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A holistic provenance and microwear study of pre-colonial jade objects from the Virgin Islands: Unravelling mobility networks in the wider Caribbean

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ABSTRACT

Pre-colonial Caribbean jade objects from the National Museum of Denmark Hatt Collection were subjected to a provenance and microwear analysis. Thirty-nine jade celts and bodily ornaments from the US Virgin Islands, i.e., St. Croix, St. Thomas, St. John, and five celts from the West Indies of unknown location, St. Vincent, Cuba and the Dominican Republic were analysed.

A comprehensive in-depth examination of jade adornments from St. Croix, combining typo-technological and microwear analysis, is compared to other lithologies used for pre-colonial ornaments. A portable laser ablation system was used to sample jade celts and bodily ornaments on site in a quasi-non-destructive manner. Low-blank trace element and Sr-Nd isotope ratio data were evaluated with a multiclass regression provenance prediction model.

This study demonstrates that the pan-Caribbean exchange of jade raw materials, pre-forms or finished objects during the Ceramic Age (400 BC to AD 1492) occurred on a more complex scale than previously thought involving jade sources in Guatemala, eastern Cuba and the northern Dominican Republic. In addition, the study of ornaments recovered from St. Croix reveals use of specific lithologies suggesting stronger ties to Indigenous communities on Puerto Rico than other Lesser Antillean Islands.

1. Introduction

The National Museum of Denmark (NMD) curates one of the largest pre-colonial collections from the Caribbean Islands, including material from Trinidad in the southeast to Cuba in the northwest. The presence of artefacts made of jadeite – and omphacite jade (subsequently referred to as jade) in pre-colonial assemblages in the Caribbean has been reported by archaeologists for decades (Hofman and Hoogland, 2011; Rodríguez Ramos and de Utuado, 2010; Rodríguez Ramos et al., 2011; Lange, 1993; Easby, 1968; Boomert, 1987). Generally, provenance studies of lithic materials are underutilized in Caribbean archaeology, and the same can be concluded for microwear analysis (Hofman et al., 2008). Most artefact studies in Caribbean archaeology have focused on functional analyses, material identification, use wear and the establishment of typological categories (Lammers-Keijsers, 2007; Armstrong, 1979; Breukel, 2013; Breukel, 2019). Harlow et al. (Harlow et al., 2006) were the first to conduct an archaeometric study on pre-colonial lithic celts excavated on the Lesser Antillean island of Antigua and demonstrated that many were made of jade. At this time the jade celts were assigned to the Motagua Valley in Guatemala (GM), two sources north and south of

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the Motagua Fault Zone (NMFZ and SMFZ), the only known jade outcrops in the circum Caribbean (Harlow, 1994; Harlow et al., 2003; Harlow et al., 2006). The outcome of this study was significant for Caribbean Archaeology as it indicated pre-colonial trade routes extending over 3000 km. Importantly, the authors did not rule out unknown sources on islands of the Greater Antilles. In the last decades, two further jade sources were identified in eastern Cuba (CU) (García-Casco et al., 2009; Cárdenas-Párraga et al., 2010; Cárdenas-Párraga et al., 2012; Cárdenas-Párraga, 2019) and the northern Dominican Republic (DR) (Schertl et al., 2012; Hertwig et al., 2016; Schertl et al., 2007a; Schertl et al., 2007b) questioning Guatemala as the only source for jade objects found on the Greater- and Lesser Antilles (Fig. 1) and the Lucayan Archipelago. During the Early Ceramic Age (ca. 500 BC – AD 600/800), body ornaments made of lapidary materials circulated in long-distance exchange networks connecting multiple islands across the Caribbean archipelago and, potentially, South - and Central America (Hofman and Hoogland, 2011; Rodríguez Ramos et al., 2011; Falci et al., 2020a; Falci et al., 2020b; Hofman et al., 2008; Hofman et al., 2010). They were made of a broad range of materials, notably amethyst, carnelian, diorite, turquoise, serpentinite, nephrite and jadeite. Ornaments in such raw materials have typically been recovered from archaeological sites associated to the Saladoid (or Cedrosan Saladoid) and Huecoid (or Huecan Saladoid) ceramic (sub)series. In particular, large bead workshop sites have been attested in the north-eastern Caribbean island of Puerto Rico (Chanlatte Baik and Narganes, 1983; Rodríguez López, 1991), one of which being the type-site for the Huecoid series (La Hueca-Sorcé in the nowadays Puerto Rican island of Vieques) (Chanlatte Baik and Narganes, 1983; Narganes Storde, 1995a; Narganes Storde, 1995b). The geological sources of the lapidary materials are various, including 1) widely-spread material sources, 2) sources limited to a few islands, and 3) sources absent from the archipelago (Hofman et al., 2007). In this panorama, the circulation of exotic jade objects in the Caribbean realm has become a key proxy for elucidating the sophisticated Indigenous networks of mobility and interaction (Harlow et al., 2019; García-Casco et al., 2013; Schertl et al., 2019; Knaf et al., 2020).

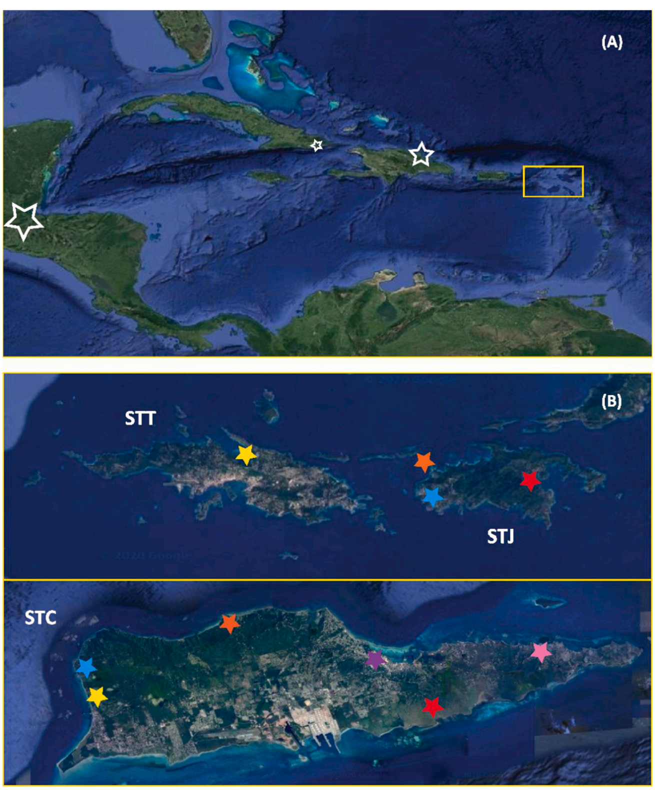

Fig. 1. Google maps satellite images showing (A) the wider Caribbean region including the Greater- and Lesser Antilles, the Lucayan Archipelago, as well as Mesoamerica and northern South America (image ~ 3500 km across). White stars represent the known jade sources in Guatemala (north and south of the Motagua Fault Zone), eastern Cuba and the northern Dominican Republic. The size of the stars is indicative for the relative size of jade sources (Guatemala $\gg$ Dominican Republic > Cuba). Yellow square indicates the location of the Virgin Islands with (B) a blow up of St. Thomas and 4 km to the east adjoining St. John (image ~ 75 km across). St. Croix is located approximately 60 km southward (image ~ 40 km across). Amerindian settlements are marked with a star. St. Thomas and St. John: yellow = Magens Bay, orange = Durloe Cay, blue = Little Cruz Bay, red = Coral Bay; and St. Croix: yellow = Prosperity, blue = Sprat Hall, orange = Cane Bay, purple = Richmond, pink = Cotton Valley, red = Longford.

The discovery of two additional Caribbean jade sources has significant implication for the NMD, as it curates almost 1900 celts from various donors, of which > 200 appear to be made of jade. Nonetheless, it is questionable whether the high percentage of jade celts is representative of pre-colonial Caribbean lithic assemblages. Recent excavations and studies have demonstrated that jade was highly valued and prized by Indigenous societies due to its physical properties, appealing colour and limited local availability although jade forms only < 20 % of the recovered lithic material (with the exception of individual sites, e.g., Playa Grande which is in vicinity of the Dominican jade source > 60 % jade celts and Pearls on Grenada ~ 30 % jade paraphernalia) (Rodríguez Ramos et al., 2011; Breukel, 2019; Falci et al., 2020b; Knaf et al., 2020). The limited availability seems to imply a biased sampling of objects by pioneer archaeologists. Our systematic multidisciplinary study focuses on the Hatt collection, named after Gudmund Hatt, a Danish archaeologist at the NMD. In 1922/1923 Hatt excavated > 30 sites in the US Virgin Islands, neighbouring Tortola and Hispaniola during a nine months expedition that recovered > 20 cubic metres of archaeological artefacts representing > 20,000 objects covered by around 4,600 registration numbers (Hatt, 1924; Vescelius and Robinson, 1979; Hardy, 2009). The large number of excavations was possible due to help of the island inhabitants who shared their knowledge of surface finds and untouched settlement deposits. On St. Croix, the plantation owner and amateur archaeologist Gustav Nordby advised Hatt where to excavate. The exact number of artefacts is still unknown, as the curation of the Hatt Collection has been dormant since 1947. The legacy Hatt collection was "rediscovered" in 2015 when the NMD digitalised, photographed and reanalysed the entire archaeological collection from the West Indies. Active curation and examination of the objects has resumed. Even though the collection is colloquially called the Hatt collection, the nomenclature is misleading, as it spans over a 200-year long acquisition history within the NMD. The first pre-colonial artefact was acquired from a Danish civil servant from the Danish Virgin Islands in 1813 and the last artefacts were transferred from the Maritime Museum in Elsinore in 2015, but the NMD collection includes multiple other donors.

Here we present new data on the wear of bodiy ornaments, trace elemental- and isotopic composition of jade celts and lapidary objects from locations on the US Virgin Islands St. Croix (STC), St. Thomas (STT) and St. John (STJ) (Fig. 1) and of jade celts recovered from the West Indies without any further specification (WI), St. Vincent (STV), the Dominican Republic (DR) and Cuba (CU). Extensive new data about archaeological sites in the Virgin Islands, which were obtained through an exhaustive study of legacy archival materials housed at the NMD are given in Appendix I. Our integrated approach contributes to a holistic view of the artefacts, including raw material collection, production, use and distribution, which enables us to place the Virgin Islands communities within the wider Caribbean context. The focus of this case study lies in the determination of the provenance of jade objects retrieved from the US Virgin Islands. A portable laser ablation sampling device allowed us to sample museum grade artefacts on location at NMD in a micro-invasive manner leaving ablation pits of the diameter of a hair (~100 μm), essentially invisible to the naked eye (Glaus et al., 2012;

Knaf et al., 2017). Subsequent geochemical analyses of the artefacts by low-blank trace elemental and Sr-Nd isotope composition analyses are performed on microgram amounts of material (Knaf et al., 2017; Koornneef et al., 2014). Knaf et al. (Knaf et al., 2020) characterized the four known jade sources in the Caribbean (GM [NMFZ and SMFZ], CU and DR). These data provide the context to determine the provenance of jade artefacts from the Virgin Islands. Specifically, a discrimination model using a multiclass regression approach will provide a better understanding of trading networks in the region. Furthermore, we complement the provenance determination of jade bodily ornaments with a typo-technological and microwear study. In order to provide a more comprehensive picture of patterns in ornament production and use, we briefly review lapidary materials from the western coast of St. Croix that are part of the Hatt Collection, followed by an in-depth examination of jade specimens. The study provides insights on how jade ornaments were treated and perceived in contrast to other lapidary materials.

2. Archaeological context and sample description

We examined 44 pre-colonial jade artefacts, 39 objects from Ceramic Age sites on the US Virgin Islands and five jade celts recovered from St. Vincent (n = 1), Cuba (n = 1), the Dominican Republic (n = 2) (Hatt, 1932) and one sample of unspecified location in the West Indies. From the Virgin Islands, we selected 30 celts and bodily ornaments from at least six different sites on St. Croix, two celts from St. Thomas, six celts from four different sites on St. John, and one celt with an unclear origin assigned to either St. Croix or St. Thomas (Hatt, 1924). Table 1 provides a list of artefacts that underwent microwear and provenance analyses. Archaeological details of the most important sites (Fig. 1) are described in Appendix I.

Prior to sample selection, the main mineral phases were determined through visual inspection using a magnifier glass (X20). It is often difficult, however, to distinguish between nephrite and jadeite-omphacite jade, both of which were used by pre-colonial Indigenous societies for the manufacture of objects. This is especially the case with intact and highly polished artifacts. Here the lustre can help, which is vitreous in lithologies containing jadeite (and omphacite) and greasy in nephrites. Furthermore, the determination of the mineralogy of intact artefacts with heavily weathered and discoloured surfaces is difficult. Differentiating between types of rock becomes more challenging, the smaller the object to be examined, e.g., beads and pendants. With this in mind, there is a slight possibility that a minority of artefacts ($< 5\%$) analysed is not jadeite-omphacite jade.

