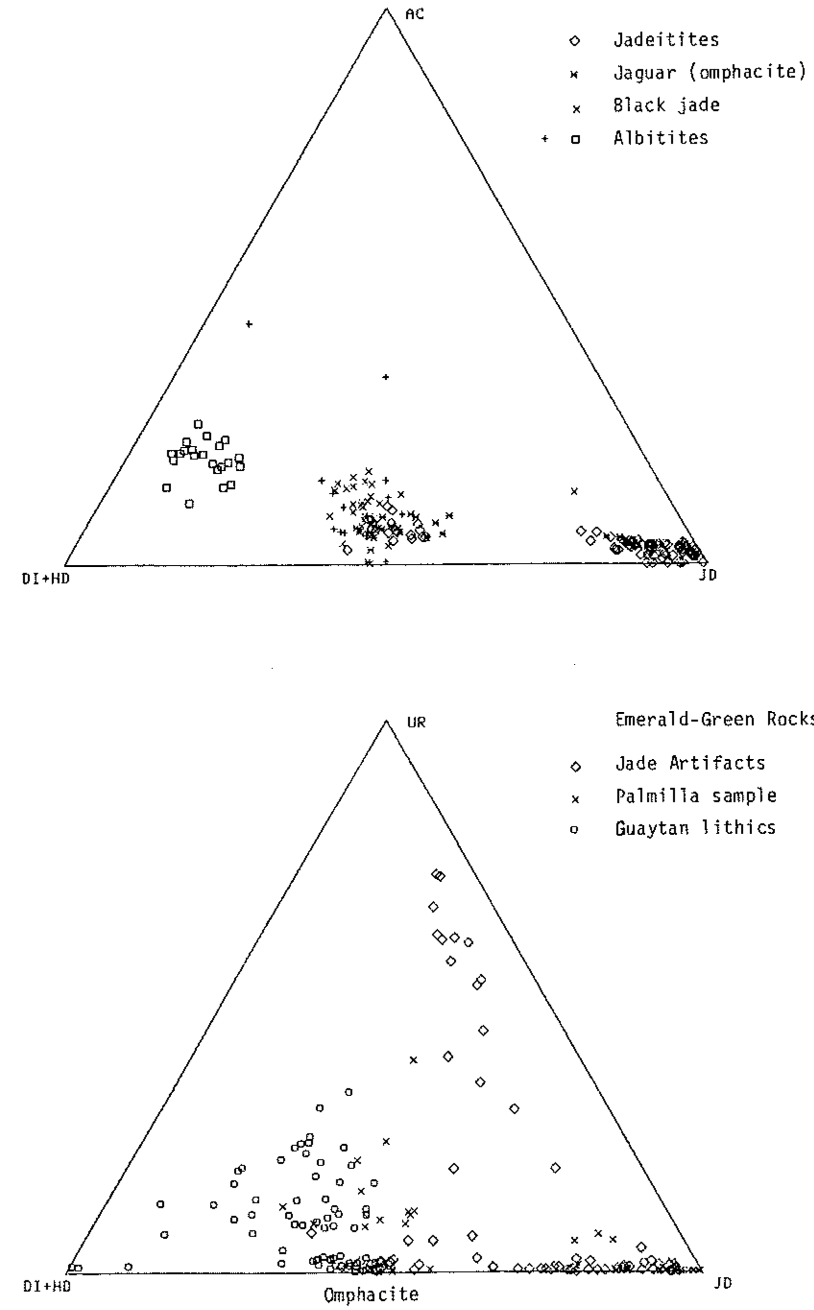


FIGURE 1.4 Fernary compositional plots of pyroxene compositions

TABLE 1.2 Mineralogy of Jadeitites and Related Jadelike Rocks from the Middle Motagua Valley (Motagua-I Source Area)

JADEITITE **Jadeitic pyroxene + omphacite + white mica** (paragonite and/or phengitic muscovite) + albite + sphene + zircon + apatite + graphite

ALTERED JADEITITE **Jadeitite + analcime + albite + blue amphibole** + zoisite + nepheline + preiswerkite + banalsite + sphene + apatite + zircon + ?

