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- The provenance analysis suggests a Guatemalan source, strengthening the view of long-distance exchange networks in the Caribbean since the Early Ceramic Age.

Pre-Columbian jadeitite artifacts from the Golden Rock Site, St. Eustatius, Lesser Antilles, with special reference to jadeitite artifacts from Elliot's, Antigua: Implications for potential source regions and long-distance exchange networks in the Greater Caribbean

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Keywords

Jadeitite, Jade, pre-Columbian artifacts, exchange networks, Caribbean.

Abstract

A detailed electron microscopy analysis of jadeitite celts from the Early Ceramic Age Golden Rock settlement on the small volcanic island of St Eustatius, Lesser Antilles, is presented in an effort to identify the source region(s) of these jadeitite axes and evaluate the extent of trade networks in the Caribbean during pre-Columbian times through which those tools (or source rocks) circulated. Habitation at the site occurred between ca. AD 230 - 890, and the jadeitite tools most likely date between cal. AD 600 and 825/890. We argue that in provenancing jadeitite emphasis should be placed on the identification of the entire mineral assemblage (including the accessory minerals) and textures, given the complex geological histories and processes that form this quasi-monomineralic rock. Indeed, the mineral assemblages and the characteristics of the individual minerals within the studied jadeitite samples are far from homogeneous, suggesting either the source has a high degree of internal variation or there are multiple sources. We have identified three jadeitite groups among the analyzed samples on the basis of mineralogical assemblages: Group 1 consists of samples bearing phlogopite (plus phengite and epidote but without lawsonite or quartz); Group 2 contains lawsonite (plus phengite and quartz but without phlogopite and epidote); and Group 3 is defined by containing hematite. Importantly, we have not identified glaucophane in the analyzed materials. The comparison of these artifact data with those of jadeitites from the four potential known source regions of Caribbean jade, i.e., Guatemala (North and South Motagua Fault mélanges), Cuba (Sierra del Convento mélange) and Dominican Republic (Río San Juan complex) allows us to conclude that both the North and South Motagua Valley mélanges are the most likely sources for artifact groups 2 and 3, and perhaps also for group 1. This identification supports earlier hypotheses on the existence of pan-regional exchange networks, tying the northern Antilles with the

Isthmo-Colombian region (Colombia, Panama and Costa Rica) during the Ceramic Age of the Caribbean.

1 Introduction

Caribbean archaeology has recently experienced an increased interest in the study of inter-island and pan-regional interactions (e.g., Berman, 2011; Hofman and Hoogland, 2011; Hofman et al., 2007, 2011; Rodríguez Ramos and Pagán Jiménez, 2006). One of the major lines of research has focused on the study of the exchange of exotics between the islands and the existence of regional and macro-regional exchange networks (Berman, 2011; Cody, 1991, 1993; Hardy, 2008; Hofman et al., 2007; Knippenberg, 2004, 2006, 2007; Rodríguez Ramos, 2002, 2010, 2011). Research on lithic artifacts plays a key role in this endeavor, as it is the material category that can provide very detailed insights into the entire systemic process of acquiring, making, distributing, and using tools and objects (Knippenberg, 2006; Torrence, 1986). Among the transacted materials in these networks is jadeitite, a rock primarily composed of the sodic clinopyroxene jadeite. Jadeitite is well-known due to the very important role it fulfilled and broad usage it had in the great Meso- and Central American civilizations, including the Olmec, Maya, Aztec and Costa Rican cultures (Jones, 1998; Lange, 1993). The more limited use of jadeitite in the Caribbean had previously been hypothesized from rare finds of green lithic artifacts resembling this semi-precious stone (Chanlaitte Baik, 1984; Chanlaitte Baik and Narganes Storde, 1990; Fewkes, 1922; Haag, 1970; Sued Badillo, 1979). However, more recent work has shown that most of the personal adornments were erroneously identified, as these are mainly composed of nephrite and serpentinite (Cody, 1991; Murphy et al., 2000; Watters and Scaglion, 1994). Initial X-ray diffraction studies conducted on a Bahamian celt by Rose (1987) together with the in-depth petrographic and mineralogical work by Harlow et al. (2006) on a number of celts (axes) and celt fragments from the Elliot's site on the island of Antigua identified with high resolution techniques the use of jadeitite for the first time in the Antilles.

The identification of jadeitite artifacts in the Caribbean has had profound implications for our understanding of Antillean interaction networks operating in pre-Columbian times because, until recently, the closest jadeitite sources were only known in the Motagua Valley in Guatemala (Harlow, 1993, 1994; Harlow et al., 2006). Close similarity between the Antiguan artifacts and Guatemalan source material allowed both Rose (1987) and Harlow et al. (2006) to propose this distant Meso-American source region as being of significance to the pre-Columbian cultures of the Caribbean. Subsequent work by Harlow on greenstone celts and adzes from Tecla I and II, Punta Candelero, and Río Tanamá on Puerto Rico (Rodríguez Ramos, 2007) and Judith Fancy and Aklis

in the Virgin Islands (Hardy, 2008) confirmed the common presence of jadeitite in the archaeological record of the Antilles and its close association with the use as raw material for axes and much rarer adzes. Combined with iconographic, botanical, metallurgical, technological and stylistic concomitances between the Isthmo-Colombian area – particularly Costa Rica, Panama, and Colombia – and Early Ceramic Age northeastern Caribbean cultures, initial ideas on a distribution trajectory from Guatemala via the Isthmo-Colombian area directly towards the northeastern Antilles (Puerto Rico) were formulated (Rodríguez Ramos, 2007, 2010, 2011).

Harlow et al. (2006), however, noted some mineralogical/petrological dissimilarity between the Antiguan artifacts and the South Motagua mélange, and indicated that *" yet unknown sources in a similar geological terrane (serpentinite–matrix mélange) on Cuba, Hispaniola or Jamaica cannot be ruled out*". In fact, since that study was published, two new sources of jadeitite have been discovered in the Greater Antilles (Figure 1), in the Río San Juan region, northern Cordillera, Dominican Republic (Schertl et al., 2007, 2012) and in the Sierra del Convento, Guantanamo province, SE Cuba (Cárdenas-Párraga et al., 2010, 2012; García-Casco et al., 2009). These recent discoveries are extremely important for archaeological studies in the region. First, because they provide potential local sources for Caribbean jadeitite artifacts, including perhaps those that have been located in archaeological contexts as far as the Lesser Antilles. Second, because they represent only two out of a larger number of potential geological deposits in the region, suggesting that the discovery of new geologic deposits cannot be ruled out (e.g., in central Cuba, Jamaica, northern Venezuela and Colombia; Figure 1). The possibility of finding new sources in the region makes the task of firmly establishing the provenance of jadeitite artifacts in the Greater Caribbean very challenging. However, not positively identifying a source should not detract from the effort, as a negative result may suggest an additional unknown source, which by itself would be of major significance for the archaeology of the region.

One of the main current issues regarding the use of jadeitite, therefore, centres on the roles that these newly discovered Antillean sources played in the pan-regional networks where artifacts made of this raw material circulated in the Greater Caribbean. In order to address the aforementioned issues, this work presents the results of an in-depth mineralogical, petrological, and geo-chemical analysis of jadeitite artifacts from the site of Golden Rock in St. Eustatius to determine their geological provenance by comparing their signatures with those documented in the different potential source regions.

1.1 Some facts about jade

The gemological term jade collectively encompasses two different types of semiprecious rocks that are different mineralogically and in geologic origin. Jadeite jade (or jadeitite) is a quasi-

monomineralic rock made of jadeite, a sodic clinopyroxene, while nephrite jade (or actinolitite/tremolitite), the classical Chinese jade, is composed essentially of actinolite or tremolite, both calcic clinoamphiboles. The latter is relatively common in nature, whereas jadeitite is rare. Only ca. 20 localities for jadeitite are known worldwide (e.g., Tsujimori and Harlow, 2012), including the four located in the Caribbean realm, namely the North Motagua Fault region of Guatemala, the South Motagua Fault region of Guatemala, the Rio San Juan of Dominican Republic, and the Sierra del Convento of eastern Cuba. There are two additional localities in North America: New Idria in California and the Vizcaino peninsula in Baja California.

All jadeitite deposits are related to geological complexes that have undergone high pressure due to subduction of lithospheric plates, and most are hosted in ultramafic rock complexes formed in the Earth's mantle at > 30 km depth. Fluids released by subducting oceanic lithosphere at great depth interact with upper plate ultramafic mantle rocks (i.e., mantle wedge) forming serpentinites and, locally, jadeitite deposits by hydrothermal deposition in veins and/or metasomatic transformation of other adjacent rock types (Harlow and Sorensen, 2007; Tsujimori and Harlow, 2012). These ultramafic complexes are characterized by tectonic mélanges consisting of serpentinite (essentially, antigoritite) matrix and tectonic blocks of high-pressure rocks such as blueschist, eclogite, garnet-epidote amphibolite and jadeitite, among others. This high-pressure metamorphic characteristic is important for understanding archaeological jadeitite distributions in the Caribbean (and elsewhere) because, although ultramafic rock complexes are abundant in the region (e.g., Lewis et al., 2006), only some of them experienced high-pressure in subduction zones and thus are potential sites for hosting jadeitite deposits (Figure 1).