In order to obtain temporal and spatial provenance results, artefacts were primarily chosen from the Hatt collection's corpus to cover a wide range of islands, sites and cultural periods. Secondly, artefacts were selected based on an earlier unpublished study using Raman spectroscopy, which focused on objects < 7 cm in length, which was a legal requirement when transporting the artefacts from the National Museum of Denmark to the facility in Orgnac, France.

Thirty-five jade objects (31 celts and 4 pendants) were selected for micro-invasive sampling and geochemical analyses (Figs. 2 and 3). A brief petrographic description of samples ranging from jadeite – and omphacite – rich jade, lawsonite jade, jadeitite sensu lato (s.l., > 75 vol% jadeite) (Hertwig, 2014) to jadeitite sensu stricto (s.str., > 90 vol% jadeite) is presented in Appendix II.

A total of 13 jade bodily ornaments underwent typo-technological and microwear analysis to provide insights into how they were manufactured, worn and attached (Table 3 in the supplementary materials). Typological and technological data generated for jade ornaments is compared to other examined lapidary materials (n = 52) found in the Hatt collection. The study of the collection from the NMD provides new insights on a poorly known node in the Early Ceramic Age networks of interaction. The Hatt collection contains lapidary materials collected from the neighbouring sites of Prosperity and Sprat Hall on the western coast of St. Croix. In addition to the Hatt collection, we included all lapidary materials retrieved from these locations (n = 65). The majority of the lapidary assemblage comes from the collections of Gustav Nordby, who conducted excavations on domestic middens on coastal sites and purchased artefacts from throughout the island. Three of the donations made by Nordby are included in the lapidary study: 1920 (registration numbers O.2416 to O.2909), 1923 (registration numbers O.30.1 to O.30.658), and 1946 (registration numbers O.9393 to O.9467). The first comprises eight artefacts, which could have been collected throughout the island of St. Croix. The second series includes 30 artefacts from the sites of Prosperity and Sprat Hall. Seven artefacts in this group (O.30.345 – O.30.353) are identified as coming from Krause, a field within the Prosperity estate.

3. Methodology

3.1. Typo-technological and microwear analysis

Ornaments were analysed through a combination of typo-technological and microwear analyses. This approach provided evidence of production processes, use, recycling, breakage, and discard. In a first stage, we classified ornaments according to raw material, morphological type, and technical stage through macroscopic examination. The ornament typology used here follows the definitions used in Falci et al. (Falci et al., 2020b) that take into account both artefact morphology and the number and position of perforations. Four bead subtypes, four pendant subtypes, one unperforated disc type, and one indeterminate group are defined. Among pendants, zoomorphic specimens reminiscent of frogs were classified in two subtypes: flat and three-dimensional. Flat frog pendants encompass both geometric specimens presenting simple rectangular shapes and segmented frogs (Fig. 4). The shape of the latter is reminiscent of three stacked circles. This typology was devised with reference to other lapidary collections from the Early Ceramic Age Caribbean (Narganes Storde, 1995a; Narganes Storde, 1995b; Watters and Scaglion, 1994) and allows us to draw comparisons with other assemblages across the Antilles. Technical stages encompass rough-outs, successive stages of preforms, and complete artefacts. Artefacts with incomplete or no perforations were labelled preforms. In the presence of a complete perforation, we can only assess if an artefact is still a preform after analysis of its shaping stage and surface treatment. Non-perforated discs are oval artefacts that are too large to be preforms of disc beads. They were classified as preforms of other ornament types, such as geometric pendants and plano-convex beads.

In a second stage, artefacts were examined through microwear analysis. Microscopic analysis of wear traces has become a widely-used method for reconstructing the production sequence of ornaments made of various lithic materials and that have undergone extensive grinding and polishing (Sax and Ji, 2013; Van Gijn et al., 2017; Strafella et al., 2017; Alarashi, 2016; Groman-Yaroslavski and Mayer, 2015; Milner et al., 2016; d'Errico et al., 2000). Microscopes from the Laboratory of Artefact Studies of Leiden University were transported to the NMD. The ornaments were examined using a DinoLite digital microscope (model AD7013MZT Premier) with low magnifications (X20-60). In a second step, specimens were observed under an incident light Nikon Optiphot-1 metallographic microscope that allows for higher magnifications (X100-200). Artefacts were cleaned with water, soap and alcohol prior to examination. We report here the results of the material and typo-technological classification of all ornaments, but focus the microwear results on the jade ornaments.

3.2. Portable laser ablation sampling

Artefacts (CPH02-CPH36) were sampled using a portable laser ablation (pLA) sampling device (Glaus et al., 2012; Knaf et al., 2017). The detailed sampling protocol can be found in Knaf et al. (Knaf et al., 2017). Individual jade objects were ablated 20 times onto a filter to gain a representative sample and sufficient material for reproducible trace

Table 1
List of Indigenous jade artefacts from the National Museum of Denmark (NMD) selected for microwear – (MW) and provenance (P) analyses. Abbreviations for location and predicted provenance are St. Croix = STC, St. Thomas = STT, St. John = STJ, West Indies = WI, St. Vincent = STV, Dominican Republic = DR, Cuba = CU, GM = Guatemala, NMFZ = north of the Motagua Fault Zone in GM, and SMFZ = south of the Motagua Fault Zone in GM. Note that dates determined by accelerator mass spectrometry (AMS) carbon dating for the Prosperity site on St. Croix range from AD 700 – 900 (n = 4) with 2 outliers at AD 1200 and 1675. As a consequence of low elemental abundances it was not possible to determine the provenance of CPH28.

NMD ID	VU ID	Location	Site	Age	Artefact Type	L [mm]	W [mm]	Th [mm]	Analyses	Provenance	NMD Acquisition History
O.16.162	CPH08	STC	Longford	AMS AD 550 - 1000	butt end of an petaloid celt	88	46	35	P	DR/CU	Hatt excavation 1922/23
O.16.184	CPH09	STC	Longford	AMS AD 550 -1000	repurposed celt fragment	25			P	DR/CU	Hatt excavation 1922/23
O.16.128	CPH10	STC	Longford	AMS AD 550 - 1000	celt fragment	50			P	DR/CU	Hatt excavation 1922/23
O.16.26	CPH11	STC	Longford	AMS AD 550 - 1000	celt	58			P	DR/CU	Hatt excavation 1922/23
O.30.625		STC	Prosperity Plantation	AMS AD 700 - 900, AD 1200 and AD 1675	flat frog pendant	13			MW		Donation Nordby, 1923
O.30.341		STC	Prosperity Plantation	AMS AD 700 - 900, AD 1200 and AD 1675	plano-convex bead	15	10	3	MW		Donation Nordby, 1923
ODIg.26	CPH29	STC	Prosperity	?	celt	68			P	DR/CU	Donation Mr. Sarauw/Mr. Juel
O.30.352		STC	Krause Field, Prosperity Plantation	AMS AD 700 - 900, AD 1200 and AD 1675	figure pendant	14	8	5	MW		Donation Nordby, 1923
O.30.353		STC	Krause Field, Prosperity Plantation	AMS AD 700 - 900, AD 1200 and AD 1675	segmented frog pendant	30	28	5	MW		Donation Nordby, 1923
O.30.345	CPH28	STC	Krause Field, Prosperity Plantation	AMS AD 700 - 900, AD 1200 and AD 1675	three-dimensional frog pendant	41	36	15	MW + P		Donation Nordby, 1923
O.9412	CPH36	STC	Possibly Prosperity	AMS AD 700 - 900, AD 1200 and AD 1675	flat frog pendant	19	13	7	MW + P	DR/CU	Donation Nordby, 1946
O.2846		STC	Possibly Prosperity	AMS AD 700 - 900, AD 1200 and AD 1675	segmented frog pendant	19	8	5	MW		Donation Nordby, 1920
O.9424	CPH27	STC	Possibly Prosperity	AMS AD 700 - 900, AD 1200 and AD 1675	flat frog pendant	26	13	4	MW + P	GM	Donation Nordby, 1946
O.9411	CPH26	STC	Possibly Prosperity	AMS AD 700 - 900, AD 1200 and AD 1675	tear-drop pendant	22	16	7	MW + P	DR/CU	Donation Nordby, 1946
O.10457	CPH31	STC	Cane Bay	?	celt	64			P	DR/CU	Transfer National Maritime Museum Elsinore 2015/16
O.10467	CPH32	STC	Cane Bay	?	celt	55			P	GM	Transfer National Maritime Museum Elsinore 2015/16
O.10466	CPH34	STC	Cane Bay	?	celt	58			P	GM	Transfer National Maritime Museum Elsinore 2015/16
O.10446	CPH33	STC	La Valle or Cane Bay	?	celt	103			P	GM	Transfer National Maritime Museum Elsinore 2015/16
O.20.23	CPH14	STC	Cotton Valley	?	celt fragment	33			P	DR/CU	Hatt excavation 1922/23
O.30.362	CPH16	STC	Sprat Hall	AD 650 - 1600	celt fragment	78			P	DR/CU	Donation Nordby, 1923
O.33.341	CPH19	STC	Richmond	AD 850 - 1500	celt	91			P	GM	Donation Frieda Moeller-Jørgensen, 1955
O.9413		STC	?	Saladoid/ Huecoid	plano-convex bead	13	13	6	MW		Donation Nordby, 1946
O.9414		STC	?	Saladoid/ Huecoid	tear-drop pendant	20			MW		Donation Nordby, 1946
O.2838		STC	?	Saladoid/ Huecoid	tear-drop pendant	19			MW		Donation Nordby, 1920
O.2844		STC	?	Saladoid/ Huecoid	unperforated disc	15	14	4	MW		Donation Nordby, 1920
O.1119	CPH12	STC	?	?	celt	70	37	14	P	DR/CU	Donation Holger Lassen, 1892
O.2461	CPH13	STC	?	?	celt fragment	50			P	DR/CU	Donation Nordby, 1920
O.2451	CPH15	STC	?	?	celt fragment	35			P	DR/CU	

(*continued on next page*)

Table 1 (*continued*)

NMD ID	VU ID	Location	Site	Age	Artefact Type	L [mm]	W [mm]	Th [mm]	Analyses	Provenance	NMD Acquisition History
											Donation Nordby, 1920
O.30.31	CPH24	STC	?	?	celt	67			P	DR/CU	Donation Nordby, 1923
ODIg.49	CPH30	STC	?	?	celt	180			P	DR/CU	Donation Dr. Pingel, 1836, Museum of Natural History
ODIg.4	CPH17	STC or STT	?	?	celt	72			P	GM	Donation pharmacist A.H. Riise, 1861
O.30.642	CPH02	STT	?	?	celt	111			P	DR/CU	Donation Bank Manager Holst
O.1.315	CPH03	STT	Magens Bay	AMS AD 400 - 1500	butt end of an petaloid celt	25			P	DR/CU	Hatt excavation, 1922/23
O.8.2	CPH04	STJ	Little Cruz Bay	AMS 600 BC - AD 650	celt	180			P	GM	Hatt excavation, 1922/23
ODIg.105	CPH05	STJ	Abrahams Fancy	?	celt	58			P	DR/CU	Donation Dr. Lund, 1858
ODIg.19	CPH25	STJ	Abrahams Fancy	?	celt	118			P	GM	Donation Dr. Lund, 1858
O.9.4	CPH06	STJ	Durloe Cay	?	celt fragment	42			P	DR/CU	Hatt excavation, 1922/23
O.5.91	CPH07	STJ	Coral Bay	AMS AD 500 - 900	celt fragment	52			P	DR/CU	Hatt excavation, 1922/23
O.5.122	CPH23	STJ	Coral Bay	AMS AD 500 - 900	celt fragment	53			P	DR/CU	Hatt excavation, 1922/23
O.1754	CPH18	WI	?	?	celt	48			P	DR/CU	Donation M.Y. Lund 188(0)
O.4619	CPH35	STV	?	?	celt	70			P	GM	Museum of the American Indian New York
O.22.236	CPH20	DR	Rio Chavon	?	celt fragment	28			P	GM	Hatt excavation, 1922/23
O.28.291	CPH21	DR	Constanza Valley	?	celt	57			P	DR/CU	Hatt excavation, 1922/23
ODIg.20	CPH22	CU	?	?	celt	195			P	DR/CU	Donation Prydtz, 1859

element (TE) and isotope composition (IC) analyses. Each ablation was conducted for 90 s, collecting between 1 and 4 μg of material per ablation. It needs to be stressed that absolute element concentrations are highly imprecise as the uncertainty in the sample weight is at least 36% as this depends on the ablation efficiency, which is impossible to quantify. Consequently, TE ratios and the slope observed in TE and REE normalised figures are considered relevant. Hence all provenance discrimination is performed using TE ratios (Knaf et al., 2017). Sampling was concentrated on damaged surfaces to minimise the visibility of the micro-invasive sampling. Moreover, ablation of bodily ornaments was carried out to avoid destruction of wear traces and carvings, incisions, and drill holes. Before switching to a new sample, the laser ablation module and the tubing to the sample wheel were disassembled and thoroughly cleaned. Approximately every 8 samples, a 20 min ambient air blank was collected. In addition, after every 10 samples, a USGS basalt glass standard (BHVO-2G) was ablated. To allow correction for any sampling blank, dust was collected from the NMD storage facility in Brede. Individual filters were stored in pre-cleaned centrifuge tubes and returned to the Vrije Univeristeit, Amsterdam for low-blank geochemical analyses.