OMPHACITE ROCK (JAGUAR) **Omphacitic pyroxene** + jadeitic pyroxene + albite + chlorite + graphite

EMERALD GREEN PYROXENITE **Omphacite rock + kosmochloric omphacite** + Zn–Mn-rich chromite

BLUE/GREEN-BLACK METASOMATIZED BASALT (BLACK JADE) **Blue amphibole (taramite - ferroan pargasite) + ferroan omphacite + sphene + clinozoisite** + grossular + biotite + albite + jadeitic pyroxene + white mica

ALBITITE 1 (ALBITIZED JADEITITE) **Albite + diopsidic pyroxene + green amphibole (Na-actinolite) + quartz** + zoisite + sphene + vesuvianite + apatite + zircon

ALBITITE 2 **Albite + phengite (barian) + quartz** + green amphibole (Na-actinolite) + zoisite + dolomite + celsian + apatite + K=feldspar + ?

GREEN QUARTZITE/JASPER (GUATEMALITA) **Quartz + green mica (fuchsite) or chrysocolla + dolomite/calcite + magnetite** + chromite + sulfides (pyrite, chalcopyrite, galena) + titanite + zircon + mimetite + barite + ?

NOTE: Names printed in boldface are either the rock name or the primary constituent mineral in the rock.

JADEITITES AND RELATED JADELIKE ROCKS FROM THE MIDDLE MOTAGUA VALLEY

A complete description of the occurrence in the Middle Motagua Valley of jadeitites and related jadelike rocks is beyond the scope of this chapter, but the salient features and information are summarized here (see Harlow, 1993, for a fuller description).

The area examined is the region north of the Motagua River between El Rancho, where the Atlantic Highway (CA 9) enters the valley from Guatemala City to the southwest, and Río Hondo, approximately 50 km to the east. The search for jadeitite consisted of checking those occurrences that have been published (e.g., Hammond et al. 1977), following the suggestions of T. W. Donnelly (of the State University of New York at Binghamton) and examining boulders in the streams coming off the Sierra de las Minas and through serpentinite terrain (particularly sheared serpentinite) as mapped for the area. No jadeitites or their associations have been discovered south of the river, so this side was not investigated. The region that contains jadeitite is the area of serpentinites between Río El Cintillo (the town of Estancia de la Virgen) and Río La Palmilla. The zone is about 13 km long and is covered almost completely on the San Agustín Acasaguastlan Quadrangle map. Visited sites where jadeitite (and albitite) occurs are shown on the map in Figure 1.2, as are sites noted by other investigators but not personally visited. This region is considered the Motagua-I source. The significant rock types that could be considered potential varieties of jade are listed in Table 1.2.

Jadeitite has two major kinds of occurrence in the area: in streams and as rubbly mounds of jadeitite and albitite. Jadeitite occurs as cobbles and boulders in the streams that drain through bearing serpentinite, particularly in Río La Palmilla above Quebrada La Oscurana. The boulders range up to at least three meters in diameter and are conspicuous by their rusty brown to tan to white cortex, whitish green to apple green to mottled forest green color on fresh broken surfaces, massive appearance, extraordinary tenacity (hammers bounce off and ring when struck against the boulders), and occasional drill and blast holes left by jade entrepreneurs. No place was found where the jadeitite could be seen weathering directly out of the hosting serpentinite adjacent to the streams. Local jade collectors report jadeitite in abundance above Dos Ríos on Río La Palmilla, just north of the map boundary in Figure 1.2. Two other areas of stream boulders that are reported but were not visited are on Río Uyus between Cruz del Valle and Guapinol, as reported by Bosc (1971) and on Río Uijo east of Uijo, as reported by local jade collectors. There appear to be no macroscopic differences in the varieties of jadeitites and associated rocks found among these localities. In low, weathered ocher-earthed serpentinite hills near the Río Motagua, particularly between La Palmilla and Uijo and north of Manzanal (McBirney's locality), light tan-colored mounds and ridges can be found that are littered with small fragments and blocks (up to about a half meter) of jadeitite and albitite. These occurrences stand out from a fair distance both because of their color and because of a change in vegetation from brush and cactus to mostly grass. Similarly, they show up in aerial photographs as light-colored specks. The mounds range in size from a few meters in diameter to 20 by 50 m. One curious mound between Cerro Gallinero and the town of Uijo is called Hoyo de las Minas (Hole of the Mines) and consists of a volcanic tuff cone-shaped structure about 50 m in diameter at its base, about five meters high, and mostly barren except for a tree-filled "crater" four meters deep. Whereas many of the mounds are littered with knapped obsidian, which suggests work by precolumbian natives (e.g., the Maya), Hoyo de las Minas does not manifest this; its morphology is a curiosity and needs to be studied.