2 Archaeological context

The jadeitite artifacts discussed in this paper were excavated at Golden Rock, a large Ceramic Age settlement site centrally located on the small volcanic island of St. Eustatius, one of Netherlands' overseas municipalities in the Caribbean (Figure 2). Following earlier work in the 1920s by de Josselin de Jong (1947), who attested to the significance of the site, rescue excavation work in the 1980s by Versteeg and Schinkel (1992) from Leiden University unearthed the remains of a multi-phase Amerindian settlement. The findings include six different house plans flanked by several smaller structures and an associated circumscribed refuse midden deposit, all within an area of approximately 1200 m^2. The investigated area only represents a portion of the original settlement (Figure 2; Versteeg and Schinkel, 1992).

The systematically excavated midden deposit, ca. 400m^2 in size, produced a wealth of artifacts made from pottery, lithics, shell, and coral, as well as enormous quantities of food debris,

comprising predominantly shells, small fish and rodent bones. Multiple radiocarbon dates showed that the site was inhabited between cal. AD 230 - 890 making it the oldest Ceramic Age site on this small volcanic island. Dated hearths (h1-h3) situated underneath the artifact rich midden deposit suggest refuse material started to accumulate there somewhere between cal AD 230 – 660 (Versteeg and Schinkel, 1992, 204). On the basis of dates from the associated house structures, its most significant period of use, however, is later and must have been between AD 600 and 825-890, (Versteeg and Schinkel, 1992, 229; see also Knippenberg, 2006). This is likely the period when the jadeitite artifacts of the site were used and this usage is probably for a large part contemporaneous with that at Elliot's on Antigua. It should be noted that although in their original paper Harlow et al (2006) did not provide specific dates for the use of the jadeitite on Antigua, as the Elliot's site had not been absolutely dated, the description of the ceramic assemblage associated to these jadeitite celts provided in Murphy's (2001, 84-174) dissertation indicates that these are associated to a younger cultural component than that documented in the neighboring radiocarbon dated Royall's site (cal AD 250 – 630), therefore most likely dating to the later part of the Early Ceramic Age (AD 400 – 800).

Of the 3238 lithic artifacts found in the refuse and comprising the entire stone tool inventory and related manufacturing debris associated with the different Amerindian households identified at the site, seven axe fragments were classified as possibly being made from jadeitite, making up ca. 8% of all axes recovered. The jadeitite pieces include three edge flakes, another flake with a ground dorsal face, as well as two medial-lateral and one proximal-lateral axe fragment (Table 1). All jadeitite artifacts came from the top two thirds of an on average 60 to 70 cm thick midden deposit. Recorded depths of the specimen varied between 0 and 40 cm below the surface. Within the midden deposit no distinction could be made between different occupation phases; the finding of the jadeitite in the top 40 cm suggests that most likely this material should not be associated with the earliest use of the midden area. All of the identified jadeitite pieces came from finished tools, indicating that local manufacture of jadeitite axes at Golden Rock had not occurred. Furthermore, the items still possessing (part of) the edge exhibit macroscopic use-wear types that are typically found on axes, suggesting these jadeitite tools had likely been used as wood chopping implements. From these seven specimens, four were selected for in-depth petrographic, mineralogical, and geo-chemical analysis (see Table 2 and figure 2).

Apart from these jadeitite axe fragments, the Golden Rock site produced a wealth of other axes and axe manufacture related debris made from a range of rock materials. Predominant is a fine-grained grey-green tuffaceous mudstone originating from St. Martin, making up almost 73% of the total axe inventory. High amounts of manufacture debris in the form of flakes, shatter, and pre-

forms, as well as fragments of finished pieces (ca. 20% of all found lithics) shows that Golden Rock was involved in the on-site production of celts of this raw material (Knippenberg, 2006). In addition the inventory includes rare fragments of finished axes made from fine-grained mafic igneous rocks and different metamorphic rocks other than jadeitite.

3 Analytical and computation techniques

The provenancing of jadeitite has proven to be a very challenging task (see Lange, 1993 and contributions therein). Unlike other lithic sourcing studies (e.g., obsidian, chert) where the use of geochemical techniques for determining trace-element compositions and fingerprinting artifacts has proven highly effective, jadeitite appears to be less suitable for such approach (Harlow, 1993). As a consequence of the common occurrence of recurrent metasomatic (i.e., chemical infiltration and reaction) and vein filling-jadeite forming events in a specific rock mass involving fluids (i.e., chemicals) of varied sources and fluid paths, jadeitite rocks are not likely to cluster into narrow or highly restricted zones in plots of multidimensional chemical space.

This notion has guided the methodology of the present work and that of the earlier Antigua study (Harlow et al., 2006). The primary objective of the current work therefore is to determine the entire mineralogical constitution of the jadeitite artifacts and to characterize the important mineral phases. This has been done by a combination of analytical and computation techniques, including optical (polarized light) microscopy and electron beam examination (microprobe; WDS, EDS, and X-ray imaging) as well as projection and condensation of the multidimensional chemical space in order to produce tetrahedral diagrams (ACFN deluxe diagram) containing the full mineralogical information of the samples (Appendix A). Representative chemical analyses and structural formulas of the phases are given in table A1

The four samples that were analyzed (Figure 3) were cut to prepare polished thin sections for microscopy and electron-probe analysis. As described below, all samples are jadeite jade (jadeitite). Both, sodic clinopyroxene, jadeite, and sodic-calcic clinopyroxene, omphacite, are present in all samples except GR4-FIII.4 which contains only jadeite. The detailed mineralogical descriptions given below are important for both archaeological and geological reasons, as they can be used as a reference for future descriptions of Caribbean jadeitite artifacts and geological source samples, including any new sources in the region.

4 Textures and mineral composition

4.1 Sample GR24-B-III.1

Sample GR24-B-III.1 (Figure 3A) shows variations in green color as a result of variation in the concentration in jadeite, omphacite and, to a lesser extent, white mica and other minerals. Discrete grains or clots of grains of white mica (phengite) are distinctive visually, particularly with a hand lens. The entire mineral assemblage identified in this sample consists of (in order of abundance; Table 2) jadeite, omphacite, phengite, epidote, titanite and biotite, in addition to minor amounts of apatite, albite and analcime. This sample has a massive heterogranular (fine to coarse grained) texture, in which distinct coarse grained jadeite, clots of omphacite and distinct single crystals or clots of phengite (up to 3 mm in length) are set in a fine-to-medium grained (ca. 0.1-0.5 mm in size) matrix of jadeite and, to a lesser extent, omphacite (Figure 4). The textural relationships suggest the following crystallization scheme: Omp1 >> Jd >> Omp2+Phl+Ph+Ep+Ttn >> Anl+Ab (where the symbol >> points along the temporal sequence). The analyzed minerals of this sample are plotted in the ACFN deluxe diagram of Figure 5a.

Jadeite constitutes much of the rock. The crystals are fine to coarse grained. Backscattered electron (BSE) and X-ray (XR) images show variable composition (Figures 4b, d, e and f and 6a, b and c). The largest grains show an ill-defined concentric zoning, with cores generally richer in Ca, Mg and Fe and rims (and regions close to clots of omphacite and phengite) richer in Na and Al. However, the cores and rims also show patchy zoning. In the cores, Na-Al richer regions are located adjacent to inclusions of corroded omphacite. These regions are, in turn, surrounded by patchy Ca-Mg-Fe richer regions which are also present in the rims, although the outermost jadeite in contact with omphacite and phengite is rich in Na-Al. These relations suggest complex growth of jadeite with recurrent changes in composition from Na-Al rich through Ca-Mg-Fe rich to Na-Al rich (Figure 7). The amounts of calculated of Fe^{3+} and Fe^{2+} are low, indicating jadeite-diopside solid solution with low hedenbergite and aegirine content.

The compositions of the pyroxene are presented and classified in the ternary q-jd-aeg diagram (Morimoto et al., 1988; Figure 8). Most of the analyses are classified as jadeite, but some analyses with higher q-component (q >20 mole%) should be described as omphacite following these authors. The phase relations for clinopyroxenes calculated at a reference temperature of 500 ^{O}C by Green et al., (2007) have been included in this diagram in order to show the solvus relations in the jadeite-diopside-aegirine system. It should be noted that jadeite (and coexisting omphacite, see below) do not conform to the phase relations calculated at 500 ºC in this system (Figure 8), suggesting displacement of the forbidden region due to the effect of temperature of formation (which should be higher than 500 ºC) and/or of extra-components (notably FeO, cf. García-Casco et al., 2009) and/or

inaccuracy in the model (as suggested by Harlow et al., 2011). However, these point analyses of jadeite with high-q component may also represent cryptic Jd-Omp mixtures not readily discernable in BSE images.