3.3. Geochemistry, standard and blank data

Sample preparation and geochemical analyses were conducted in a class 10,000 clean laboratory equipped with class 1000 laminar flow hoods. Acids were of analytical reagent grade and purified by double sub-boiling distillation in silica glass or PTFE stills. Water was purified using a Milli-Q® integral water purification system, Merck Millipore Corporation (resistivity 18.2 MΩ cm at 25°C).

Roughly 20 – 80 μg of the laser ablated sample aerosol deposited on hydrophobic and inert PTFE filter was digested following the sample dissolution registration described in Knaf et al. (Knaf et al., 2017). Samples were processed in two different approaches for low-blank TE and double spiked lead (Pb) -, strontium (Sr) - and neodymium (Nd) isotope dilution (ID) and isotope composition (IC). Samples of the first batch, which exclusively contained artefacts from St. Croix (CPH08-CPH16, CPH19, CPH26, CPH27, CPH31-CPH34), went through a miniaturized Pb-, Sr- and Nd- column chemistry as total solutions following Koornneef et al. (Koornneef et al., 2015). Lead isotope composition analyses were, however, unsuccessful as most samples contained < 200 pg Pb. Pre- and post-fractions from the column chemistry were collected for subsequent ICPMS analyses. Before loading the sample solutions onto the columns, samples were spiked for Sr - and Nd isotope dilution analyses (^{84}Sr spike = 3.691 ppb and ^{150}Nd spike = 0.07951 ppb). Samples of the second batch, including artefacts from St. Croix, St. Thomas, St. John, St. Vincent, Cuba and the Dominican Republic (CPH02-CPH07, CPH17, CPH18, CPH20-CPH25, CPH28, CPH30, CPH35, CPH36) were aliquoted for TE - and IC analyses. After digestion, samples were dissolved in 500 μL 3 M HNO_3. A 10% aliquot was taken and further diluted to reach 500 μL of 5% HNO_3 for ICPMS analyses. The remaining 450 μL were used to purify Sr from the whole rock matrix.

Strontium and Nd isotope analyses were performed on a Thermo Scientific Triton*Plus* TIMS according to the method described in Knaf et al. (Knaf et al., 2017). Neodymium isotope compositions were measured using 10^{13} ohm resistors (Koornneef et al., 2014). Trace elements were determined on a Thermo Fisher X-series-II ICP-MS following an analytical protocol from Knaf et al. (Knaf et al., 2017). Trace element abundances are reported after blank correction. Trace element data from the first batch were normalized to a quality control BHVO-2 standard to correct for column yields (Knaf et al., 2017).

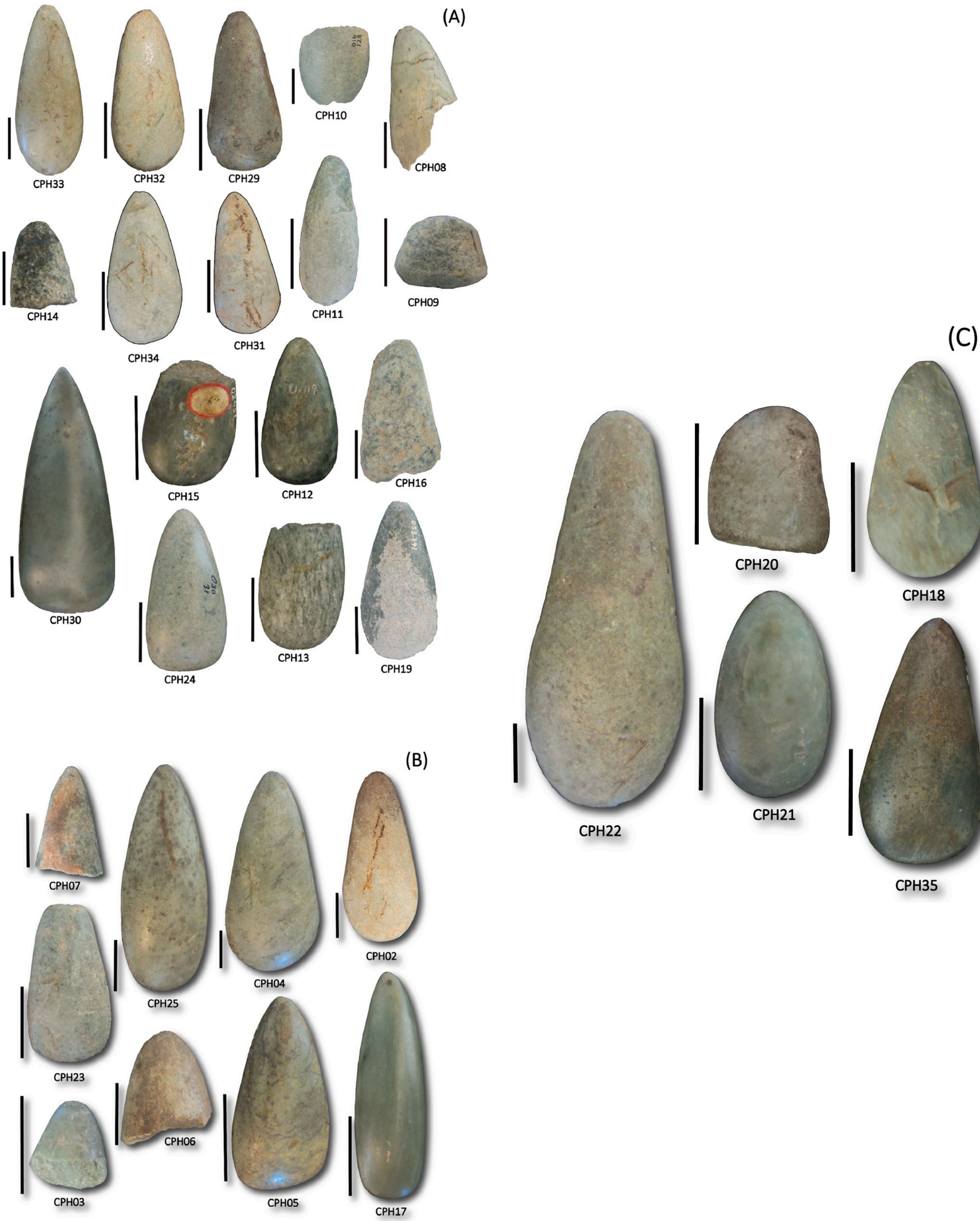

Fig. 2. Jade celts and celt fragments with sample numbers which were selected for provenance analyses recovered from various sites on (A) St. Croix, (B) St. John and St. Thomas, and (C) West Indies – St. Vincent – Dominican Republic – and Cuba. Note black scale bars are 3 cm. Pictures courtesy of A.C.S. Knaf.

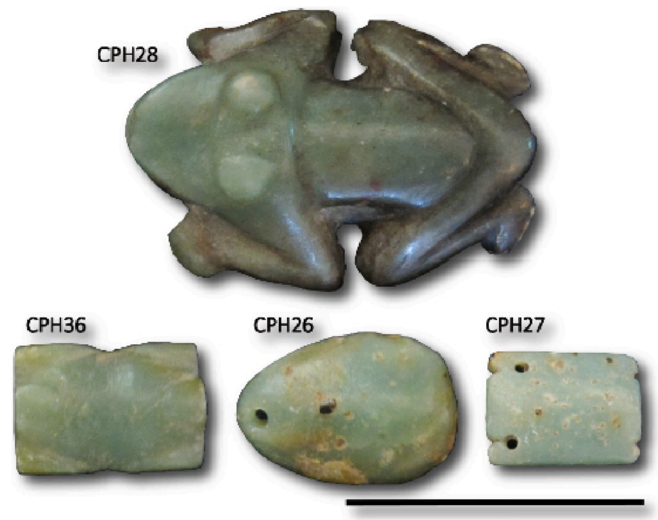

Fig. 3. Jade pendants with sample numbers which were selected for provenance analyses recovered from the Cedrosan Saladoid Prosperity site on St. Croix. Note black scale bar is 3 cm. Picture courtesy of A.C.S. Knaf.

Mass spectrometric performance was monitored by repeated measurements of 100 ng Sr standard NBS SRM 987 which yielded an average of $^{87}Sr/^{86}Sr = 0.710255 \pm 18$ (2SD, n = 14), which is within error of the long-term value of $^{87}Sr/^{86}Sr = 0.710242 \pm 25$ (2SD, n = 45). Analyses of 100 ng Nd standard JNdi yield an average of $^{143}Nd/^{144}Nd = 0.512151 \pm 18$ (2SD, n = 2) and 200 pg of the in-housed Nd standard CIGO resulted in $^{143}Nd/^{144}Nd = 0.511338 \pm 73$ (2SD, n = 3). The accepted value for JNdi is $^{143}Nd/^{144}Nd = 0.512115 \pm 7$ (Tanaka et al., 2000) and the long-term value for the analysis of 200 ng of the in-house CIGO is $^{143}Nd/^{144}Nd = 0.511332 \pm 11$ (2SD, n = 129).

Isotopic composition reproducibility of the entire methodology, including monitoring of mass fractionation during laser ablation sampling, was evaluated using USGS basaltic certified glass reference, BHVO-2G. Isotope compositions yielded for a maximum amount of 15.56 ng Sr, which gave after blank correction $^{87}Sr/^{86}Sr = 0.703447 \pm 107$ (2SD, n = 3) within error of published values ($^{87}Sr/^{86}Sr = 0.703469 \pm 14$ of Elburg et al. (Elburg et al., 2005); and a maximum of 1 ng of Nd which gave $^{143}Nd/^{144}Nd = 0.512959 \pm 84$ (2SD, n = 1), which is within error of the reference value of $^{143}Nd/^{144}Nd = 0.512957$ from Raczek et al. (Raczek et al., 2003) without blank correction. Evaluation of three ablated USGS BHVO-2G samples establish that TE ratios are within the propagating error of the true USGS BHVO-2G value. For full details see Appendix III (Table 6 and Fig. 9).

The Copenhagen dust blank yielded $^{87}Sr/^{86}Sr = 0.709405 \pm 18$. Strontium and Nd isotope compositions of the Amsterdam clean lab blank are $^{87}Sr/^{86}Sr = 0.71112 \pm 0.00005$ (2SD, n = 3) and $^{143}Nd/^{144}Nd = 0.51186 \pm 0.00009$ (2SD, n = 3) (Koornneef et al., 2015). Total procedural blanks were determined by isotope dilution using ^{84}Sr and ^{150}Nd spikes. Blanks are 103 pg for Sr and 7.5 pg for Nd, of which the sampling blank contributes 76 pg Sr and 6.5 pg Nd, respectively. The average blank contribution to the sample for Sr is 2.61% (median 2.17%) and for Nd 3.48%, with a median of 1.03%.