In addition to jadeitite and albitite, the mounds display fragments of silica (stained opal, chalcedony, and milky quartz), deep green omphacite clots or fragments, aggregates of acicular actinolite, dusty mammillary knots of magnetite, flakes of chlorite, and weathered serpentinite. Because there were no indications of their manufacture, we assumed that the mounds were weathered outcrops of tectonic blocks. Excavation did show a zoning profile and no evidence of human manifestation. The local occurrence of jadeitite and albitite terminates abruptly in the east-west direction, the lateral direction of the Motagua Fault(s). In the area surveyed by us and by Donnelly's co-workers, no such rocks have been found more than a few tens of meters east of Río La Palmilla, and none west of Estancia de la Virgen.

The key minerals for the Motagua-I jadeitites are jadeite (jadeitic pyroxene), omphacite, albite (a sodium feldspar), white mica (either paragonite, a sodium mica; or phengitic muscovite, a Mg-rich potassium mica), and titanite (formerly called sphene, $CaTiSiO_5$) (see Table 1.2). Increasing amounts of omphacite, usually as overgrowths on jadeite grains or in veins, make the jadeitite increasingly dark green in color. Omphacite can occur in large veins or clots of a dark green color that are commercially exploited as a jade variety known as Jaguar. Virtually all jadeitites are observed texturally to be in the process of breakdown by hydration and silicification to become albitite (albite rock). The process turns the typical green jadeite into zones of relict jadeite; often internally included by breakdown minerals, surrounded by veins and regions of albite, such rock is colored blue-gray by small crystals of blue amphibole. The albite mineralization is accompanied by analcime, zoisite, preiswerkite (a rare white, sodic mica), sphene, and occasional apatite and zircon. Omphacite-rich regions show the effects of alteration much less. Occasionally jadeitites and other rocks are gray to black from dusty microscopic inclusions of graphite.

There are two distinct types of albitite. The first, called here albitite 1, is considered to be the product of silicification of jadeitite because a general progression of textures can be seen of alteration of jadeitites to albitites. The blue to green color is caused by the relative amounts of pyroxene and amphibole contained by the altered rock. The pyroxene that is found varies from omphacite to aegerine-augite (sometimes referred to as chloromelanite—the term has been abandoned in mineralogy [Morimoto et al. 1988]). Typically these grains are found in textural settings that look like the pyramid terminations of relict pyroxene grains, the interiors occupied by albite plus blue-green amphibole. The remaining mineralogy is similar to that of the alteration veins in jadeitite: euhedral zoisite and titanite, occasional vesuvianite, apatite, and zircon in a sea of rarely twinned albite. However, quartz is found in these albitites, usually as blebs in albite or as small to large interstitial grains. In albitites with no obvious replacement textures, the main difference in mineralogy is that the amphibole is a sodic actinolite rather than a sodic calcic amphibole, and the pyroxene is likely to be aegerine-augite rather than omphacite; these albitites are always green rather than bluish.

The second kind of albitite, called albitite 2, is rich in white to greenish-white mica. The micaceous albitites do not manifest a replacement texture after jadeitite. Commonly they have a granular texture with intergrown albite, phengitic muscovite, penetrating sodic actinolite prisms, occasional blebby diopsidic pyroxene, and with or without quartz and/or dolomite. Occasionally zoisik chlorite and barium-rich minerals (celsian, barian phengite) are found.

It is obvious from the field expression and appearance of green albitites that they look like jade and can be easily mistaken for jade unless one is aware of the possible ambiguity. Results from artifact studies (Chapter 7; Bishop et al. 1985) show that these albitites were used as jade by the Maya. Besides the difference in specific gravity (SG is only about 2.6 to 2.7 for albitites), the albitites have a decreased tenacity, a typically more granular (sugary) texture, an absence of coarse mottled (jadeite) grains, and contain quartz.