Omphacite occurs as inclusions within jadeite, as clots dispersed in the matrix and as overgrowths at the edges of jadeite grains (Figures 4 and 6a, b and c). The textural relations indicate that omphacite inclusions represent former single grains that were replaced (corroded) by jd-rich pyroxene, in a first step, and jd-poorer pyroxene in a late stage. However, it cannot be excluded that some of the smaller omphacite grains within jadeite represent late non-lamellar exsolutions (unmixing) rather than inclusions. The clots of omphacite are associated with phengite and, locally, biotite (phlogopite). These clots appear to occupy former "voids" in the rock, as demonstrated by the textural position of the associated phlogopite (see below). However, towards the rims of the clots, omphacite replaces jadeite. Similarly, the fine-grained crystals of omphacite adjacent to jadeite replace the latter and are associated with phengite. The composition of omphacite is diverse but mostly showing jadeite-diopside solid solution with minor contribution of hedenbergite and aegirine components (Figures 7 and 8). The compositions of omphacite with different textural types overlap, but generally the omphacite replacements after jadeite have the most jd-rich compositions while the clots have the most jd-poor compositions. As with jadeite compositions plotting in the "forbidden" jd-omp solvus region, some analyses of omphacite with higher q-component plot in the "forbidden" omphacite-diopside solvus region calculated at 500 $^{\circ}$C. This may result from either not considering hedenbergite in the calculated phase relations and/or the temperature of formation being higher than 500 ºC.

Phengite occurs as discrete crystals and clots of crystals dispersed in the rock (Figures 4a and b). As indicated above, it is generally associated with late omphacite (Figures 4c and d), showing and interstitial position denoting a relatively late stage of crystallization. The composition of phengite shows a broad compositional spectrum (Figure 9) with Si up to 6.89 atoms per formula unit indicating solid solution in the muscovite-phengite series with some contributions of paragonite and barian muscovite components. The largest deviations of composition from the muscovite end-member are due to the Tschermak substitution ((Mg,Fe)$Si^{VI}Al_{-1}{}^{IV}Al_{-1}$), implying an important increase in Fe+Mg and Si (Figure 9), as expected for K-white micas crystallized at high-pressure.

The presence of Ba-rich K-white mica compositions (up to 3.44 wt% BaO) is a significant feature. The XR map of Ba(Lα) performed in this sample shows the chemical zoning at the grain-size scale (Figure 6e). It can be appreciated that the highest concentration in Ba is located towards the borders of the grains, where the contents in Al are also high (Figure 6d), but Si and K decrease (not shown) and Mg and Fe are uncorrelated. This indicates the "celsian-like" substitution

$^{[XII]}Ba^{[IV]}Al^{[XII]}K_{-1}{}^{[IV]}Si_{-1}$ instead of the "barian-muscovite" (or "ganterite") substitution $^{[XII]}Ba^{[VI]}Mg^{[XII]}K_{-1}{}^{[VI]}Al_{-1}$, in agreement with Harlow (1995) and Blanco-Quintero et al. (2011). Though not exclusively found in subduction zones, the existence of K-white micas rich in Ba is typical of rocks formed in this environment, interpreted as a result of jadeitite-forming fluids bearing a component derived from the dehydration of subducted oceanic sediments (e.g., Blanco-Quintero et al., 2011; Harlow, 1995). This type of mica has been described in Guatemalan jadeitite from both the North and South Motagua mélanges (Harlow et al., 2011) but not in jadeitites from the Cuban Sierra del Convento or the Dominican Rio San Juan mélanges (Cardenas-Párraga et al., 2012; Schertl et al., 2012).

Phlogopite is associated with omphacite and with phengite (Figure 6f). The textural position in the center of the clots of omphacite suggests crystallization in voids, reinforcing the view that all the mineral grains from these clots crystallized in cavities filled by hydrothermal fluid. Phlogopite associated with phengite is fine-grained, occupies interstitial positions and appears to be a late-stage alteration of phengite. Similar textural features of phlogopite have been described in jadeitites from the Cuban Sierra del Convento (Cárdenas-Parraga et al., 2012; García-Casco et al., 2009) and the Guatemalan North (common) and South (rarer) Motagua mélanges (Harlow et al., 2011). In these cases, phlogopite is late and appears with or after omphacite, ±albite, ±phengite, ±chlorite in interstitial growths (i.e., late veining but not necessarily cavities). All compositions have similar Mg# (0.80-0.81), but the latter type of phlogopite is poorer in Al, Ba and Na and richer in Si, Fe and Mg than that associated with omphacite (Figures 6f and 10).

Epidote is present in the clots of omphacite (±phengitee ±phlogopite), is fine grained and occupies an interstitial position, suggesting late growth. The composition of epidote has Fe^{3+} in the range 0.47-0.59, which corresponds to 48-61 mole% pistacite component (Figure 5a). **Titanite** is fine to coarse-grained (Figure 4b). The analyzed content of Al is ca. 0.05 apfu. **Plagioclase** appears within jadeite crystals associated to inclusions of omphacite. Its composition is albitic, though with measurable anorthite content (up to 5.5 mole%; Figure 5a). **Analcime** occupies interstices and is a late alteration product of pyroxene; Figure 4c). Its composition is almost stoichiometric $NaAlSi_2O_6 \bullet H_2O$ (Figure 5a).

4.2 Sample GR24-J-IV.05

Sample GR24-J-IV.05 (Figure 3B) is medium to fine grained, green in color with some variation in the shade of green. The lighter regions reflect the presence of white mica (and albite). The mineral assemblage consists of jadeite, omphacite, epidote, phengite, phlogopite, chlorite, albite, pumpellyite, and titanite (Table 2). This artifact shows an isotropic texture with no preferred orientation of grains, except fine-grained titanite that appears oriented. The texture is heterogranular

showing a noteworthy nodular structure (Figures 11a and b). The nodules (up to 0.5 mm in length) consist of omphacite, phengite, jadeite, epidote, albite, ±phlogopite, ±chlorite, ±pumpellyite and are set within a matrix of jadeite and intergrown smaller crystals of jadeite, omphacite and epidote (Figures 11c and d). However, the distribution of crystals in the intergrowths appears to delineate former large single crystals (0.5 mm), probably of omphacite transformed to jadeite+epidote (Figure 11d). The textural relationships suggest the following crystallization sequence: Ttn >> Omp1 >> Jd+Ep/Omp2+Phl+Ph+Ep >> Ab±Chl±Pmp. Except for the prominent presence of epidote within the intergrowths, the sequence of crystallization, the mineral assemblage, and the textures resemble those of artifact GR24-B-III.1. The analyzed minerals of this sample are presented in the ACFN deluxe diagram of Figure 5b.

The composition of **jadeite** is heterogeneous (Figures 7, 8 and 11b and d). The matrix grains enclosing the nodules and the Omp+Ep+Jd intergrowths, and "vein" and "pool" regions that crosscut previous blocky jadeite, show compositions richer in Na and Al (jd component), while jadeite in the intergrowths show the reverse. The low amounts of calculated of Fe^{3+} and Fe^{2+} indicate jadeite-diopside solid solution with low hedenbergite and aegirine contents (Figure 8). As with artifact GR24-B-III.1, most of the analyses are jadeite, but some analyses with q component >20 mole% can be described as omphacite. Also, jadeite (and omphacite) with high q-component plot in the “forbidden” solvus region calculated a 500 ºC (Green et al., 2007), suggesting formation at higher temperature and/or unaccounted components.

The range of **omphacite** compositions is similar to but more restricted than in artifact GR24-B-III.1, probably the result of limited analyses (Figures 7 and 8). However, a higher concentration in Fe^{2+}_{total} is apparent (0.15-0.17 apfu, Figure 7) and the amounts of calculated of Fe^{3+} and Fe^{2+} indicate jadeite-diopside solid solution with minor contribution of hedenbergite and aegirine components. The grains in the Omp+Ep+Jd replacements are poorer in jd content while the jd-richer compositions are present in the nodules. Most analyses with q-component plot in the “forbidden” solvus region for the omphacite-diopside system at 500 ºC with the same explanations as stated earlier.

The composition range of **phengite** is wide (Figure 9), indicating solid solution in the muscovite-phengite series (Tschermak substitution) with some contribution of paragonite component. The amount of Fe+Mg and Si is consistent with crystallization at high-pressure. It is noteworthy that Ba-rich compositions have not been detected in this artifact, and that Fe^{2+}_{total} is higher than in artifact GR24-B-III.1. Similarly, **phlogopite** has more Fe^{2+}_{total} (1.64-1.72 apfu), with lower Mg#, than in artifact GR24-B-III.1, approaching the field of biotite (Figure 10).