4. Results

4.1. Typo-technological and microwear analyses

The ornaments from the Hatt collection encompass 11 raw materials and were classified into 33 beads (50.76%), 29 pendants (44.61%), and three discs without perforations (4.61%). An overview of raw materials and morphological types present in the Collection is given in Table 2. The most numerous raw materials were jadeitite and diorite, with 13

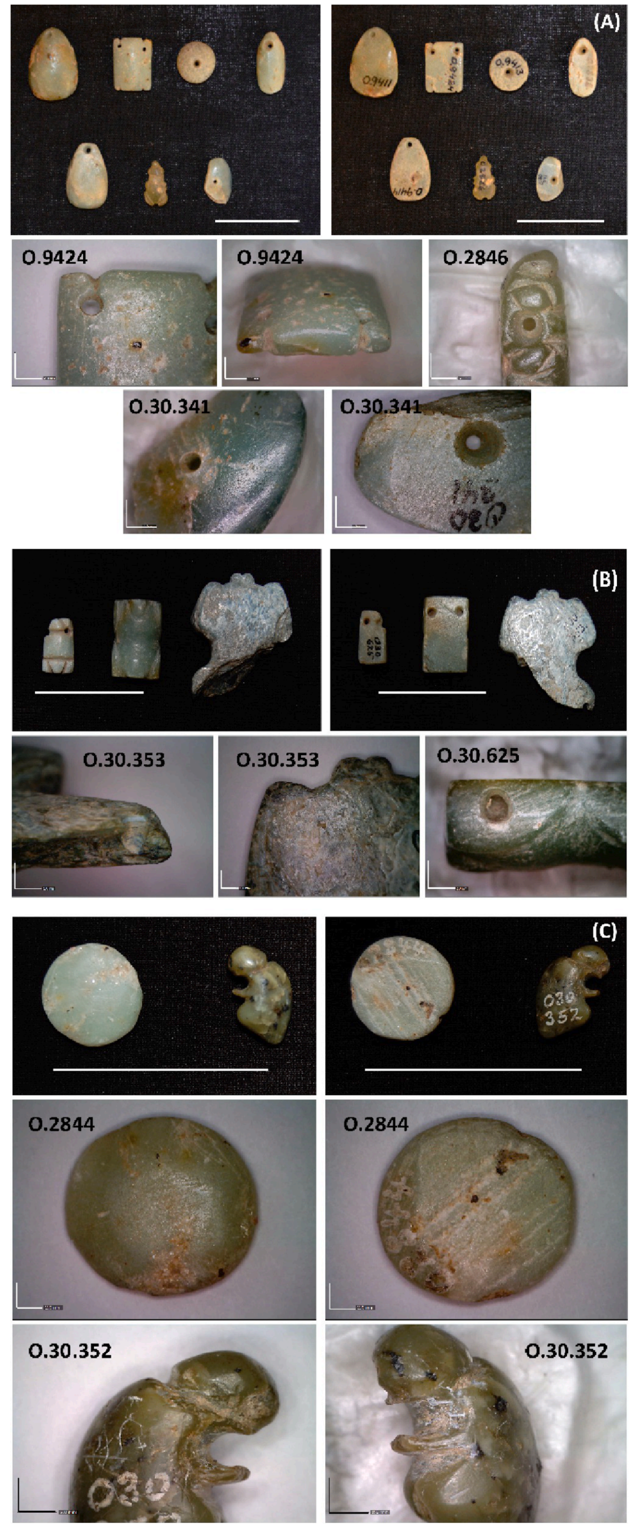

Fig. 4. Traces identified on 12 jade ornaments. (A) O.9424 and (B) O.30.625: Use-wear on perforations and artefact edges, in the form of rounding, polish, and deformation. (A) O.2846: Perforation displaying no use-wear and V-shaped carving traces. (B) O.30.353: Unfinished broken perforation and polished surface. (A) O.30.341 and (C) O.2844: Plano-convex beads with evidence of being produced on flake blanks, namely bulb of percussion and flake scar negatives. (C) O.2844: Coarse grinding traces. (C) O.30.352: Figure-in-profile pendant with traces of sawing on the perforation and isolated cut marks. Horizontal scale bars are 3 cm and small x/y scale bars are 2 mm. Pictures courtesy of C. Guzzo Falci.

Table 2
Overview of lithologies and morphological types of selected and examined bodily ornaments comprised in the Hatt Collection.

Material groups	Beads Disc	Tubular	Barrel-shaped	Plano-convex	Non-perforated discs	Pendants Geometric	Carved flat	Figure-in-profile	Carved 3D	Indeterminate	Total
Jadeite/Nephrite	-	-	-	2	1	3	5	1	1	-	**13**
Diorite	4	6	1	-	-	-	-	-	1	1	**13**
Plutonic rock	-	1	-	-	-	-	-	-	-	-	**1**
Serpentinite	1	-	-	1	1	-	8	-	-	-	**11**
Calcite	2	4	-	-	-	-	2	-	-	-	**8**
Jasper	1	-	-	2	1	2	3	-	-	-	**9**
Malachite	-	-	-	1	-	1	-	-	-	-	**2**
Quartz	-	1	-	-	-	-	-	-	-	-	**1**
Amethyst	-	1	3	-	-	-	-	-	-	-	**4**
Hydrothermally altered plutonic rock	-	-	-	-	-	1	-	-	-	-	**1**
Indeterminate	-	-	-	1	-	1	-	-	-	-	**2**
Total	**8**	**13**	**4**	**7**	**3**	**8**	**18**	**1**	**2**	**1**	**65**

ornaments each (20%). Whereas most diorite ornaments were disc and tubular beads, most jadeitite specimens were geometric pendants and plano-convex beads. The other two most numerous raw materials, serpentinite and jasper, were also predominantly made into geometric pendants and plano-convex beads. Few ornaments in quartz varieties were identified (n = 5; 7.69%). Twelve artefacts were identified as unfinished ornaments (18.46%). They are preforms with most of the shaping production stages completed. There are no debitage products (flakes and cores) or rough-outs in this collection. Most jadeitite artefacts have a light green colour and red inclusions consisting of either iron oxide or garnet (n = 10, 76.9%). The raw material of a plano-convex bead (O.9413) is different, consisting of two generations of jadeite and titanite. This resulted in a mottled light and dark green colour, with both fine- (< 250 µm) and coarse-grained (≥ 1 mm) sectors. A figure-in-profile pendant (O.30.352, Fig. 4) was made of a dark green and opaque rock with black inclusions, which differs markedly from the other materials.

Morphological types and technical stages of jade bodily ornaments recovered from Spratt Hall and Prosperity are displayed in Table 3 in the supplementary materials. A first stage of reduction of jadeitite blocks through flaking must have taken place, even though we do not find cores or flakes in this assemblage. We identified two alternative techniques to produce ornament blanks from preliminarily reduced jadeitite blocks. These techniques varied according to the desired end product, i.e. pendants or plano-convex beads. Flakes were used as blanks for the production of plano-convex beads. The bulb of percussion on the ventral surface of the flake was used as a natural convexity, while any flaking scars on the dorsal face were flattened by grinding. A bead preform (O.2844, Fig. 4) displays on its flat face a ridge that would have divided the flaking scars on the dorsal face of a flake, while the opposing face retains the convexity of the bulb of percussion (Fig. 4C). Similar traces are observed on a broken plano-convex bead (O.30.341, Fig. 4A). Five pendants display sawing marks or morphological anomalies resulting from the poor snapping of the blank. These traces can be interpreted as evidence for the use of groove-and-snap as blank acquisition technique. This technique was used to produce both plain and zoomorphic pendants. Other pendants may have been produced in the same way but preserve no diagnostic traces.

Through grinding, blanks were given a geometrical shape (circular, rectangular, or drop-shaped). Traces of grinding are observed on six artefacts (46.15%), both beads and pendants. They appear as bands of coarse white striations and faceting when observed with low magnification. With high magnification, grinding is identified by a poorly linked polish located predominantly on the tops of the microtopography. The non-perforated disc is the only jadeitite preform (O.2844, Fig. 4A) in an early stage of production. It displays irregular and faceted faces and sides (1.45 × 1.40 × 0.35 cm). Individual grinding striations are wide, being visible with the naked eye. The traces point to the use of a coarse-grained grinding stone for carrying out this preliminary grinding stage. The shaping stage of bead production was not completed. The inclusions on the raw material may be the reason behind the irregularities in the bead's shape, which ultimately led to its discard. On five of the specimens displaying grinding traces, this first stage of the surface treatment has been partially superposed by a linked and invasive polish visible with high magnification, accompanied by multidirectional scratches inside the polish (Fig. 4, O.30.353; Fig. 5H). This treatment is most likely the result of polishing with a soft contact material. It was the predominant treatment on four artefacts (30.76%).

Carving was attested on six ornaments in the form of notching (n = 6), incising (n = 5), excising (n = 2), and drilling (n = 1). The individual carvings have a V-shaped cross-section and are notably marked, features that suggest the use of solid saws with a triangular edge, made of hard and brittle materials. Notching is the only decorative technique found isolated on an ornament. In fact, this specimen (O.9424, Fig. 4A) is the only ornament in which the carvings do not create a figurative depiction. All other specimens are figurative pendants, including three flat frog-shaped pendants (Fig. 4B), a figure-in-profile pendant (Fig. 4C), and a three-dimensional frog-shaped pendant (Fig. 5). Several carving stages were identified on the large three-dimensional frog-shaped pendant (O.30.345, Fig. 5). The carving of the complex frog shape required four different techniques, namely incising, notching, excising, drilling, and possibly string-sawing. The head, the eyes, and the belly of the frog are isolated from the surrounding material through excision (Fig. 2E). Selective polishing of these areas also enhances the effect of excision, as carved sectors are left rough and dull. Drilling is used as a decoration technique on this specimen. Complete biconical perforations were drilled close to each side of the pendant, in between the frog's fore and hindlimbs (Fig. 2A/F/G). The perforations were placed on these areas to assist with the creation of side notches in which the centre of the notch is wider than its end. For this purpose, a sawn groove was made with a solid V-shaped saw from the edge of the pendant. The centre of this notch was connected to the perforation by sawing from the inside of the hole with potentially a string saw. The narrow morphology of the cut suggests the use of string-sawing; however, micro-traces that can be linked to this technique have not been well preserved. Whereas this pendant differs from the others due to its size and elaborate carving, its raw material is similar to the one predominant among the jadeitite specimens. Sawing of a drilled hole is also observed on the figure-in-profile pendant (O.30.352, Fig. 4C), although its purpose in that case is not clear and the tool used is different (i.e. likely a massive saw). Drilling was used for perforating the ornaments. Most perforation diameters are between 0.20 and 0.30 cm (69.23%), suggesting the use of similarly-sized drill bits. Apart from two ornaments, the perforations of all specimens are biconical and display concentric scratches on their inner walls. Four pendants are double perforated, that is, they have two attachment holes. The cones that compose the holes can be placed in

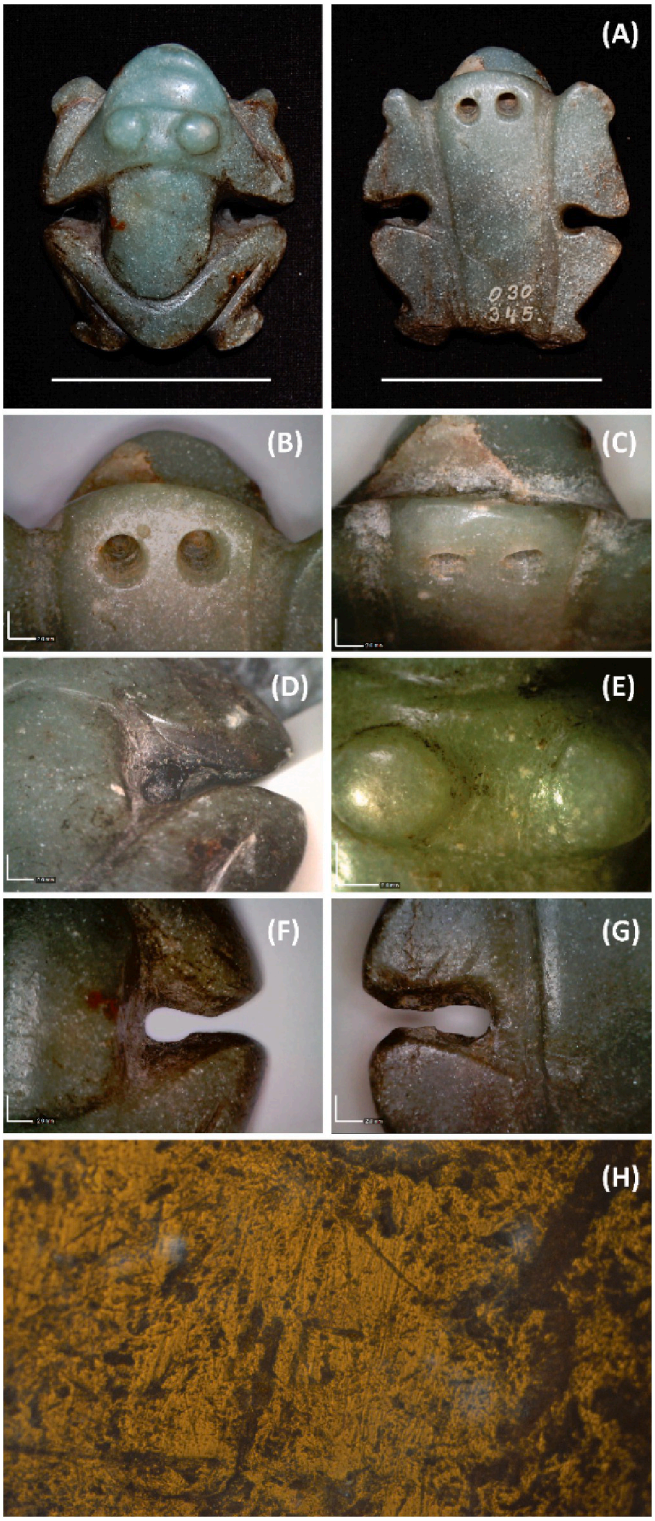

Fig. 5. Traces observed on the (A) three-dimensional frog-shaped pendant (O.30.345). (B) shows the two complete perforations, alongside an abandoned perforation cone. (C) depicts use-wear rounding and polish on the top edge of the pendant, where a string would have connected both sides of the perforations. (D), (F), and (G) show different views of the side notches. Note cut marks made with a solid saw (G) superposed by drilling, and possible string sawing traces (D). Polishing scratches in between the excised eyes of the frog (E). (H) depicts polishing on the surface viewed with high magnification (X100). Horizontal scale bars are 3 cm and small x/y scale bars are 2 mm. Pictures courtesy of C. Guzzo Falci.

different angles in relation to each other on the different pendants: acute angles, 90°, and 180°.