One of the rocks desirable to lapidaries and usually found in rivers is typically a cryptic fine-grained black to dark green rock. It is very durable and known commercially as black jade; it takes a very good polish and shows little grain definition. It is frequently found as stream boulders and resembles basalt. Grain size macroscopically varies most conspicuously where clots of acicular amphiboles exceed one centimeter. Some blocks show a foliated appearance (having a planar element to the texture), probably a mylonite texture. Brittle deformation has produced veins that can be filled with dark green pyroxene, greenish jadeitite mineralogy (jadeite and mica), or orange-brown grossular garnet with included black amphibole. In thin sections the rock is a medium- to fine-grained (1–0.5 mm maximum grain size) mesh-textured intergrowth of blue pleochroic amphibole (taramite to ferroan pargasite), with lesser amounts of ferroan omphacite and corroded-looking titanite, variable amounts of clinozoisite, and occasional small interstitial fillings of albite.

Whereas black jade may not be an important material for handsomely worked artifacts, there are strong similarities between it and some dark green to black celts. It is also likely to be the same or similar material as Foshag's (1957) metadiorite. Petrologically, it is a singularly unusual rock, more unusual than jadeitite (Harlow and Donnelly 1989).

Occurring in the same area as the other rocks are a variety of fine-grained quartz rocks, or quartzites, or jaspers, depending on the preference in nomenclature, which vary from light green to a dark forest green, often with white (milky quartz) veining or banding and rusty staining. It is most abundant to the east of Río La Palmilla and up Quebrada La Oscurana, as described by Hammond and co-authors (1977). It is composed largely of submillimeter quartz grains with variable evidence of strain and deformation. Its green color is caused by small inclusions and intergranular coatings of either green mica (fuchsitic or ferroan muscovite) or chrysocolla. The micaceous variety also contains calcite/dolomite, magnetite, rutile, and occasionally zircon, mimetite, and barite. Other mineral inclusions are likely to be found when the material is more intensively studied. The chrysocolla-bearing variety shows evidence of hydrothermal sulfide mineralization with galena and probably pyrite in addition to magnetite and the altered copper minerals such as chalcopyrite. Iron staining, probably from hematite or limonite, is also visible macroscopically. Some of the quartz may be vein filling—voids are often present in the material—but altered chert is also a likely possibility. Samples of this material have also been found at Guaytán Castillo (Walters 1982; Chapter 7). The material has been used commercially as a jade substitute known as Guatemalita or Guatemalite.

COMPARISON OF MIDDLE AMERICAN JADES AND GUATEMALAN ROCKS

A number of artifacts were examined with the microscope and the electron microprobe. As already discussed in the case of two varieties of emerald green jades, both the minerals they contain and their mineral compositions are similar to those of rocks from the Motagua-I source. This is diagrammatically clear in Table 1.3, where the presence of jadeite, white mica, and albite stand out as being typical of Guatemalan jadeitite. It is obvious that the artifacts could not, for example, be confused with Burmese jade, which has no mica, little albite, and ubiquitous pale green Mg-rich sodic alkali amphibole (see Harlow and Olds 1987). In the case of the Chichén Green jade, even before a rock with exactly the same color and mineralogy was found the association of jadeite and white mica was completely consistent with Motagua-I jadeite rock. Moreover, based on the reasoning previously discussed, the admixture of chromite with the jadeite-mica rock by tectonic activity is reasonable.

Based on the observations of Motagua-I rocks and Middle American jades, by me and by previous workers (e.g., Bishop et al. 1985; Foshag 1957), comparisons of color to rock type (Table 1.4) and jade type to rock type (Table 1.5) can be made. Most of the assignments are fairly straightforward but may need refinement. Some remaining problems are the blue-green Olmec and Costa Rican types and an emerald green variety labeled by Bishop, Maya Green.