Clinozoisite (Fe^{3+} 0.07.-0.12; Figure 5b) rather than epidote is found in this artifact. **Titanite** has 0.046 Al apfu. **Plagioclase** is albite with anorthite content 1-2 mole% (Figure 5b). **Chlorite** is magnesian (Mg# = 0.66-0.67) and relatively rich in Al (5.26-5.44 apfu). **Pumpellyite** composition is pumpellyite-Al with Mg# = 0.94.

4.3 Sample GR3-NII.3

Sample GR3-NII.3 (Figure 3C) has a dark to light green color. The texture is fine-grained and massive. The mineral assemblage consists of jadeite (ca. 0.5 mm in size), omphacite (0.5 mm), lawsonite (0.3 mm) phengite (0.1 mm), and titanite plus quartz in trace amounts and albitic plagioclase and analcime (Figure 12; Table 2). Lawsonite and phengite show partial preferred orientation (Figure 12a). Jadeite shows patchy and concentric zoning, locally oscillatory, and replaces omphacite and lawsonite (Figure 12b-c). Interestingly, small grains of quartz occur as inclusions within jadeite (Figure 12c). Plagioclase and analcime appear as discrete inclusions/replacements within jadeite (Figure (Figure 12b). Textural analysis indicates that the sequence of mineral growth is Omp+Lws+Ms+Ttn(Ab?) >> Qtz+Jd >> Ab/Anl. The presence of lawsonite, the stability of Jd+Qtz and the lack of epidote suggest relatively low temperature of formation at high pressure.

Jadeite has varied composition (Figures 7 and 8). The total amounts of calculated Fe^{3+} and Fe^{2+} are low, indicating jadeite-diopside solid solution with limited hedenbergite and aegirine contents. This range is similar to the other described samples. Jadeite grains show concentric zoning patterns (Figure 12b), with cores richer in Ca-Mg-Fe and rims richer in Na-Al, though the reverse is also locally observed (see below). Furthermore, some crystals show oscillatory zoning with a general increase in Ca-Mg-Fe towards the rims (Figure 12b). Finally, jadeite replacing omphacite and lawsonite is zoned, with increasing Ca-Mg-Fe towards the outer zone of the replacement (Figure 12d), but in general this type of jadeite has higher Ca-Mg-Fe (i.e., lower jd) contents than matrix jadeite. These relationships indicate a complex history of jadeite growth which makes resolving the general pattern of chemical evolution difficult. In this regard, however, it is important to emphasize the trend towards more Ca-Mg-Fe rich compositions in the crystals with oscillatory zoning, as is typical of Guatemalan jade (Harlow et al., 2011).

Omphacite occurs as inclusions within jadeite and as discrete crystals associated with lawsonite (Figure 12b and d). Textural relations indicate omphacite replacement by jadeite (Figure 12b), suggesting that the inclusions represent omphacite grains replaced by jadeite. The compositional range is relatively restricted (Figures 7 and 8) and indicates jadeite-diopside solid solution with minor contribution of hedenbergite and aegirine components. It should be noted that the composition of omphacite is not similar to that of previously described artifacts. The amounts of

jd and q components are higher and lower, respectively, which permit omphacite to plot fully within the permitted region (at 500 ºC) and results in the shrinking of the measured compositional gap between jadeite and omphacite (Figure 8). This is consistent with a lower temperature of formation, in agreement with the presence of lawsonite and lack of epidote in this artifact.

The composition range of **phengite** is relatively restricted, with Si up to 7.00 atoms apfu (Figure 9). The amount of Tschermak (i.e., Si-Fe-Mg content) and paragonite (i.e., Na content) substitutions are respectively higher and lower, than in phengite from the previously described artifacts. This suggests lower temperature (and/or higher pressure) of formation. The amount of Ba is low. **Plagioclase** is albite with 0.003 mole% anorthite content (Figure 5b). **Lawsonite** is almost pure, with Fe = 0.01-0.02 apfu. **Titanite** has 0.04-0.05 Al apfu.

4.4 Sample GR4-FIII.4

Sample GR4-FIII.4 (Figure 3D) is green with locally darker patches and massive in texture. The mineral assemblage consists of jadeite, titanite and hematite, with minor amounts of albite and analcime (Table 2). We have not identified omphacite in this sample. The fine grained jadeitite matrix surrounds larger crystals of titanite and hematite (Figure 13). The crystals of jadeite are locally replaced by late albite and analcime. The latter occupies clear interstitial positions along cracks and within voids. Jadeite shows oscillatory zoning (Figure 13b), which zoning is truncated by regions richer in Ca-Mg-Fe typically located adjacent to voids/fractures filled with analcime (Figure 13b). The deduced sequence of crystal growth is Jd+Hem+Ttn >> Ca-Fe-Mg rich Jd/Ab/Anl.

The range in composition of **jadeite** is relatively restricted (Figures 7 and 8). This composition differs from that of other artifacts in having higher aeg content, consistent with the presence of the Fe^{3+} saturated phase hematite and, henceforth, high fO_2 conditions. Also, jadeite from this artifact reaches almost pure jadeite composition.

Hematite is nearly pure (Ti = 0.00, Mn < 0.003 apfu). **Plagioclase** is albite (1 mole % anorthite; Figure 5d). **Titanite** has 0.08 Al apfu. Analcime is almost pure (Ca = 0.01 apfu).

5 Discussion and Conclusions

5.1 Source region of the artifacts

The detailed discussion on the composition of the jadeitite artifacts recovered from Golden Rock attests to the need to conduct multi-faceted characterization studies of this raw material in order to come to terms with the geological signatures that will allow us to pinpoint its most

probable provenance in the Caribbean and elsewhere. To our knowledge, the work of Harlow et al. (2006) on the late Saladoid artifacts from the island of Antigua is the only published in-depth mineralogical-petrological study of jadeitite artifacts within the Caribbean that has provided comparable results to the ones hereby presented. The other studies on jadeitite identification and characterization in the Antilles (Hardy, 2008; Johnson, 1980; Rodríguez Ramos, 2007) were constrained to non-destructive X-ray diffraction techniques, which are basically restricted to mineral identification and limit the range of minerals to be identified to only those present in sufficient concentrations in the jadeitite (see for example Harlow et al., 2006, table 2). Given the subtle differences in mineralogical composition between the different jadeitite sources discussed in this paper, it is obvious that these X-ray diffraction results are not as useful in pinpointing the exact provenance of jadeitites.

From a mineralogical-petrological point of view, the Golden Rock artifacts on nearby St. Eustatius are similar to their Antiguan equivalents. Samples containing phengite+biotite/phlogopite, lawsonite, or quartz are common at both sites (Table 3). However, there are some differences as well, which include the presence of paragonite or glaucophane in some of the Antiguan artifacts, which have not been identified within the St. Eustatius assemblage, as well as abundant hematite in one St Eustatius specimen, absent from the Antigua artifacts. However, these differences may be the result of sample bias, taking into account the limited number of artifacts analyzed and the considerable variation that can exist between different jadeitite pieces from a single locality. Despite these differences, it is likely that jadeitite artifacts from both archaeological sites were extracted from the same source region.

On evaluating the provenance of the Antiguan artifacts, Harlow et al. (2006) indicated that they matched with jadeitite from the South Motagua Fault serpentinite mélanges of Carrizal Grande, La Ceiba and Ensenada, particularly given the presence of quartz, phengite+biotite/phlogopite, lawsonite, glaucophane and the lack of preiswerkite (Harlow et al., 2006, 2011; Table 3). Harlow et al. (2006), however, also reported important mismatches with this source, such as the presence of paragonite and (c)zoisite/epidote+quartz±lawsonite in the Antiguan artifacts that have not been described in jadeite from the South Motagua mélange. Paragonite and (c)zoisite/epidote are, however, abundant in jadeitite from the North Motagua mélange, but quartz and lawsonite are absent. Due to these dissimilarities, Harlow et al. (2006) concluded that other unknown sources in the Caribbean realm could not be ruled out, and specifically suggested the serpentinite mélanges from Cuba and Dominican Republic as possible alternatives.

With the discoveries of jadeitite occurrences on those two islands, a comparison with the results from the study of the Antiguan material can now be made. As evident in Table 3, key

mineralogical characteristics do not match with the material from Cuba or the Dominican Republic, so these were not the source of the Antiguan artifacts. Even if paragonite and (c)zoisite/epidote/allanite±quartz, also common in the Cuban material, are characteristics of the Antiguan artifacts, the presence of lawsonite and glaucophane in the artifacts is a significant mismatch. These two minerals have not been observed in any studied samples from the Cuban source. The jadeitites from the Rio San Juan deposit, on the contrary, commonly bear abundant glaucophane, but paragonite and biotite/phlogopite have not been described. Furthermore, lawsonite is common in this deposit, but not in jadeitite s.s. but in jadeite-lawsonite quartzite and lawsonite-quartzite, two rather different rock types than that of the Antiguan artifacts.