Some ornaments display evidence of reworking due to technical errors. For instance, a plano-convex bead displays evidence of regrinding in order to repair a broken side (O.30.341, Fig. 4A). However, the artefact was abandoned prior to the completion of the repair. The perforation is de-centred on the flat side, due to the invasiveness of the break. The inner cone of the perforation is narrow and displays no use-wear, thus suggesting that the breakage and the attempt to repair the bead took place during production. Despite being polished, a plano-convex bead (O.9413) has an asymmetrical shape, with a slightly off-centred perforation. A misplaced perforation inset is present on the three-dimensional frog-shaped pendant (O.30.345, Fig. 5) next to one of its complete perforations. It is the result of the poor positioning of the hole in relation to the cone on the other face. It is unclear why it has not been erased by grinding. The figure-in-profile pendant (O.30.352, Fig. 4C) displays evidence of recycling. Whereas it appears to depict the profile of a biomorphic figure, it is not clear what its intended shape was. The artefact is not finished, and the perforation has been sawn through. Abandoned and partially ground-over cut marks in multiple directions are observed on different sectors of this artefact. These appear to be connected to a blank production stage. At the same time, other cut marks are much fresher and appear on top of the general surface treatment. The last technical operations to take place were incisions and the sawing of the perforation.

Three ornaments display evidence of having been used (30%): the three-dimensional pendant (O.30.345, Fig. 5), the rectangular carved pendant (O.9424, Fig. 4A), and a drop-shaped pendant (O.9411, Fig. 4A). The use-wear is characterised by well-developed polish and rounding on the top of the rim of the perforation. This distribution suggests that the 3 artefacts were hanging asymmetrically. A plano-convex bead (O.9413) displays limited rounding on the perforation suggesting use. At the same time, the centre of the perforation hole remains very narrow, thus pointing to a non-extensive use period. The two frog-shaped pendants (O.9412 and O.2846) did not display use-wear. The inner rim of their perforations is very narrow and there is no distinctive polish. Finally, five ornaments are interpreted as artefacts abandoned during manufacture and therefore prior to use: two bead preforms (O.2844, Fig. 4C and O.30.625, Fig. 4B), the partially recycled bead (O.30.341, Fig. 4A), the figure-in-profile pendant (O.30.352, Fig. 5), and a large flat frog-shaped pendant broken on the perforations (O.30.353, Fig. 4B). Even though the last three artefacts have complete perforations, our analysis has shown that they are most likely unfinished ornaments.

4.2. Trace elemental data and Sr-Nd isotope compositions

The geochemical data of jadeite - and omphacite - rich jade, lawsonite jade and jadeitite artefacts are presented in Table 4 (trace element abundances in ppb/mL) and Table 5 (Sr-Nd isotope compositions, IC). Trace element data are presented in Fig. 6, rare earth elements (REE) normalised to chondritic values (Fig. 6A) and trace elements (TE) normalised to mid ocean ridge basalt (N-MORB, Fig. 6B) (Sun, S.S. and McDonough, W.F., 1989), respectively. The variability of selected discriminatory TE ratios and the isotopic data for each island are compared to the jade sources in box whisker diagrams in Figs. 7 and 8 respectively.

Artefacts from the Hatt Collection show variably fractionated REE patterns ($Ce_N/Yb_N = 0.23 – 64.87$ with a median of 2.37), with 3 samples from St. Croix holding the most extreme REE fractionation with $Ce_N/Yb_N = 64.87$ (CPH31), 31.25 (CPH14), and 24.19 (CPH27). Most artefacts feature slightly positive Eu* anomalies with a median of 1.15 ($Eu^* = 0.40 – 2.73$, $Eu^* = Eu_N/SQRT(Sm_N + Gd_N)$), except for sample CPH02 with an extreme positive Eu* of 8.99. Samples CPH05/08/12/18/20/22/24–27/31 have minor negative Eu* anomalies. Artefact samples CPH05/10/14/16/22/26/27/31 exhibit REE pattern similar to

Table 4
Trace element content of artefacts sampled with the portable laser ablation device from the Virgin Islands (CPH08-CPH25), St. Vincent (CPH35), Dominican Republic (CPH20 and CPH21) and Cuba (CPH22) in ppb/mL. Trace elements of samples CPH08 – CPH34 were collected as pre- and post-fraction during ion-exchange chromatography, whereas samples CPH30 – CPH22 were aliquoted for ICPMS (5% of total solution) and TIMS analyses (95% of total solution), resulting in concentration differences of several orders of magnitude. Note that nd stands for not detected, i.e. below limit of quantification (LOQ) or blank. Because of ion-exchange chromatography Pb, Sr and Nd (together with Pr) were separated from the whole rock matrix and are therefore not present in the TE content of samples CPH08 – CPH34. HFSE data (Nb/Ta/Zr/Hf) are affected by laser sampling, as accessory phases are underrepresented in the sample aerosol, and therefore not reported.

VU ID	Sc	Ti	Rb	Sr	Y	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Tb	Gd	Dy	Ho	Er	Tm	Yb	Lu	Pb	Th	U
CPH08	1.19	207	0.34	nd	0.09	0.01	5.62	0.08	0.14	nd	nd	0.01	0.004	0.002	0.02	0.02	0.003	0.01	0.001	0.01	0.001	nd	nd	0.14
CPH09	1.92	240	0.21	nd	0.38	0.005	3.96	0.27	0.46	nd	nd	0.06	0.03	0.01	0.06	0.05	0.01	0.03	0.005	0.03	0.004	nd	nd	0.05
CPH10	3.10	196	0.71	nd	0.36	0.05	16.47	0.31	0.42	nd	nd	0.08	0.04	0.01	0.08	0.06	0.01	0.03	0.004	0.02	0.003	nd	nd	0.04
CPH11	2.51	592	0.45	nd	3.07	0.02	7.85	0.59	1.12	nd	nd	0.48	0.23	0.09	0.52	0.54	0.12	0.30	0.04	0.26	0.03	nd	nd	0.06
CPH12	3.65	232	1.13	nd	0.74	0.02	11.39	0.38	0.50	nd	nd	0.07	0.02	0.01	0.07	0.09	0.03	0.07	0.01	0.05	0.01	nd	nd	0.01
CPH13	4.28	206	0.59	nd	0.23	0.02	4.11	0.08	0.16	nd	nd	0.04	0.01	0.01	0.04	0.04	0.01	0.02	0.003	0.02	0.004	nd	nd	0.06
CPH14	1.46	290	0.34	nd	0.62	0.01	11.09	2.53	4.78	nd	nd	1.26	0.59	0.10	0.92	0.38	0.04	0.06	0.01	0.04	0.005	nd	0.02	0.03
CPH15	2.48	909	4.04	nd	1.37	0.08	82.33	1.27	2.08	nd	nd	0.27	0.11	0.04	0.25	0.25	0.05	0.15	0.02	0.12	0.02	nd	nd	0.20
CPH16	4.28	293	0.35	nd	0.57	0.01	7.01	0.62	1.20	nd	nd	0.16	0.05	0.02	0.14	0.10	0.02	0.05	0.01	0.03	0.004	nd	nd	0.02
CPH19	3.72	264	0.18	nd	0.80	0.01	9.85	0.22	0.42	nd	nd	0.07	0.03	0.01	0.08	0.10	0.03	0.08	0.01	0.10	0.01	nd	nd	nd
CPH26	5.23	159	0.82	nd	0.06	0.01	25.86	0.11	0.18	nd	nd	0.01	0.002	0.001	0.01	0.01	0.002	0.01	0.001	0.004	0.001	nd	nd	nd
CPH27	5.37	133	0.33	nd	0.03	0.01	11.05	0.11	0.23	nd	nd	0.003	0.001	0.0004	0.004	0.005	0.001	0.003	0.0003	0.003	0.0004	nd	nd	nd
CPH29	4.60	1547	0.48	nd	4.62	0.01	14.56	0.73	1.78	nd	nd	0.93	0.31	0.14	0.89	0.81	0.16	0.40	0.05	0.28	0.03	nd	nd	0.34
CPH31	3.34	188	0.46	nd	0.32	0.01	8.51	2.24	3.35	nd	nd	0.17	0.02	0.01	0.09	0.05	0.01	0.03	0.003	0.01	0.002	nd	0.003	nd
CPH32	5.28	170	0.58	nd	2.07	0.01	14.50	0.28	0.51	nd	nd	0.25	0.22	0.05	0.31	0.32	0.06	0.15	0.02	0.10	0.01	nd	nd	0.02
CPH33	5.31	151	0.58	nd	0.27	0.02	8.29	0.13	0.22	nd	nd	0.04	0.02	0.01	0.04	0.04	0.01	0.03	0.004	0.02	0.004	nd	nd	nd
CPH34	3.85	183	0.18	nd	0.35	0.02	5.99	0.05	0.08	nd	nd	0.02	0.01	0.004	0.02	0.03	0.01	0.04	0.01	0.07	0.01	nd	nd	0.04
CPH30	nd	24.10	0.02	nd	0.05	nd	0.16	0.01	0.02	0.004	0.02	0.01	0.004	0.002	0.01	0.01	0.002	0.01	0.001	0.004	0.001	0.30	0.004	0.01
CPH36	nd	12.13	0.38	0.27	0.02	0.001	9.54	0.02	0.03	0.003	0.01	0.002	0.002	0.0004	0.003	0.003	0.001	0.002	0.0003	0.002	0.0003	0.02	0.002	0.001
CPH24	nd	21.01	0.01	0.42	0.02	nd	0.14	0.02	0.04	0.01	0.03	0.01	0.002	0.001	0.01	0.005	0.001	0.002	0.0003	0.002	0.0003	0.05	0.005	0.001
CPH28	nd	nd	0.04	nd	nd	0.00001	1.07	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.01	0.0001	nd
CPH17	nd	3.75	0.01	nd	0.01	0.00002	0.01	0.001	0.003	0.001	0.004	0.001	0.001	0.0003	0.002	0.002	0.0003	0.001	0.0001	0.001	0.0002	0.26	0.0004	nd
CPH02	nd	16.80	0.01	nd	0.001	nd	1.13	0.001	0.003	0.0004	0.001	0.0004	0.001	0.0001	0.0004	0.0005	0.0001	0.0003	0.00003	0.0004	0.0001	0.10	0.001	0.0005
CPH03	nd	104	0.003	0.97	0.02	nd	0.36	0.01	0.02	0.004	0.01	0.003	0.002	0.001	0.003	0.005	0.001	0.004	0.001	0.005	0.001	nd	0.0004	0.0001
CPH04	nd	20.93	0.01	0.05	0.02	nd	0.30	0.0001	0.00	0.001	0.005	0.002	0.001	0.0004	0.003	0.003	0.001	0.002	0.0003	0.003	0.001	0.04	0.0004	0.004
CPH05	nd	15.14	0.06	0.63	0.09	0.001	1.45	0.21	0.34	0.05	0.15	0.03	0.004	0.003	0.02	0.02	0.003	0.01	0.001	0.01	0.002	0.26	0.03	0.01
CPH06	nd	0.73	0.01	0.12	0.004	0.0001	0.33	0.004	0.01	0.001	0.004	0.001	0.001	0.0002	0.001	0.001	0.0001	0.001	0.0001	0.001	0.0001	0.001	0.001	nd
CPH07	nd	12.26	0.01	nd	0.05	nd	0.06	0.01	0.02	0.01	0.05	0.01	0.004	0.002	0.01	0.01	0.002	0.01	0.001	0.005	0.001	0.01	0.002	0.002
CPH23	nd	71.49	0.02	nd	0.08	nd	0.16	0.002	0.01	0.002	0.02	0.01	0.01	0.003	0.01	0.02	0.003	0.01	0.001	0.01	0.001	0.03	0.001	0.001
CPH25	0.001	3.28	nd	nd	0.01	nd	nd	nd	0.001	0.0004	0.002	0.001	0.0003	0.0003	0.002	0.002	0.0003	0.001	0.0001	0.001	0.0001	0.02	0.0002	nd
CPH18	nd	6.64	0.08	nd	0.02	0.00003	0.22	0.01	0.02	0.004	0.01	0.004	0.001	0.001	0.004	0.004	0.001	0.003	0.0004	0.002	0.0004	0.19	0.004	0.001
CPH35	nd	3.01	nd	nd	0.001	nd	0.13	0.001	0.002	0.0003	0.001	nd	0.0001	0.0001	0.0004	0.0003	nd	0.000002	0.00001	0.0002	nd	0.02	0.0003	nd
CPH20	nd	2.99	0.06	0.25	0.01	0.00004	0.10	0.01	0.02	0.002	0.01	0.001	0.0003	0.0002	0.002	0.001	0.0002	0.001	0.0001	0.001	0.0001	0.01	0.003	0.0001
CPH21	0.007	22.92	0.008	nd	0.09	nd	0.29	0.003	0.01	0.003	0.02	0.01	0.01	0.002	0.02	0.02	0.003	0.01	0.001	0.01	0.001	0.04	0.001	0.001
CPH22	0.002	64.53	0.18	1.89	0.13	0.001	3.84	0.19	0.33	0.06	0.24	0.06	0.02	0.005	0.04	0.03	0.005	0.01	0.001	0.01	0.001	3.30	0.02	0.03

Table 5
Low blank Sr and Nd isotope compositions of artefacts sampled with the portable laser ablation device from the Virgin Islands (CPH08 – CPH25), West Indies (CPH18, without greater specification), St. Vincent (CPH35), Dominican Republic (CPH20 and CPH21) and Cuba (CPH22). Note Sr IC are given after blank correction of < 3%, whereas Nd IC are representing measured, not blank corrected ratios; nd stands for not determined.