The blue-green jades vary from light to relatively dark in overall color, with a common characteristic being that they contain cloudy-looking "jadeite" grains. Only the light variety has been studied so far; it contains slightly iron-enriched jadeite, a fair amount of titanite, albite, and occasional white mica (see Table 1.3), all typical for the range of minerals found in the Motagua-I rocks. A conspicuous textural feature in blue-green jades is the white cloudy patches. In light green varieties these appear to be partially decomposed jadeite grains whose original compositions were more jadeite-rich than surrounding areas. This texture is again a typical feature of Motagua-I jadeitites. Very little of what has been found from the Motagua-I area truly resembles the blue-green varieties. The Motagua-II material looks tantalizingly similar to the darker "blue-green" varieties, but there are as yet inadequate sampling and data available. Preliminary examination indicates that the cloudiness is caused by clusters of acicular eckermannitic amphibole in jadeite; this is a new mineralogy for Guatemala and unknown in artifacts I have studied. However, it is still very interesting that the comparison of mineral assemblages from the Motagua-I jadeitites versus the blue-green jades yields such a consistent similarity in spite of the possibility that they come from Motagua-II or some other Motagua Valley source. This suggests a very similar set of geologic conditions (pressure, temperature, rock types involved, etc.) in producing the jadeitites of the Motagua Valley, which should be and is significant both geologically and archaeologically. Thus, I interpret that the Motagua Valley sources are the

TABLE 1.3 Mineralogical Comparison of Guatemalan Rocks and Jade Artifacts

	GUATEMALAN ROCKS (MOTAGUA-I)														
	ko	jd	omp	cm	ab	wm	amp	anl	nph	zoi	tit	chl	pr	qz	other	locality/comment
Jadeitites and partially altered jadeitites																El Progreso and Zacapa districts
MVJ84-9B		x			x	pa	x	x	x	x			x		apatite	Río La Palmilla
MVJ84-9C		x	x		x	pa	x	x	x	x	x		x		banalsite, zircon	Río La Palmilla
MVJ84-9D		x			x	pa	x	x	x	x	x		x		graphite, apatite, cancrinite	Palmilla
MVJ84-12-5		x			x	pa	x	x							banalsite, zircon	
MVJ84-32-3		x	x		x	pa					x		x		graphite	Palmilla
MVJ84-42-2		x			x	pa	x	x		x			x			Manzanal
AMNH 33399		x			x	pg		x								Motagua-I
AMNH 45049		x	x		x	pa	x			x	x		x			Motagua-I
NMNH 112538-3		x	x		x	pa,pg		x							K-spar	Motagua-I
R-1		x			x	pa				x	x					Maya Sea Foam
R-4		x			x	phl			x	x	x		x			Maya Mint
R-6		x	x		x	pa	x				x					Maya Pearl
R-7		x			x	pa	x	x		x						Maya Forest Fog
R-11		x			x	pa		x		x	x		x		apatite	Olmec Blue
R-12		x	x		x	pa,phl	x	x	x	x			x		zircon	Maya Dusk
R-13		x	x		x	pa										Maya Foliage
R-15		ko6	x		x	pa	x	x	x							Río La Palmilla emerald green
Omphacite rock—Jaquar																
MVJ84-41-4			ko37	x	x							x				Palmilla emerald green
MVJ84-44-2			x		x		x				x				apatite, chalcopyrite	Río La Palmilla
MVJ84-51-2		x	x		x		x				x				biotite, zircon	Quebrada el Escorpión
LACMNH 20368		x	x		x	pa					x	x			zircon, graphite	Motagua-I
R-10			x		x	phl						x			graphite, celsian, K-spar	Maya Herb
Albitites																
MVJ84-3-2					x	pg						x		?	cymrite apatite	Manzanal
MVJ84-5C			di		x	pg	x					x		x	zircon	Manzanal
MVJ84-12-1					x		x	x		x	x				grossular, apatite	Río La Palmilla
MVJ84-24-2			di		x		x			x	x	x		x	zircon	Usumatlán
MVJ84-29-1					x	pg,phl				x		x			celsian, K-spar	Usumatlán
Black Jade																
MVJ84-51-1			x		x		x				x				grossular, zircon	Río La Palmilla
LACMNH 20370			x		x		x			x	x				grossular	Motagua-I
Motagua-II																
R-16		x					x									new Olmec Blue (dark)
R-17			di		x		x				x	x			zircon	Aventurine (albitite)
R-18			x		x	pg					x	x			pyrite, garnet	Dark blue green