The source assignment of the St. Eustatius artifacts suffers from similar uncertainties. Since the studied artifacts represent exchanged items that may come from different sources, we have defined three groups based on mineralogical assemblages: Group 1 (GR24-B-III.1 and GR24-J-IV.05) consists of samples bearing phlogopite (plus phengite and epidote but minus lawsonite and quartz); Group 2 (GR3-NII.3) represents the sample bearing lawsonite (plus phengite and quartz but minus phlogopite and epidote); and Group 3 (GR4-FIII.4) is defined by containing significant hematite. Significantly, we have not identified paragonite or glaucophane in any of the artifacts. In general terms the different groups can be associated with different known sources. Group 1 exhibits strongest similarity with the North Motagua and Sierra del Convento deposits, while group 2 fits the South Motagua and Río San Juan deposits best, and group 3 matches up the North Motagua deposit, particularly that of Cerro Colorado (Harlow et al., 2011). Major element composition of the minerals does not add much in discriminating the sources, as illustrated by the composition of clinopyroxenes and phengite. The published analyses of these minerals have been compared with those of the studied artifacts (Figure 14). The micas compare well with the South Motagua source, but the scarcity of published analyses for the Sierra del Convento and Rio San Juan mélanges prevent definitive conclusions. The case for pyroxenes is similar, though the uncertainties in calculated Fe^{3+} and aegirine contents prevent further considerations. Hence, at present, mineralogical assemblages constitute the best proxy for evaluating provenance (Table 3).

In this regard, even if the Sierra del Convento deposit could be raised as a potential source of the phlogopite-bearing artifacts, the lack of lawsonite in this deposit (but present in Group 2) is a major mismatch. Similarly, the Dominican deposit seems an unlikely source due to the lack of phlogopite/biotite (present in Group 1), the common presence of glaucophane (absent in the artifacts), and the presence of lawsonite only in quartz-rich rocks. Also, hematite-bearing samples are lacking in these two deposits. There is also discrepancy with the North Motagua mélange, such as the lack of paragonite in group 1, but this mineral is only present in a portion of the North

Motagua samples and the discrepancy may therefore be insignificant. Only the South and North Motagua mélanges clearly stand out as likely sources for groups 2 and 3, respectively.

Consequently, it can be concluded that the Motagua Valley (North and South Motagua mélanges) is the most likely source for artifact groups 2 and 3, and probably also group 1. It is plausible that both Guatemalan deposits supplied the trade goods that arrived to the Golden Rock site. This conclusion agrees with the South Motagua source assignment of the Antiguan jadeitite artifacts by Harlow et al. (2006), though our conclusion of multiple Guatemalan sources for Golden Rock seems to make more sense because no major political/geographical barrier that may have hampered trade divided the North and South Motagua Valley deposits in pre-Columbian times. However, additional deposits yet to be discovered are possible (Jamaica, Nicaragua, Colombia and Venezuela; Figure 1), at least for the Antiguan artifacts which do not fully match with the known sources. Likewise, new finds and increased diversity within the known sources is another possibility, as the source areas and diversity in Guatemala alone have grown since the work on the Antigua artifacts in 2005; the picture is likely to change.

5.2 Archaeological implications

The jadeitite axes from Golden Rock clearly suggest the existence of interaction webs that led to the import of this important raw material into the Lesser Antilles in contexts post-dating AD 600. This evidence corresponds to that recovered from contemporaneous sites in Puerto Rico (e.g., Río Tanamá and Tecla II) and other islands in the Lesser Antilles (e.g., Spring Bay 1a on Saba, Elliot's on Antigua) where this type of material has also been documented (Rodríguez Ramos, 2007, 2011). The higher frequencies of these jadeitite artifacts in the northern Antilles when compared to the southern islands, indicates the unlikelihood that these circulated from northeastern South America via the Lesser Antilles. This opens the door for one or more of the following scenarios: a) the direct trans-Caribbean circulation of axes through interaction spheres articulated between these northernmost islands and the Isthmo-Colombian area, to where jadeitites were moved south from their original source in Guatemala (Harlow, 1993); b) that these materials came from one of the recently identified sources in the Dominican Republic or Cuba, or; c) that materials come from a yet unidentified source in either the Greater Antilles and Central or South America.

The petrological evidence hereby presented tends to supports the first possibility, as it indicates that the Motagua River Valley is the most likely source for these materials, as was also suggested in previous research on materials from Antigua (Harlow et al., 2006), Puerto Rico (Harlow, 2006, unpublished, cited in Rodríguez Ramos, 2007) and the Virgin Islands (Harlow, 2008, unpublished, cited in Hardy, 2008). The presence of Motaguan jadeitite in these islands might serve as evidence of the participation of its inhabitants in these long-distance trans-Caribbean

networks that seem to have been configured since the early peopling of the islands. Although the evidence of jadeitite pieces in the Antilles pre-dating AD 600 is scant, being limited to several petaloid celts possibly related to pre-AD 600 occupation phases of the multi-component Tecla 1 and Punta Candelero sites (Harlow 2006, unpublished, cited in Rodríguez Ramos 2007), there is clear evidence of other continental materials coming into the northern Antilles from the continental Caribbean since early on in the occupation of the Antilles that reaffirm the possibility for a continental origin for these jadeitite artifacts. The presence of these continental products in the northern Antilles initially involved the circulation of cultivars such as maize, manioc, and sweet potatoes during the Archaic Age and later. During the Early Ceramic Age (400 BC – AD 800), it entailed the movement of jaguar, peccary, and tapir tooth pendants, guanín (i.e., tumbaga or gold copper alloys), nephrite adornments, and possible other products that have clearly an extra-Antillean derivation (Rodríguez Ramos, 2010, 2011; Rodríguez Ramos and Pagán Jiménez, 2006). The iconographic resemblances between personal adornments documented in the northern Antilles and those observed in the Isthmo-Colombian region, which conforms the southernmost distribution of Motaguan jadeitite documented thus far in the American continents, has led to the suggestion of the existence of an Isthmo-Antillean interaction sphere that started to take shape since the earliest occupation of the islands (Rodríguez Ramos, 2013). The jadeitite distribution networks were inserted into other Antillean webs through which stone celts were being moved, particularly grey-green tuffaceous mudstone from St. Martin and silicified tuff from eastern Puerto Rico (Knippenberg, 2004, 2006; Rodríguez Ramos, 2001). These webs also included the circulation of porphyry *cemí* three pointers from St. Martin (Knippenberg, 2004, 2006). These webs must initially have been a very important means by which the earliest Ceramic Age settlers secured their survival in a new and sparsely populated islands setting (Hofman et al., 2007, 2011; Knippenberg, 2006).

Although the evidence presented here pinpoints the Motagua area as the exclusive source for the jadeitites documented in St. Eustatius, Antigua, Puerto Rico and the Virgin Islands, this line of research will benefit immensely with more complete characterization of the Dominican and Cuban sources, which is underway (e.g., Cárdenas-Párraga et al., 2012; García-Casco et al., 2009; Schertl et al., 2012; Hertwig et al., 2012), and the search for new sources in the Circum-Caribbean region. However, regardless of its source, the jadeitite material at Golden Rock represented a true exotic for its inhabitants, and it likely had one of the most distant origins of all lithics found at the site, much further than the grey-green mudstone celts and calcirudite conglomerate *cemí* three-pointer stones from neighboring St. Martin or flint material and tools from Antigua (Knippenberg, 2006). Despite its distant provenance, jadeitite axes were primarily used and valued as tools at Golden Rock, as well as at many other sites in which these have been documented. The relative hardness and toughness of the rock compared to the other available rock types in the region must have been the

main reason for this. Still examples exist from undated and unpublished contexts that show that in some instances it also fulfilled ceremonial or ritual functions, which may primarily be associated with its' brilliant lustre, green colour, and exotic nature (see also Berman, 2011; Rodríguez Ramos, 2007, 2011).

Its presence at Golden Rock furthermore shows that, despite the disappearance of the extensive Early Ceramic Age bead and pendant network somewhere between AD 400 and 600 (Knippenberg, 2006), other materials such as jadeitite became important in long-distance interactions. It possibly also signifies that networks were re-directed. This likely was the result of a combination of factors, including population growth, cultural diversification, and migration of groups to the Lesser as well as the Greater Antilles. These processes shifted the social landscape and opened up new territories, including previously unused raw material sources.

Following this early presence at Golden Rock during the late phase of the Early Ceramic Age, jadeitite use has been firmly attested at different well dated Late Ceramic Age (AD 800 – 1500) sites, such as for example Anse à la Gourde on Guadeloupe, and El Cabo and Playa Grande in the Dominican Republic, Tecla II and Rio Tanamá in Puerto Rico and other sites in the Virgin Islands and the Grenadines. This evidence suggests that the use of jadeitite had become a structural element in Caribbean Amerindian culture until the late pre-Columbian occupation of the islands.