VU ID	$^{87}Sr/^{86}Sr$	± 2SE	$^{143}Nd/^{144}Nd$	± 2SE
CPH08	0.70633	0.00002	nd	
CPH09	0.70396	0.00001	0.51286	0.00008
CPH10	0.70363	0.00001	0.51285	0.00007
CPH11	0.70462	0.00001	0.51309	0.00006
CPH12	0.70815	0.00001	0.51275	0.00006
CPH13	0.70613	0.00002	nd	
CPH14	0.70354	0.00001	0.51310	0.00003
CPH15	0.70823	0.00002	0.51283	0.00001
CPH16	0.70363	0.00001	0.51295	0.00005
CPH19	0.70371	0.00001	0.51294	0.00007
CPH26	0.70858	0.00001	nd	
CPH27	0.70850	0.00003	nd	
CPH29	0.70653	0.00001	0.51267	0.00003
CPH31	0.70776	0.00002	0.51291	0.00003
CPH32	0.70795	0.00001	0.51277	0.00006
CPH33	0.70632	0.00002	0.51283	0.00018
CPH34	0.70723	0.00003	0.51280	0.00027
CPH30	0.70739	0.00004	nd	
CPH36	0.70915	0.00005	nd	
CPH24	0.70401	0.00001	nd	
CPH28	0.70861	0.00002	nd	
CPH17	0.70469	0.00002	nd	
CPH02	0.70543	0.00008	nd	
CPH03	0.70395	0.00002	nd	
CPH04	0.70743	0.00002	nd	
CPH05	0.70848	0.00002	nd	
CPH06	0.70420	0.00002	nd	
CPH07	0.70729	0.00006	nd	
CPH23	0.70564	0.00002	nd	
CPH25	0.70664	0.00006	nd	
CPH18	0.70872	0.00003	nd	
CPH35	0.70715	0.00005	nd	
CPH20	0.70897	0.00001	nd	
CPH21	0.70704	0.00002	nd	
CPH22	0.70559	0.00001	nd	

continental crust with Ce_N/Yb_N ranging from 4.79 to 64.87, four samples from St. John resemble MORB REE patterns (CPH04/07/23/25). All samples have pronounced positive Pb anomalies, with Pb concentrations ranging from 0.0013 to 3.30 ppb/mL. The majority of the artefact samples record positive Ti anomalies with concentrations ranging from 0.73 to 1547 ppb/mL (median of 118 ppb/mL).

Blank correction of 13 samples (CPH02/05/07/14/15/18/20/22/35/36) results in insignificant change to the measured Sr isotope ratios. The remaining samples have corrections of up to 3%, which results in an $^{87}Sr/^{86}Sr$ change of < 0.00028 (median < 0.00007). The low Nd blank (6.45 pg sampling blank and 1 pg geochemical blank) and the small isotopic differences between the samples and blank ($^{143}Nd/^{144}Nd \sim 0.5130$ and ~ 0.5120) results in Nd blank correction smaller than the analytical error.

The Sr isotope data for 30 artefacts retrieved from the Virgin Islands vary from 0.70354 to 0.70915 with an average of $^{87}Sr/^{86}Sr = 0.70626 \pm 372$ (median $^{87}Sr/^{86}Sr = 0.70633$). Strontium IC from St. Vincent (STV), the West Indies (WI, without greater specification), the DR and CU encompassed in the Hatt Collection have $^{87}Sr/^{86}Sr$ of: STV = 0.70715 ± 5 (CPH35), WI = 0.70872 ± 3 (CPH18), DR = 0.70897 ± 1 (CPH20) and = 0.70704 ± 2 (CPH21), CU = 0.70559 ± 1 (CPH22). Neodymium IC were only determined for artefacts from St. Croix with $^{143}Nd/^{144}Nd$ ranging from 0.51267 to 0.51310 (mean $^{143}Nd/^{144}Nd = 0.51287 \pm 25$, mode $^{143}Nd/^{144}Nd = 0.51285$).

4.3. Prediction of artefact provenance

For the provenance assessment of jade artefacts we adapted a multi-class logistic regression analyses following Knaf et al. (Knaf et al., 2020), employing two modified models that are explained in detail in Appendix IV. The provenance of individual artefacts is presented in Table 1. Predictive modelling of artefact provenance revealed, with a probability of > 88–93%, that 24 jade objects are assigned to the DR/CU sources and 10 jade artefacts to GM. Furthermore, with a probability of > 73–76%, 13 of the 24 samples are assigned a DR source and 11 to CU. Thirdly, with a probability of > 75–86%, seven artefacts are predicted to have their origin in SMFZ and 3 to the NMFZ source region.

Three-quarters (75%) of artefacts collected from St. Croix exhibit a DR/CU provenance. All 4 celt and celt fragments (CPH08/09/10/11) excavated by Hatt in 1922/23 from the late Early Ceramic Age site Longford have their origin in DR/CU sources (all are assigned to CU). Two pendants (CPH26 = O.9411, CPH36 = O.9412) donated by Nordby in 1946 and one petaloid celt (CPH29), retrieved from the Cedrosan Saladoid Prosperity site can be sourced back to DR/CU (CPH26 and CPH29 to CU, CPH 36 to DR). One sample, a flat frog pendant (CPH27 = O.9424), possibly retrieved from Prosperity, can be sourced back to the SMFZ region of GM. It was impossible to model the provenance of the three-dimensional frog pendant (CPH28 = O.30.345) found on the Krause Field by Nordby in 1923, as the elemental abundancies for most of the discriminatory TE ratios were below the limit of quantification, due to inefficient sampling of the gem quality jade. Two celts found on the Cane Bay site have a GM signature (SMFZ, CPH32/34), whereas one celt can be assigned to the DR/CU region (CPH31 to CU). Moreover, of 9 celt and celt fragments discovered at various Early (500 BC – AD 600/800) to Late (AD 600/800 – 1492/1500) Ceramic Age sites (La Valle or Cane Bay, Cotton Valley, Sprat Hall, Richmond and unknown locations on St. Croix), two were apportioned to GM (SMFZ, CPH19 and CPH33), and seven to the closer DR/CU source regions (CPH14/24/30 to DR and CPH12/13/15/16 to CU).

Only two of the six celts from St. John, Little Cruz Bay (CPH04) and Abrahams Fancy (CPH25), have a GM provenance (SMFZ). The remaining artefacts found on other sites on St. John, such as Durloe Cay (CPH06), Coral Bay (CPH07 and CPH23) and Abrahams Fancy (CPH05), as well as two celts found on St. Thomas (Magens Bay and unknown location, CPH02 and CPH03), have a Dominican origin. Sample CPH17, a celt from either St. Croix or St. Thomas is sourced back to GM (NMFZ).

The three celts recovered from the Constanza Valley in the DR (CPH21), CU (CPH22) and the West Indies without a specific location (CPH18) are derived from a DR source, whereas a celt fragment from the Río Chavón region in the south of DR and a celt recovered on St. Vincent (CPH35) originate from the NMFZ area in GM.

5. Discussion

5.1. Typo-technological and use evidence of bodily ornaments from Prosperity and Spratt Hall, St. Croix

Most common ornament types are similar to those found in lapidary workshops in Puerto Rico: frog pendants, drop-shaped pendants, plano-convex beads (Chanlatte Baik and Narganes, 1983; Narganes Storde, 1995a; Narganes Storde, 1995b). Among the flat frog pendants, we note the presence of segmented frog pendants (n = 12), but only one is jadeitite. This pendant subtype was recovered in large numbers from the Puerto Rican sites, being typically Huecoid (Chanlatte Baik and Narganes, 1983). A single figure-in-profile pendant was recovered in the studied collection (O.30.352, Fig. 4C). This contrasts with the Puerto Rican sites, where such specimens are found in large numbers, particularly in the form of vulture pendants (Chanlatte Baik and Narganes, 1983; Rodríguez López, 1991). It should be noted that the artefact found in this collection is a reworked specimen with no clear attribution regarding the depicted figure.

The three-dimensional frog-shaped pendant differs significantly in style from other three-dimensional frog pendants known from elsewhere in the archipelago. The position of the perforations on the pendant also

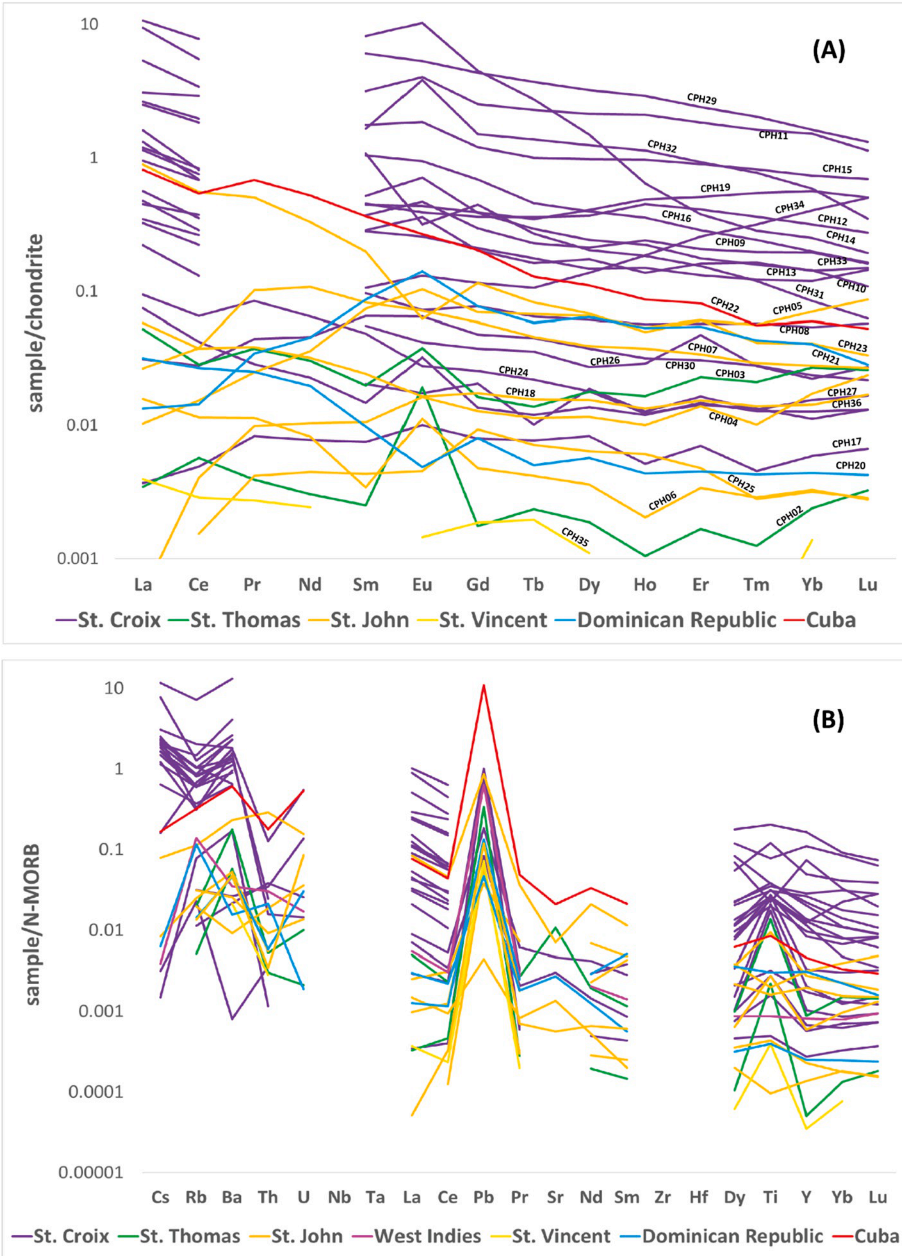

Fig. 6. Whole rock REE (A) and multi-element variation (B) diagrams showing the range of jadeite – and omphacite – rich jade, lawsonite jade, jadeitite s.l. to jadeitite s.str. from artefacts recovered from Ceramic Age sites on the US Virgin Islands (St. Croix, St. Thomas, St. John), St. Vincent, the Dominican Republic and Cuba. Deviation in element abundances for samples from St. Croix compared to other Caribbean islands are related to different analytical approaches. TE concentrations for most of the artefacts recovered from St. Croix (CPH08 – CPH34) are several orders of magnitude higher, as TE were collected as pre- and post-fractions during ion-exchange chromatography, whereas samples CPH30 – CPH22 were aliquoted for ICPMS (5% of total solution) and TIMS analyses (95% of total solution). Note REE pattern of CPH35 < 0.001. Normalisation values for C1 chondrite and N-MORB from Sun and McDonough (Sun, S.S. and McDonough, W.F., 1989).

contrasts with other three-dimensional zoomorphic pendants found across the archipelago: two perforations are placed on the top end of the pendant, right behind the head of the figure (Fig. 5A/B/C). This position suggests a different attachment system. This piece has also undergone distinct sawing and has other unique aspects of its carving. Variability in the depiction styles of such pendants across the Caribbean has been previously noted (Falci et al., 2020a; Falci et al., 2020b; Queffelec et al., 2020; Falci, 2020) and may suggest some degree of personalization on the part of the craftsperson in the creation of such large pendants.