TABLE 1.3 Mineralogical Comparison of Guatemalan Rocks and Jade Artifacts (continued)

	ko	jd	omp	cm	ab	wm	amp	anl	nph	zoi	tit	chl	pr	qz	other	locality/comment
GUAYTÁN–CASTELLO (MAYAN WORKSHOP) LITHIC FRAGMENTS																
																San Agustín Acasaguastlán
4-5-8-1			ko29	x	x											pasty emerald green
4-8-11-2			x		x	x	x				x					pasty emerald green
4-8-11-3			x		x	x	x			x	x					dark/light green
4-8-11M			x		x	?				x						light green albitite
4-8-11X			x		x		x			x	x					green albitite
4-8-15-1			ko30	x	x											pasty dark green, emerald green spots
A5-6-1			x		x						x					pale green
A6-2			x		x					x	?	?				pasty green
Mexican Artifacts																
NMNH 106891	ko72	x	ko18	x		pg										Olmec bead; Xalitla (NMNH Min. Sci.)
NMNH 364966		x	x			pa	x									cylindrical bead (NMNH Anthropology)
NMNH 391073		ko2	ko7		x	pa?									Au, Cu alloy	ring; Chichén Itzá (NMNH Anthro)
NMNH 407254		ko40	ko6	x												bead; La Venta (NMNH Anthropology)
NMNH 419801		ko2														figurine; Guerrero (NMNH Anthro)
AMNH N/27		x	x		x	pa				x	x				apatite	spotty green pendant; Yucatán
AMNH 30/7393		x	x		x	pa,pg				x					zircon	disk; Nochistlan, Oaxaca
AMNH 30/10359		x	x			x	x				x					Olmec-style blue-green dish
AMNH 30/10763		x	x		x	pg		x			x				zircon	off-white disk; Oaxaca
AMNH 30/10765		x	x		x			x		x	x					pale green disk; Maya, Oaxaca
AMNH 30/10818		x	ko2			pg										emerald green disk; Mixteca, Oaxaca
AMNH 30/10824		x	x													pale green figurine
AMNH 30/11520		x	x		x	pg		x			x				zircon, ananite	pendant figurine; Nazareno, Oaxaca
Guatemalan and Costa Rican Artifacts																
NMNH 106457		x	di													celt; Guatemala
NMNH 106461		x	x		x					x	x					celt; Guatemala
AMNH 30/5556			ko2			pg									pyrite	emerald green pendant; F. Pompaya, Guat.
AMNH 30.0/1023		x	x													blue-green blade; Nicoya Peninsula, C.R.
AMNH 30.2/9759		x	x		x						x					dark bird axe; Costa Rica

NOTE: AMNH = American Museum of Natural History; LACMNH = Los Angeles County Museum of Natural History; NMNH = National Museum of Natural History; R = Ridinger, Jade, S.A.; MVJ = author's study; ko-kosmochlor (# refers to max. molar content in pyroxene); jd-jadeite; omp-omphacite (di=diopside); cm-chromite; ab-albite; wm-white mica (pa=paragonite, pg=phengite, phl=phlogopite); amp amphibole; anl-analcime; nph-nepheline; zoi-zoisite; tit-titanite; chl-chlorite; pr-preiswerkite; qz-quartz.

TABLE 1.4 Color Characterization of Jades and Their Equivalent Rocks from the Middle Motagua Valley

COLOR	TYPE
White to medium green	jadeitite or albitite or green quartzite/jasper
Blue-green (Olmec- or Costa Rican-like)	jadeitite (possibly slightly altered)
Dark blue-green (also Olmec- or Costa Rican-like, Motagua-II)	omphacitic jadeitite to omphacite rock
Apple or emerald green	jadeitite with Cr-bearing jadeite (kosmochloric)
Dark green (jaguar)	omphacite rock
Dark emerald green rock	kosmochloric omphacite
Gray or blue-gray	altered jadeitite
Gray to black	jadeitite or altered jadeitite with graphite
Black jade	metasomatized basalt