This exchange involving jadeitite, along with other materials and information, was part of complex multi-vectorial networks that shifted in configuration and directionality throughout the pre-colonial history of the Antilles (see also Hofman and Hoogland, 2011; Hofman et al., 2007, 2011). Hopefully, this study provides a step forward towards a better understanding of the millenary engagements that took place within and between the insular and the continental Caribbean.

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7 References

Berman, M. J. 2011. Good as Gold: the Aesthetic Brilliance of the Lucayans. In, A.L. Curet and M.W. Hauser (eds.), Islands at the Crossroads. Migration, seafaring, and interaction in the Caribbean, The University of Alabama Press, Tuscaloosa, 104-134.

Blanco-Quintero, I.F., Lázaro, C., García-Casco, A., Proenza, J., Rojas-Agramonte, Y., 2011. Barium-rich fluids and melts in the subduction environment (La Corea and Sierra del Convento mélanges, eastern Cuba). Contrib. Mineral. Petrol. 162, 395–413.

Cárdenas-Párraga, J., García-Casco, A., Harlow, G.E., Blanco-Quintero, I.F., Rojas Agramonte, Y., Kröner, A., 2012. Hydrothermal origin and age of jadeitites from Sierra del Convento Mélange (EasternCuba). Eur. J. Mineral. 24, 313–331.

Cárdenas-Párraga, J., García-Casco, A., Núñez- Cambra, K., Rodríguez-Vega, A., Blanco-Quintero, I.F., Harlow, G.E., Lázaro, C.. 2010. Jadeitite jade occurrence from the Sierra del Convento mélange (eastern Cuba). Bol. Soc. Geológica Mexicana 62, 199–205.

Chanlatte Baik, L.A., 1984. Arqueología de Vieques. Centro de investigationes arqueologicas, Universidad de Puerto Rico Recinto de Rio Piedras.

Chanlatte Baik, L.A., Narganes Storde, Y.M., 1990. La nueva arqueologia de Puerto Rico. Puerto Rico.

Cody, A.K., 1991. Prehistoric patterns of exchange in the Lesser Antilles: materials, models, preliminary observations. Master's thesis on file, San Diego University.

Cody, A.K., 1993. Distribution of exotic stone artifacts through the Lesser Antilles: their implications for prehistoric interaction and exchange. Proceedings of the Fourteenth International Congress for Caribbean Archaeology, 204-225.

de Josselin de Jong, J.P.B. 1947. Archaeological materials from Saba and St. Eustatius, Lesser Antilles. Mededelingen Rijksmuseum voor Volkenkunde, NO. 1, Leiden.

Deer, W.A., Howie, R.A., Zussman, J., 1962. Rock forming minerals. Vol. 3, Sheet silicates. John Wiley, New York, 270 p.

Fewkes, J.W., 1922. A prehistoric island culture area of America. 34th Annual Report of the Bureau of American Ethnology 1912-1913, Washington, DC.

Fisher, G.W., 1989. Matrix analysis of metamorphic mineral assemblages and reactions. Contrib. Mineral. Petrol. 102, 69-77.

Fisher, G.W., 1993. An improved method for algebraic analysis of metamorphic mineral assemblages. Am. Mineral. 78, 1257-1261.

García-Casco, A., Rodríguez-Vega, A., Cárdenas-Párraga, J., Iturralde-Vinent, M.A., Lázaro, C., Blanco-Quintero, I.F., Rojas Agramonte, Y., Kröner, A., Núñeez-Cambra, K., Millán, G., Torres-Roldán, R.L., Carrasquilla, S., 2009. A new jadeitite jade locality (Sierra del Convento, Cuba): first report and some petrological and archaeological implications. Contrib. Mineral. Petrol. 158, 1–16.

Green, E.C.R., Holland, T.J.B., Powell. R., 2007. An order-disorder model for omphacitic pyroxenes in the system jadeite-diopside-hedenbergite-acmite, with applications to eclogite rocks. Am. Mineral. 92, 1181–1189.

Guidotti, C.V., 1984. Micas in metamorphic rocks. Reviews in Mineralogy and Geochemistry 13, 357–467.

Haag, W.G., 1970. Stone artifacts in the Lesser Antilles. Proceedings of the Third International Congres for the Study of Precolumbian Cultures of the Lesser Antilles, 129-138.

Hardy, M., 2008. Saladoid economy and complexity on the Arawakan frontier. Unpublished PhD dissertation, Florida State University.

Harlow, G.E., 1993. Middle American jade: geologic and petrologic perspectives on its variability and source. In: F.W. Lange (ed.) Precolumbian Jade: New geological and cultural interpretations. University of Utah Press, Salt Lake City, Utah, 9-29.

Harlow, G.E., 1994. Jadeitites, albitites, and related rocks from the Motagua Fault Zone, Guatemala. J. Metamorphic Geol. 12, 49-68.

Harlow, G.E., 1995. Crystal chemistry of barian enrichment in micas from metasomatized inclusions in serpentinite, Motagua Fault Zone, Guatemala. Eur. J. Mineral 7, 775–789.

Harlow, G.E., Murphy, A.R., Hozjan, D.J., de Mille, C.N., Levinson, A.A., 2006. Pre-Columbian jadeite axes from Antigua, West Indies: Description and possible sources. Can. Mineral 44, 305-321.

Harlow, G.E., Sisson, V.B., Sorensen, S.S., 2011. Jadeitite from Guatemala: new observations and distinctions among multiple occurrences. Geologica Acta 9, 363-387.

Harlow, G.E., Sorensen, S.S., Sisson, V.B., 2007. Jade. In: L.A. Groat (ed.) The Geology of Gem Deposits. Short Course Handbook Series 37, Mineral. Assoc. of Canada, Quebec, 207-254.

Hertwig, A., Maresch, W.V., Schertl, H-P., 2012. REE geochemistry of jadeitite and related rocks from the Dominican Republic. Abstract V43C-2846 presented at 2012 Fall Meeting, AGU, San Francisco, CA, 3-7 Dec.

Hofman, C.L., Boomert, A., Bright, A.J., Hoogland, M.L.P., Knippenberg, S., Samson, A.V.M., 2011. Ties with the homelands: Archipelagic interaction and the enduring role of the South and Central American mainlands in the Pre-Columbian Lesser Antilles. In: L.A. Curet and M.W. Hauser (eds.), Islands at the crossroads. Migration, seafaring, and interaction in the Caribbean, The University of Alabama Press, Tuscaloosa, 73-86.

Hofman, C.L., Bright, A.J., Boomert, A., Knippenberg, S., 2007. Island Rhythms. The web of social relationships and interaction networks in the Lesser Antillean archipelago between 400 B.C. and A.D. 1492. Latin American Antiquity 18, 243-268.

Hofman, C.L., Hoogland, M.L.P., 2011. Unravelling the multi-scale networks of mobility and exchange in the pre-colonial circum-Caribbean. . In: C.L. Hofman and A. van Duijvenbode (eds.), Communities in Contact. Essays in archaeology, ethnohistory & ethnography of the Amerindian circum-Caribbean, Sidestone Press, Leiden, 15-44.

Johnson, K. R., 1980. Results of tests to determine mineralogy of an artefact from San Salvador, Bahamas. Bahama Archaeology Reports and Papers, College Centre of the Finger Lakes Bahamian Field Station San Salvador, Bahamas.

Jones, J. (ed.), 1998. Jade in Ancient Costa Rica. The Metropolitan Museum of Art, New York.

649 Knippenberg, S., 2004. Distribution and exchange of lithic materials: three-pointers and axes from St. Martin. In, A.
650 Delpuech and C.L. Hofman (eds.), Late Ceramic societies in the eastern Caribbean. British Archaeological
651 Reports International Series 1273, Paris, Monographs in American Archaeology 14, 121-38.

652 Knippenberg, S. 2006. Stone artefact production and exchange among the Lesser Antilles. Ph.D. dissertation. Leiden
653 University, Leiden.

654 Knippenberg, S., 2007. Long Island flint production, distribution and exchange among the northern Lesser Antilles.
655 Proceedings of the Twentieth First International Congress of Caribbean Archaeology, 813-821.

656 Lange, F.W. (ed), 1993. Precolumbian jade: New geological and cultural interpretations. University of Utah, Salt Lake
657 City.

658 Lewis, J.F., Draper, G., Espaillat, J., Proenza, J.A., Jiménez, J., 2006. Ophiolite-Related Ultramafic Rocks
659 (Serpentinites) in the Caribbean Regiona Review of their Occurrence, Composition, Origin, Emplacement and Ni-
660 Laterite Soil Formation. Geol. Acta 4, 237-264.