Despite the advanced degree of modification and the reduced number of the studied specimens, microwear analysis allowed us to gain insights into the biographies of jade ornaments from St. Croix. This particularly concerns their sequences of production and instances of repair/recycling. The small numbers of unfinished ornaments and the absence of debitage and rough-outs may be related to the collecting strategy: amateur collectors are likely to give priority to finished ornaments or other aesthetically-pleasing artefacts. This would result in the gathering of preforms in different production stages, but not of chipping waste or dull pieces without clear typology. It is possible that early reduction of jade blocks did not take place in Prosperity or Sprat Hall, but elsewhere, for instance close to the source of the raw material.

Preliminary archaeological research had identified the Prosperity site as the location of a Saladoid lapidary workshop (Vescelius and Robinson, 1979). While only two artefacts were identified as preforms in our study, three other artefacts likely broke during production and two record attempts at repair. Even though most pieces appeared thoroughly polished and therefore finished, only three specimens displayed evidence of having been used as part of composite ornaments. This combined evidence supports the idea that sectors in the Prosperity and Spratt Hall sites were dedicated to lapidary working. Ornament production took place locally, but it is not possible to assess to which degree due to the unsystematic nature through which the collection was formed.

The low presence of ornaments comprising quartz varieties suggests restricted contact with the main providers of such raw materials, namely the lapidary workshops to the south (in Montserrat, Antigua, and Grenada). Malachite was identified in only two ornaments, but has

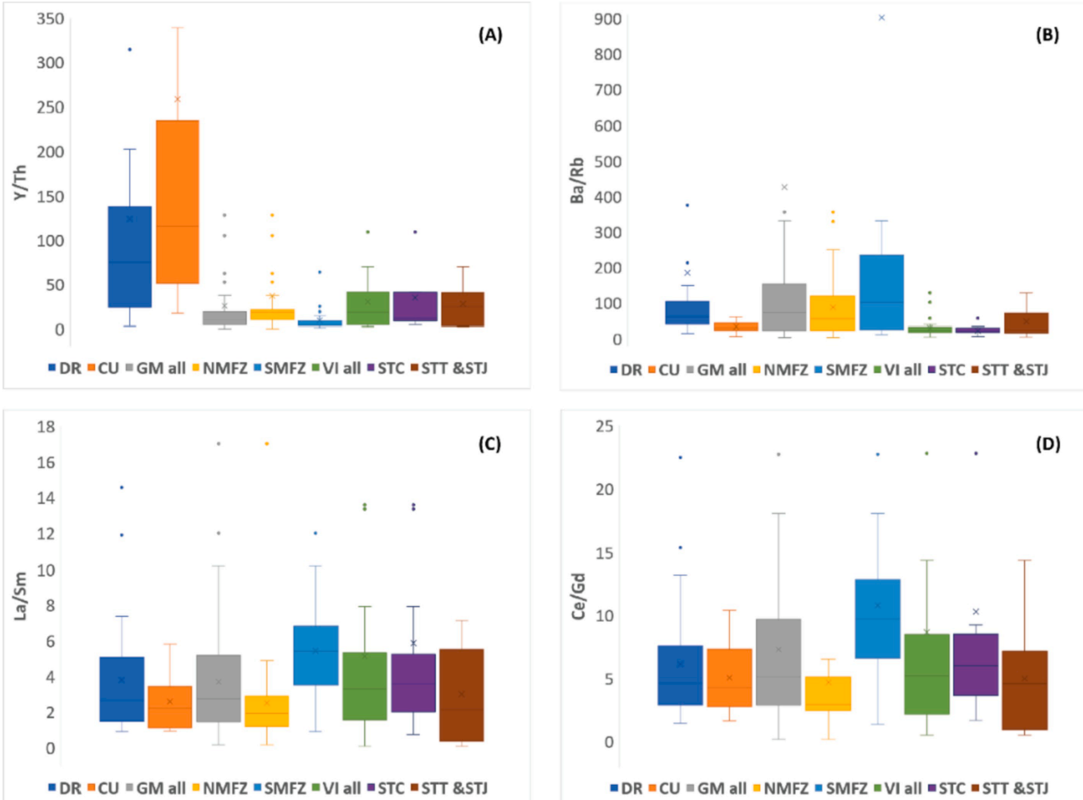

Fig. 7. Variability of selected discriminatory TE ratios presented as boxplots of jadeitite to jadeite-omphacite rich source rocks, (A) Y/Th variability which is employed for discriminating the DR/CU sources from the GM sources, (B) Ba/Rb variability which is applied to discriminate the DR from the CU source, (C) La/Sm variability and (D) Ce/Gd variability which are used to separate the GM sources from each other, i.e. NMFZ versus SMFZ. Source and artefact location abbreviations, as well as colour coding are: Río San Juan Complex (dark blue DR), Sierra del Convento Mélange (orange CU), Guatemala (GM) considered as one source (grey GM all) and divided into two sources as NMFZ (yellow) and SMFZ (bright blue), Virgin Islands (VI) including St. Croix + St. Thomas + St. John (green VI all), St. Croix (purple STC), as well as St. Thomas and St. John (brown STT & STJ). Crosses indicate average TE ratios, the interquartile range (IQR = Q1-Q3) displays 50% of the data and the median TE ratio is marked by a horizontal line inside the box. Samples lying outside the whiskers (< Q1-1.5xIQR and > Q3 + 1.5xIQR) represent 0.7%, meaning 99.3% of the data are within ± 2.698σ. Note that variability plots are zoomed in to better visualize samples within the box and whiskers, i.e. 99.3% of the data. Not displayed are sample outliers for Y/Th (DR-SR-15 = 587.30, DR-SR-62 = 673.19, CU-SR-16 = 607.98, CU-SR-12 = 1078.83, CU-SR-11 = 1207.79, NMFZ-SR-09 = 459.96), for Ba/Rb (DR-SR-50 = 2996, SMFZ-SR-03 = 8632, SMFZ-SR-05 = 5542, SMFZ-SR-06 = 2796, MVE02-15–6 = 1181), for La/Sm (CPH27 = 34.15), and for Ce/Gd (NMFZ-SR-05 = 45.76, SMFZ-SR-04 = 26.57, CPH31 = 36.47, CPH27 = 54.41).

previously been reported in larger numbers as part of the Folmer Andersen Collection housed in St. Croix (Hardy, 2009; Hardy, 2008). The raw material may have been obtained from the nearby island of Virgin Gorda (Knippenberg, 2007), providing further support to the existence of constant contacts between communities in different islands in this northern tip of the eastern Caribbean.

In terms of ornament typology and production technologies, jadeitite is not treated differently from other "greenstones", such as jasper, serpentinite, and malachite, or from the beige calcite. All these materials are exogenous to the island of St. Croix. Jade was made into the same types of ornaments and using similar production technologies. We also notice no differences in treatment between the jade pendants whose material can be traced back to Cuba, the Dominican Republic, or Guatemala. Within our studied sample, ornament types and production techniques do not seem to have varied according to provenance of the raw materials.

The notable exception to this homogeneity is the large three-dimensional frog-shaped pendant (O.30.345), which displays a more naturalistic figure produced using sophisticated carving techniques not observed on other artefacts (e.g., string-sawing from a drilled hole, excision). In previously published research (Falci et al., 2020b), string sawing was identified for blank production in ornaments made of plutonic rocks and nephrite. The specific method described on this frog pendant differs from the others, in the modality of its application and goal: it aims to excise the limbs of the frog. Rodríguez Ramos (Rodríguez Ramos, 2010) has noted the use of string-sawing for decorating vulture pendants found in large numbers in Huecoid contexts from Puerto Rico. The lack of provenance attribution for this specimen (O.30.345) prevents us from assessing whether this special treatment could be related to provenance of the raw material.

Despite the traditional attribution of Prosperity to the Saladoid series, the observed features identified in this study suggest great affinity to lapidary production known to have occurred in sites associated to the Huecoid series in Puerto Rico. Rather than pinpointing cultural affiliation, this typo-technological similarity can be more securely linked to the positioning of the studied sites within the sphere of influence of the large sites in Puerto Rico.

5.2. Assessment and quality of geochemical data

Two different approaches were applied in determining trace element data with some samples aliquoted while others underwent chromatography. For the latter, the yields of high field strength elements (HFSE), especially Zr, Hf, Nb, Ta, Th and U were very low. For example, > 70% of Nb and Ta remained in the resin after Pb HBr-anion exchange chromatography using the Biorad^{TM} AGIx8 resin (200–400 µm mesh size). The

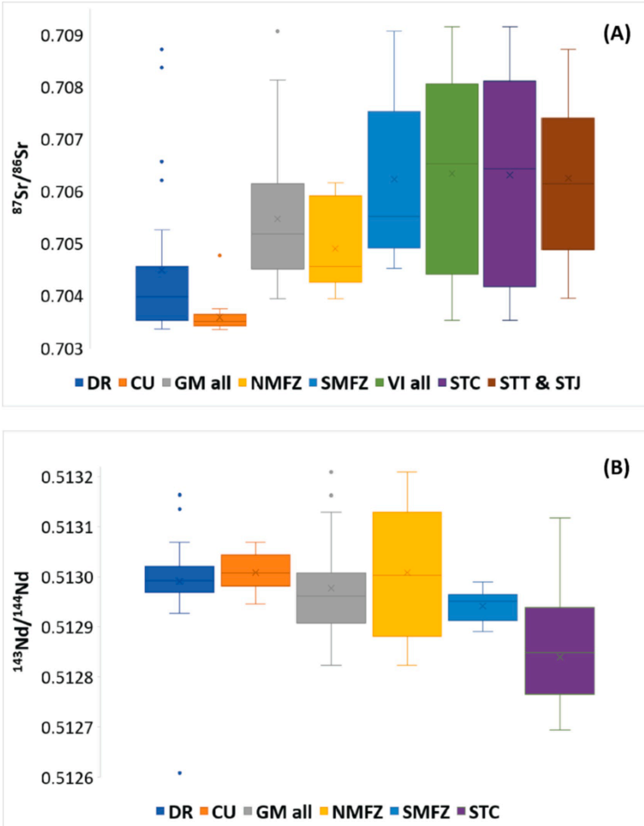

Fig. 8. Sr- and Nd isotope compositions presented as boxplots of jadeitite to jadeite-omphacite rich source rocks, (A) $^{87}Sr/^{86}Sr$ variability and (B) $^{143}Nd/^{144}Nd$ variability. Source and artefact location abbreviations, as well as colour coding are: Río San Juan Complex (dark blue DR), Sierra del Convento Mélange (orange CU), Guatemala (GM) considered as one source (grey GM all) and divided into two sources as NMFZ (yellow) and SMFZ (bright blue), Virgin Islands (VI) including St. Croix + St. Thomas + St. John (green VI all), St. Croix (purple STC), as well as St. Thomas and St. John (brown STT & STJ). Crosses indicate average isotopic compositions, the interquartile range (IQR = Q1-Q3) displays 50% of the data and the median isotopic composition is marked by a horizontal line inside the box. Samples lying outside the whiskers (< Q1-1.5xIQR and > Q3 + 1.5xIQR) represent 0.7%, meaning 99.3% of the data are within ± 2.698σ.

LREE fraction including Nd was separated from the whole rock matrix using the TRU-Spec resin medium (Eichrom^{TM}, 100–150 μm mesh size) which resulted in 42 – 49% yields for Nb-Ta-Hf, < 2% for Zr and a total loss of U and Th. All other TE elements had yields in the range of 85 – 99% for the individual resins. The Sr-Spec resin (Eichrom^{TM}, 100–150 μm mesh size) and the LN resin (Eichrom^{TM}, 50–100 μm mesh size) which purifies Nd from the LREE fraction reduced the elemental yields as expected by ≤ 10%. To correct for any yield issue for samples that were not aliquoted, all trace element data were normalized to the USGS BHVO-2 standards. For most elements the normalization factor was close to 1 and the quality control BHVO-2 was within error of the standard reference values, except for the HFSE data. We therefore do not report the Nb, U, Th, Ta, Zr and Hf data from these samples. Consequently, for future studies we recommend to aliquot samples for TE and IC analyses to avoid any elemental loss. In addition, Knaf et al. (Knaf et al., 2020) have shown that TE ratios are better suited than IC to provenance Caribbean jade artefacts. We therefore recommend that any future studies prioritize TE over IC analyses.