TABLE 1.5 Correlation Assignments of Bishop and Foshag Jade Types with the Appropriate Rock Type from the Middle Motagua Valley

BISHOP TYPE	FOSHAG TYPE	GUATEMALAN TYPE
Motagua Light	Types III & VI	Jadeitite
Motagua Dark	Type V	Omphacite rock
Chrome Green		Kosmochloric omphacite rock
Chichén Green	Type I?	Kosmochloric jadeitite
Maya Green	Type I	Kosmochloric jadeitite
Costa Rican Light?	Type II (Olmec Blue)	Jadeitite (slightly altered)
Costa Rican Dark	Type VII	Omphacite rock (Motagua-II) to black jade
Albite Light	Albite	Albitite 1
Albite Dark	Albite	Albitite 1
	Type IV	Altered jadeitite Albitite 2

only ones known or expected in Middle America, and they reasonably match the limited number of jadeite (and even other "jade") artifacts studied.

THE SIGNIFICANCE OF A SINGLE REGIONAL SOURCE

What is the significance of a single regional source to jadeite artifacts? Being a geologist, this is a question I pose to the archaeological community, but I will make a few observations anyway. First, it means that the wide distribution of these artifacts is the result of extensive and selective transport. The contexts for necessary trade between the Motagua Valley and other parts of Middle America at appropriate times are lacking. Moreover, the selective distribution of blue-green jades among the Olmec and Costa Rican artifacts, or Chichén Green at the Cenote at Chichén Itzá, indicates a specialized system of extraction, commerce, and/or state control of the jade sources in the Motagua Valley. The strong similarities among some artifacts shown by Bishop's INAA data suggest an individual "outcrop" or boulder as the source. Did each culture operate its own quarry to get its special variety, or was there a local entrepreneurial system to meet specific needs? How did single city-states maintain a supply of a specific jade variety over hundreds of years unless they developed and defended their own local (within the valley) source(s)? Or was jade treated so religiously that virtual pilgrimages to the source were made to retrieve the blessed and characteristic stone for manufacture of artifacts back home? I know of little archaeological data to select among such hypotheses.

The lack of obvious and impressive cultural presence in the Motagua Valley is cited as a problem. However, this apparent lack of occupation near the jade sources aside from Guaytán Castillo (near San Agustín Acasaguastlán), which is hardly small, may not be relevant. The valley is not the most hospitable environment, so in the past, as in the present, major centers of lapidary activities may have been elsewhere, in the Guatemalan Highlands, for example.

Second, the relatively large amounts of emerald green jade relative to the paucity found in the field suggest either a great depletion of this kind of material at the source or much more seeking through intensive occupation of the Motagua Valley and an acute awareness of rocks that could be fashioned into jade objects. Probably both points are correct. It is quite likely that literally no stone was left unturned in those areas where jade was found. The Maya and others, like many peoples, must have had an exceptionally keen eye for emerald green "rocks." There is some evidence for extensive ancient prospecting in the field: flaked obsidian is found in the natural mounds of jadeite rock rubble (the nearest obsidian source, El Chayal, is about 40 km to the southwest).

Third, it is quite obvious that jade was a precious substance, far beyond its present relative value. Exploration for this material must have been extensive, at least occasionally during the age of the Olmec and Maya. The number of people employed for the finding and the rough manufacturing of jade in the Motagua Valley must have been significant, though they may have left little mark other than subsistence occupation with modest agriculture. Perhaps the activities found in the Burmese jade fields or Colombian emerald deposits—extensive stream searching, modest to squalid habitation, armed convoys, and protection systems—serve as modern models. Presently, there is a very small jade industry in Antigua, Guatemala, which seasonally employs only a few people in the field to find blocks of jadeite rock. Much to their chagrin, they have found relatively few choice and usable pieces of emerald green jade.

It probably cannot be proved that the Motagua Valley is the only source for jadeite jade in Middle America. The kind of evidence required for that is very elusive, if not unattainable, particularly in the strict empirical environment of archaeological inquiry. However, there is reasonable geological evidence that the Motagua Valley is the main source.

NOTE

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