661 Morimoto, N., Fabries, J., Ferguson, A.K., Ginzburg, I.V., Ross, M., Seifert, F.A., Zussman, J., Aoki, K., Gottardi, G.,
662 1988. Nomenclature of pyroxenes. Am. Mineral. 73,1123–1133

663 Murphy, A.R., 1999. The prehistory of Antigua, Ceramic age: subsistence, settlement, culture, and adaptation within an
664 insular environment. Unpublished Ph.D. dissertation, University of Calgary, Alberta, Canada.

665 Murphy, A.R., Hozjan, A.J., de Mille, C.N., Levinson, A.A., 2000. Pre-Columbian gems and ornamental materials from
666 Antigua, West Indies. Gems & Gemology 36, 234-245.

667 Rodríguez Ramos, R., 2001. Lithic Reduction Trajectories at La Hueca and Punta Candelero Sites, Puerto Rico.
668 Unpublished M.A. Thesis, Department of Anthropology, Texas A&M University, College Station.

669 Rodríguez Ramos, R., 2002. Dinámicas de intercambio en el Puerto Rico prehispánico. Caribe Arqueológico 6:16-22.

670 Rodríguez Ramos, R., 2007. Puerto Rican precolonial history etched in stone. Unpublished PhD dissertation, University
671 of Florida.

672 Rodríguez Ramos, R., 2010. Rethinking Puerto Rican Precolonial History. University of Alabama Press, Tuscaloosa,
673 Alabama.

674 Rodríguez Ramos, R., 2011. The circulation of jadeitite across the Caribbeanscape. In: C.L. Hofman and A. van
675 Duijvenbode (eds.), Communities in Contact. Essays in archaeology, ethnohistory & ethnography of the
676 Amerindian circum-Caribbean, Sidestone Press, Leiden, 117–136.

677 Rodríguez Ramos, R., 2013. Isthmo-Antillean Engagements. In W.F. Keegan, C. L. Hofman and R. Rodríguez Ramos
678 (eds.) Oxford Handbook of Caribbean Archaeology, Oxford University Press, New York.

679 Rodríguez Ramos and Pagán Jiménez, 2006. Interacciones multivectoriales en el Circum-Caribe precolonial: Un vistazo
680 desde las Antillas. Caribbean Studies 34(2),103-143.

681 Rose, R. 1987. Lucayan Lifeways at the Time of Columbus. In: D.T. Gerace (ed.), Proceedings of the First San
682 Salvador Conference, Columbus and His World, CCFL Bahamian Field Station, Ft. Lauderdale, Florida, 321-340

683 Schertl, H.-P., Krebs, M., Maresch, W.V., Draper, G., 2007. Jadeitite from Hispaniola: a link between Guatemala and
684 Antigua? 20th Colloquium on Latin American Earth Sciences, Kiel, Germany, Abstract Volume, 167-168.

Schertl, H.-P., Maresch, W.V., Stanek, K.P., Hertwig, A., Krebs, M., Baese, R., Sergeev, S.S., 2012. New occurrences of jadeitite, jadeite quartzite and jadeite-lawsonite quartzite in the Dominican Republic, Hispaniola: petrological and geochronological overview. Eur. J. Mineral. 24, 199–216.

Sued Badillo, J., 1979. La industria lapidaria pretaína en las Antillas. Revista Interamericana 8, 429-462.

Torrence, R., 1986. Production and exchange of stone tools. Cambridge University Press.

Torres-Roldán, R.L., García-Casco, A., García-Sánchez, P.A., 2000. CSpace: An integrated workplace for the graphical and algebraic analysis of phase assemblages on 32-bit Wintel platforms. Comput. Geosci. 26, 779–793.

Tsujimori, T., Harlow, G.E., 2012. Petrogenetic relationships between jadeitite and associated high-pressure and low-temperature metamorphic rocks in worldwide jadeitite localities: a review. Eur. J. Mineral. 24, 371–390.

Versteeg, A.H., Schinkel, K., 1992. The archaeology of St. Eustasius. The Golden Rock site. Publication of the Foundation for Scientific Research in the Caribbean Region, no.113.

Watters, D.R., Scaglion, R., 1994. Beads and pendants from Trants, Montserrat: implications for the prehistoric lapidary industry of the Caribbean. Annals of the Carnegie Museum 63: 215-237.

Whitney, D.L., Evans, B.W., 2010. Abbreviations for names of rock-forming minerals, American Mineralogist, Volume 95, pages 185–187.

8 Figure Captions

Figure 1. Location of known jadeitite deposits in the Caribbean region, of studied archaeological jadeitite from Antigua (Harlow et al., 2006) and St. Eustatius (this work), of ultramafic bodies (high-pressure or not), and of potential regions where jade deposits (related to high-pressure ultramafic rocks) are possible (see the electronic version of the article for a color version of this figure).

Figure 2. Golden Rock Site lay-out showing the location of the jadeitite artefacts discussed in this paper in relation to the refuse midden area and house plans belonging to the different occupation phases at the site (modified after Versteeg and Schinkel, 1992, fig. 161, p.181). Numbers of the artefacts refer to numbers in Table 1. The inset shows the location of the site in the island (see the electronic version of the article for a color version of this figure).

Figure 3. Photographs of the studied artifacts from Golden Rock site (St. Eustatius). The scale shown in the photographs is given in cm. A) Fragment of axe, proximal-lateral part (sample GR24-B-III.1). B) Edge flake (sample GR24-J-IV.05). C) Fragment of axe (sample GR3-NII.3). D) Edge flake (sample GR4-FIII.4). See the electronic version of the article for a color version of this figure.

Figure 4. Textures and mineral associations of artifact GR24-B-III.1. A) and B) Optical images (crossed polars) of the sample showing large crystals of jadeite and phengite. C) and D) BSE images. Note omphacite included in jadeite and the clots of omphacite, locally associated with phengite. E) and F) Close up BSE images (see location in C) showing corroded omphacite within jadeite and the patchy zoning of jadeite (darker color denotes Na-Al richer composition). See the electronic version of the article for a color version of this figure.

Figure 5. ACFN "deluxe" diagrams for the analyzed minerals of the studied artifacts calculated with *CSpace* (Torres Roldán et al., 2000). The minerals are projected from the phases and exchange vectors indicated in A. Representative end-members of the solid solutions are indicated (lower case font). See the electronic version of the article for a color version of this figure.

Figure 6. XR maps of artifact GR24-B-III.1. The color scale bar represents relative element concentration (counts; red and purple denote higher and lower concentration, respectively). The horizontal scale bar is 1 mm. See the electronic version of the article for a color version of this figure.

Figure 7. Binary diagrams showing the composition of analyzed clinopyroxenes expressed in terms of cations per formula unit (6 oxygens), with indication of significant end-members and exchange vectors. See the electronic version of the article for a color version of this figure.

Fig. 8. Composition of jadeite and omphacite plotted in the ternary jadeite-q-aegirine diagram with the clinopyroxene classification scheme of Morimoto et al. (1988; names in italics). Also shown are the phase relations of clinopyroxene (denoted by space groups C2/c and P/2n) calculated by Green et al. (2007) at 500 ºC in the system jadeite-diopside-aegirine. Note that jadeite and omphacite with higher q component plot within the omphacite-jadeite and omphacite-diposide solvus (forbidden regions) as a likely consequence of the lack of consideration of hedenbergite in the calculated phase relations and/or different temperature of formation. Solid lines indicate varying aegirine/(q+aegirine) ratios. See the electronic version of the article for a color version of this figure.

Figure 9. Binary diagrams showing the composition of K-white micas. Representative end-members and substitution vectors are shown (note that, for convenience, the "celsian" vector has been drawn to intersect the phengite end-member). See the electronic version of the article for a color version of this figure.

Figure 10. Phlogopite composition plotted in the ‘‘ideal plane of biotite’’ (Deer et al., 1962; Guidotti, 1984) Representative end-members are shown. See the electronic version of the article for a color version of this figure.

Figure 11. Textures and mineral associations of artifact GR24-J-IV.05. A) Optical (crossed polars) and B) BSE images showing the nodular structure and Omp+Ep+Jd intergrowths. C) Optical (crossed polars) and D) BSE images showing details of the intergrowth texture. For convenience, the BSE image is presented in a color scale (red color indicates higher average atomic weight; red: epidote; green: omphacite; blue: jadeite). See the electronic version of the article for a color version of this figure.

Figure 12. Textures and mineral associations of artifact GR3-NII.3. A) Optical (crossed polars) image showing the general texture of the sample. B) BSE image showing the association of lawsonite+phengite and the chemical zoning of jadeite (i.e., cores richer in Ca-Mg-Fe, rims richer in Na-Al and local oscillatory zoning). Note that lawsonite is replaced by jadeite. C) BSE image showing quartz inclusions within jadeite. Lawsonite is replaced by jadeite. D) Replacement of omphacite and lawsonite by jadeite. Note that jadeite replacements are richer in Ca-Mg-Fe than jadeitite in the matrix. See the electronic version of the article for a color version of this figure.