5.3. Evaluation of portable laser sampling and statistical provenance approach

The TE ratios most successful in discriminating circum-Caribbean jade sources (Knaf et al., 2020) were determined by conventional geochemical preparation, i.e. crushed and digested whole rock samples in the range of 100s of μg to 10s of mg. When sampling with the portable laser it is crucial to obtain a representative sample, which is comparable to the Caribbean jade source rock data base. The Virgin Island data set obtained by portable laser ablation sample major- and minor mineral phases in a representative way as a consequence of the fine (< 250 μm) to very fine (< 50 μm) grained rocks. Significantly, accessory silicate phases in jade, such as zircon and titanite which are enriched in HFSE (especially Nb-Ta-Hf-Zr), are most probably underrepresented in the data as only 20 ablation pits are used, and these minerals represent < 0.1% of the rock. Consequently, predictive provenance modelling of artefact samples taken with the laser must exclude HFSE TE ratios. Hence, we employ two modified versions of the source discrimination model presented in Knaf et al. (Knaf et al., 2020), removing the TE ratios that include Nb-Ta-Zr-Hf data, i.e. Zr/Hf, Nb/Ta and Ta/Th (Appendix IV, Table 7).

Some trace elemental data were below the blank value and relevant TE ratios were replaced by a 0 value in the model, i.e. 0 is treated as a number and not ignored as a "null" value. The input of missing values with 0 potentially affect the logistic regression. However, the impact of a 0 value for a missing discriminatory TE ratio in the multiclass regression model is not decisive as multiple TE ratios are used for discriminating between two or more jade sources. Trace element ratios including the 0 values are listed in Appendix IV (Table 7) for each sample.

In the model used for aliquoted samples, Guatemalan jades were separated from the Dominican and Cuban sources using La/Th and Y/Th ratios with a success rate of 93%. The Dominican source was distinguished from Cuban jades by employing Er/Yb and Ba/Rb ratios with 76% certainty. Furthermore, the two Guatemala sources, north and south of the Motagua Fault Zone, were discriminated by La/Sm, Ce/Gd, Sm/Nd and Dy/Y ratios with an 85% correct classification. For unaliquoted samples we adopted a single multiclass logistic regression model which features 8 TE ratios, i.e. La/Sm, Dy/Y, Ce/Gd, Sm/Nd, Dy/Yb, Er/Yb, Ba/Rb and Gd/Yb to overcome the replacement of La/Th and Y/Th by a 0 value. The DR/CU source region is discriminated from GM with an 88% probability, DR from CU with 73% correct sample assignment and discerned between the two Guatemalan sources with a probability of 75%.

Macroscopic examination of the artefacts from the Hatt Collection determined a bilious green coloured mineral phase in samples CPH22 and CPH24 (see Appendix II), which were discovered on Cuba and St. Croix, respectively. This mineral is probably kosmochlor or another chromium – rich mineral phase (Ou and Chiu, 1984; Hänni and Meyer, 1997). Importantly however, kosmochlor is only found in jades from Guatemala (Harlow et al., 2011; Harlow and Olds, 1987), whereas chromium – rich mineral phases are present in omphacitites from Cuba (Cárdenas-Párraga, 2019). Consequently, the detection of those minerals is source discriminant. The distinction of the two phases requires classical destructive petrographic thin section or microbeam analysis. The use of portable instrumentation in the field, such as pXRF, pLIBS, or pRaman for qualitative analyses are an option. In contrast, our predictive model assigned both samples to the Dominican source. The apparent false attribution could be a consequence of the success rate of the predictive modelling; i.e., 93% correct discrimination between GM and DR/CU, and 76% accurate assignment to DR or CU. Alternatively, it is probable that the recently discovered Dominican source is not fully characterised. More samples need to be collected and analysed from the Río San Juan Complex (Schertl et al., 2012).

Knaf et al. (Knaf et al., 2020) showed that 16 of 19 artefacts excavated at the Dominican Late Ceramic Age Playa Grande site have a Dominican origin. Significantly, however, 3 celts were non-local and assigned to the Guatemalan source. The result is in accordance with the source prediction of this study for jade celts discovered in the DR. The modelling resulted in a DR origin for a sample discovered in the Constanza Valley (CPH21) in central DR, whereas celt CPH20 recovered from the Río Chavón region in the south-eastern DR has a NMFZ provenance. A celt unearthed from CU (CPH22) was sourced back to the DR.

5.4. Jade provenance and implication for pre-colonial mobility networks

Museum collections of pre-colonial lithic materials, acquired in the mid to late 19th/early 20th centuries, should be an integral component of provenance research, as they contribute enormously to broaden our understanding of intra- and inter-island exchange networks and connections to the wider circum-Caribbean. The selected lithic artefacts have not been included in any previous research, but they offer a unique opportunity to study artefacts that are now rarely encountered in the archaeological record. This is in part because many of the more elaborate lithic artefacts now stored in legacy collections were accessioned outside controlled archaeological contexts and are perceived as lacking site data, despite many having clearly associated information. Thus, museum collections are a large and important body of material that has clear value and meaning.

For the last two decades Caribbean archaeologists argued for vast pre-colonial mobility and exchange networks connecting Caribbean islands to the Central – and South American mainland (Rodríguez Ramos and de Utuado, 2010; Hofman et al., 2010; Hofman and Bright, 2010; Hofman et al., 2011). The results of this research support this conclusion and indicate a complex circulation network of jade objects within the Caribbean, including sources in the northern DR, on eastern Cuba and north and south of the Motagua Fault Zone (NMFZ and SMFZ) in GM.

Two celts from DR sites record a local (CPH21) and an exotic origin (CPH20). This makes sense because sample (CPH21) found in the inland Constanza Valley in the Cordillera Central Mountains (1200 m above sea level masl) is < 150 km from the local jade source in the northern Río San Juan Complex (Schertl et al., 2012). In contrast, celt (CPH20) from the Río Chavón region on the southeast coast of Hispaniola is ~ 300 km away and easily approached by seafaring. The Late Ceramic Age Playa Grande site situated in close proximity (< 25 km) to the Río San Juan jade occurrences served as a distribution centre for ceremonial and daily goods made of jade (López Belando, 2012; López Belando, 2019). It is therefore plausible that the majority of jade objects recovered from Late Ceramic Age sites in the northern part of the DR would exhibit a local origin.

It is noteworthy to emphasize that St. Croix is not physically part of the Virgin Island group, as it is separated by a 64 km wide passage from the other islands. Nonetheless, there is no obvious difference in provenance of jade celts and bodily ornaments from St. Croix (25% GM origin) compared to St. Thomas and St. John (33% GM origin). From the Virgin Island sample set of this study there is no suggestion of inter – or intra – island change in jade provenance. Unfortunately, this preliminary study provides insufficient data to determine if jade provenance changed over time. Based on these provenance data it is impossible to comment about specific transport routes, i.e., if objects were traded and exchanged from GM through South America and then northwards up the Lesser Antilles Island arc or directly onto a Greater Antillean island (e.g., Cuba, Cayman Islands, Jamaica). Though, the Guatemalan origin of a celt from St. Vincent (CPH35) could indicate that jade from GM entered the Caribbean from the South American continent. A consensus exists among Caribbean scholars that Grenada served as an economic portal between the mainland and Lesser Antilles Islands, trading and exchanging goods even up to the Greater Antilles Islands and the Lucayan Archipelago (Hanna, 2018; Boomert and Bright, 2007; Laffoon et al., 2014; Cody, 1993; Hofman et al., 2014). However, Hatt theorised that Early Ceramic Indigenous societies on the Virgin Islands developed extensive contact with the Lesser Antilles and the South American Mainland rather than the Greater Antilles and the Lucayan Archipelago (Hatt, 1924; Hatt, 1932). Further studies are needed to assess spatial and temporal variations in provenance across the Caribbean to address these questions. Expansion of this type of study will also allow analysis of the specific mode of exchange, i.e., down the line or direct exchange between Guatemala and the Virgin Islands. Better spatial coverage is also required to develop modern models for favoured canoe routes (Slayton, 2018; Slayton et al., 2015; Slayton et al., 2017; Slayton et al., 2016; Hofman et al., 2020; Fitzpatrick, 2013; Callaghan, 2011).

The materials from which three pendants from St. Croix were made have been attributed to different geological sources. This unexpected result shows that both Antillean and Central American sources were providing jade materials. This finding contrasts with the relative homogeneity in the types and technologies used for the working of jade objects noted in the collection from St. Croix. One possible explanation for the similar treatment of artefacts whose raw materials come from different sources could be an acquisition through down-the-line exchange, in which raw source materials progressively changed hands without necessary contacts between individuals belonging to either the starting or ending nodes (Knippenberg, 2007). This would result in materials from multiple sources arriving at St. Croix, rather than people from this island travelling to collect raw materials. The selection of the raw materials to be worked would likely have been guided by their mechanical properties and other desired characteristics (e.g., colour, purity, sheen, translucency, feel) (Rodríguez Ramos et al., 2011). A similar mode of acquisition has been suggested for "greenstones" from the lapidary workshop site of Pearls in Grenada (Hofman et al., 2014; Mol, 2014); but, the acquisition of jadeitite specimens in that site seems to have followed a different mechanism (Falci, 2020; Falci et al., 2020a; Falci et al., 2020b). The small studied lapidary sample from St. Croix and the absence of contextual information, however, limit a more detailed understanding of exchange patterns.

It is notable that no jade objects are present in the lithic assemblage (a total of 50 celts, hammer stones and grinders) of the Krum Bay site on St. Thomas, which represents the only Archaic Age site (5000 to 200 BC) in the Hatt Collection. This is a significant observation and could indicate that jade objects were not exchanged and traded in the Archaic Age. Even though ornaments have been reported from Archaic Age sites in Puerto Rico, the Dominican Republic, and Cuba, none have been identified as jade until now (Rodríguez Ramos, 2010; Boomert, 2014; Moure et al., 1984). The number of ornaments of any raw materials from Archaic Age sites is noticeably lower than observed in the Ceramic Age. That said, further detailed sampling is required to validate the theory that jade material was introduced to Indigenous societies in the Ceramic Age.

6. Conclusion

The minimally-invasive laser sampling technique in combination with low blank trace elemental and isotopic analyses is shown to be capable of producing reproducible datasets for jade artefact provenance. In the case of natural occurring jade in the circum-Caribbean, TE ratios are most powerful in discriminating between sources, as IC overlap (Knaf et al., 2020). Isotopes may, however, be discriminative when applied to other types of materials, such as obsidian, nephrite jade, turquoise, amethyst, carnelian and gold present in Caribbean collections. Using a statistical predictive modelling approach, jade celts and bodily ornaments recovered from the Virgin Islands, St. Vincent, DR and CU can be sourced back to Guatemala, Cuba and the Dominican Republic. In addition, our research supports the existence of a network of jade circulation across the Caribbean Sea from sites spanning the Early – to the Late Ceramic Age. Artefacts selected for the provenance study were, however, retrieved from multi-century contexts and have poor temporal resolution. Consequently, it must be pointed out that the intensity of the exploitation of individual jade sources might have changed over time. Nonetheless, our results also provide evidence for the multiscale nature of interaction networks in the pre-Colonial Caribbean (as previously proposed (Hofman et al., 2010; Rodríguez Ramos and Pagán-Jiménez, 2006)). We have demonstrated that jade was acquired from sources at different distances. In this sense, jade circulated as part of exchanges at multiple scales: intra-island (Dominican Republic), inter-island (at both Greater Antillean and archipelago-wide levels), and pan-Caribbean (materials from Guatemala).

The collection of ornaments from the Early Ceramic Age sites of Prosperity and Sprat Hall provides insights into ornament raw materials, types, and technologies present in the northern tip of the eastern Caribbean. In contrast with the results of previous research on a collection from the site of Pearls on the southern Caribbean island of Grenada (Falci et al., 2020b), we note a restricted range of raw materials being worked. The lower amount of worked raw materials could be related to the peripheral position of the site in long-distance networks. Our results show that jade raw materials were acquired from different sources located in the Greater Antilles and Central America. Multi-scalar interactions involving the acquisition of jade can also be attested at the site level in the case of Prosperity and Sprat Hall. The lack of detailed site data and absolute dating, however, limits further detailed interpretation.The similarity in production technologies and ornament types across different materials points to a local production. This production would have taken place in St. Croix itself or in the immediately surrounding islands where lapidary workshops are known to have existed. A close connection between the Virgin Islands sites and ornament workshop sites in Puerto Rico and Vieques can be attested in raw materials (green jasper, serpentinite), technologies, and morphological types. This points to the existence of a more localized sphere of exchange that involved Puerto Rico and the neighbouring Virgin Islands.

Further extension of similarly multidisciplinary research, including more provenance data from various Caribbean islands, will offer the possibility to examine jade networks in detail and establish the modes of exchange affording material circulation, as well as more precise temporal changes in routes.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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