Figure 13. Textures and mineral associations of artifact GR4-FIII.4. A) and B) Optical (crossed polars) and BSE images showing the texture of the sample. Note oscillatory zoning of jadeite crystals and the Ca-Mg-Fe richer composition of jadeite adjacent to analcime crystals grown in voids/fractures. See the electronic version of the article for a color version of this figure.

Figure 14. Comparison of phengite (left) and clinopyroxene (right) composition from St. Eustatius jade artifacts with Antiguan jade artifacts (Harlow et al., 2006) and jadeitites from the mélanges of North and South Motagua (Harlow et al., 2006), the Sierra del Convento (Cárdenas-Párraga et al., 2012) and the Río San Juan (Schertl et al., 2012). For clarity, only the clinopyroxenes from the South Motagua mélange have been plotted. See the electronic version of the article for a color version of this figure.

Pre-Columbian jadeitite artifacts from the Golden Rock Site, St. Eustatius, Lesser Antilles, with special reference to jadeitite artifacts from Elliot's, Antigua: Implications for potential source regions and long-distance exchange networks in the Greater Caribbean

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Tables

Table 1. Context and dimensions of Golden Rock jadeitite artefacts. Level is below surface; MD=maximum dimension; L=length, W=width; Th=thickness (all in mm); W=weight (in g). All artifacts are considered to date AD 600 and 825-890 (see text).

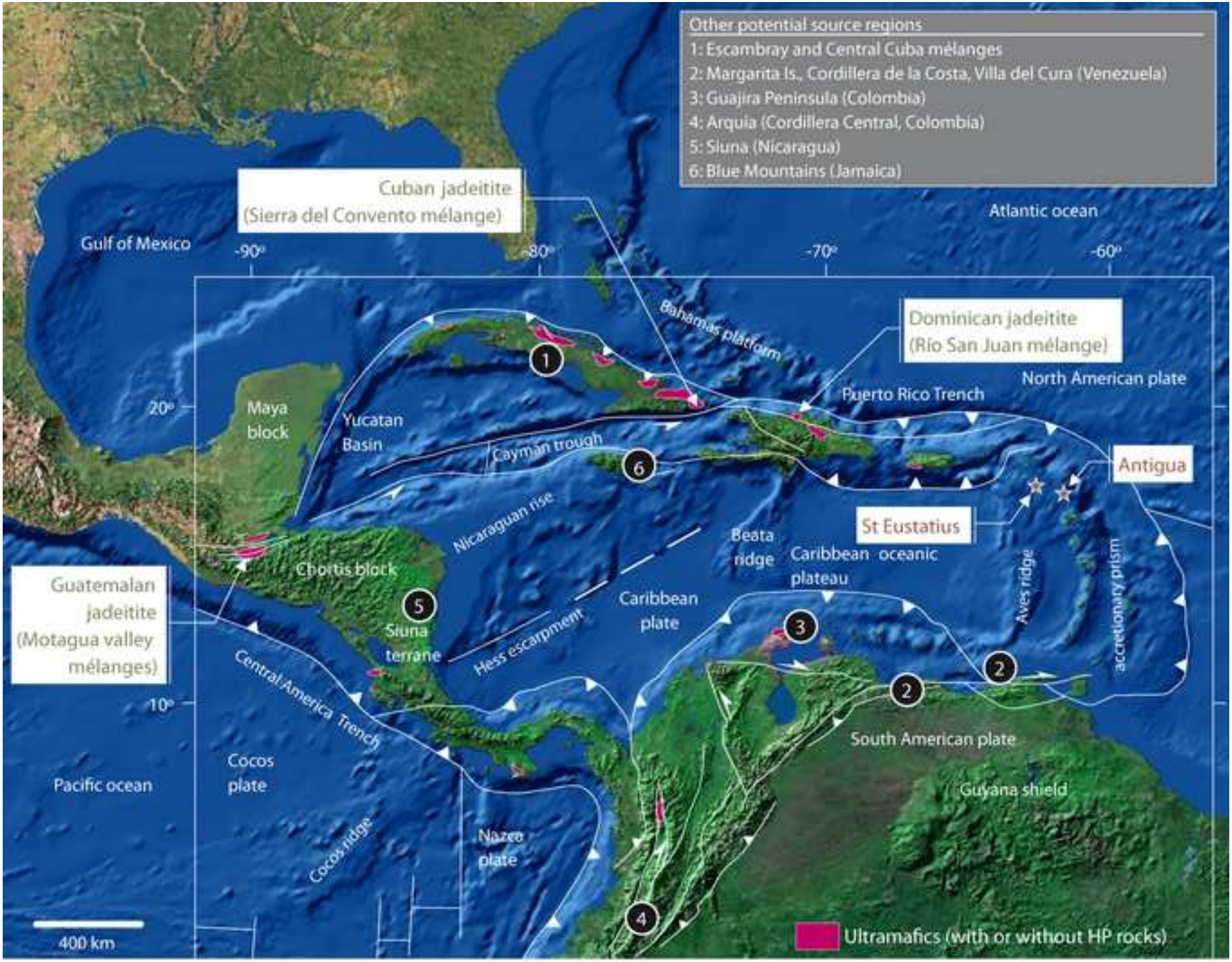
NR.	Number	1x1 m	level	Artifact type	MD	L	W	Th	W	Context
1	GR 24/B/III.01	24 B	20-30 cm	axe fragment, proximal-lateral	43	43	26	25	26,4	Refuse deposit; test-unit
2	GR 24/J/IV.05	24 J	30-40 cm	edge flake	25	25	25	6	4,2	Refuse deposit; test-unit
3	GR 3/N/II.03	3 N	10-20 cm	axe fragment, medial-lateral	29	29	15	9	3,5	Refuse deposit; test-unit
4	GR 4/F/III.04	4 F	20-30 cm	edge flake	36	29	34	6	6,8	Refuse deposit; test-unit
	GR 15/K/I.06	15 K	0-10 cm	edge flake	26	25	26	4	3,3	Refuse deposit; test-unit
	GR 15/G/I.01	15 G	0-10 cm	flake from axe	26	26	18	9	3,4	Refuse deposit; test-unit
	GR 20/B/III/01	20 B	20-30 cm	axe fragment, medial-lateral	39	39	31	26	34,1	Refuse deposit; test-unit

Table 2. Mineral assemblages of studied samples. Symbol "x" denotes the relative abundance of minerals. Symbol "–" indicates minor/trace amounts.

	GR24-B-III.1	GR24-J-IV.05	GR3-NII.3	GR4-FIII.4
Jadeite (Jd)	xxx	xxx	xxx	Xxx
Omphacite (Omp)	xx	xx	xx	
Albite (Ab)	-	-	-	-
Analcime (Anl)	-			-
Phengite (Ph)	xx (Ba-Ph)	x	x	
Phlogopite (Phl)	x	x		
Epidote(Ep)/(clino)Zoisite (Czo)	x Ep	xx (Czo)		
Lawsonite (Lws)			x	
Titanite (Ttn)	x	x	-	x
Quartz (Qz)			-	
Chlorite (Chl)		-		
Pumpellyite (Pmp)		-		
Hematite (Hem)				x

Table 3. Mineralogical comparison of studied artifacts with jadeitite artifacts from Antigua (Harlow et al., 2006) and with jadeitite from known Caribbean sources in the North and South Motagua mélanges, Guatemala (Harlow et al., 2006; 2011), Sierra del Convento mélange, eastern Cuba (Cárdenas-Párraga et al., 2010, 2012; García-Casco et al., 2009) and Río San Juan mélange, Dominican Republic (Schertl et al., 2012). The shaded cells denote critical mineral for provenance analysis. Note that all minerals indicated for the different regions do not necessarily coexist in individual samples.

Sample	**Jd**	**Omp**	**Ph**	**Phl**	**Qz**	**Pa**	**Ttn**	**Lws**	**Ep**	**Gl**	**Pl**	**Ap**	**Chl**	**Pmp**	**Anl**
GR24-B-III.1	x	x	x	x			x		x		x	X			x
GR24-J-IV.05	x	x	x	x			x		x		x		x	X	
GR3-NII.3	x	x	x		x		x	x			x				
GR4-FIII.4	x						x				x				x
From South Motagua source? (Harlow et al., 2006)															
Antigua	x	x	x	x	x	x (local)	x	x (local)	x	x (local)	x	X		X	x
Known Sources															
NM (Gua)	x	x	x	x		x	x		x		x	X	x	X	x
SM (Gua)	x	x	x	x	x		x	x	x	x	x	X	x	X	x
RSJ (DR)	x	x	x		x		x	x (local)	x	x (abun.)	x	X	x	x (local)	
SC (Cuba)	x	x	x	x	x	x	x		x		x	X	x	X	x



Figure