Introduction - The big why

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Research area: The project explores jade using cultures around the World during the Stone Age and combines researchers from areas of archaeology, archaeometry, geology, mineralogy, geochemistry and socio-economics, which is why an interdisciplinary approach is essential. All participants in the network will focus on identifying the sources, distribution of axes and using standardized comparable provenance methods.

Scientific focus: Our hypothesis is focused on investigating the emergence of value within prehistoric societies and higher ranking hierarchy together with the systematic exploitation of rare and prestigious raw materials such as jade. First we will concentrate on gaining the first world-wide overview of the jade sources and investigate when, why and how they were exploited during the prehistoric times. Secondly it is necessary to exchange geological samples and discuss which analysis methods should be used, in order to compare the provenance results on a global scale. Thirdly it is essential to compare the chemical composition of the geological samples with the archaeological assemblages of jade axes. Fourthly it is important to explore the possibilities for making some of the methods, like LC-ICP MS portable, so that it can be used on archaeological assemblages such as axes/adzes stored in countries, where borrowing samples of archaeological materials is difficult. Finally, it is of cardinal importance to discuss the heritage management of the jade sources, as some are threatened by modern exploitation despite being archaeological localities.

Geological environments that create jade (jadeite jade) and where to find them

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Jade is a term used to describe an extremely tough, essentially monomineralic, rock used as a tool stone and for higher value worked objects. Jadeite, $NaAlSi_2O_6$, makes up an important variety of jade, known by the rock name jadeitite. Jadeite is conspicuously dense for a sodium aluminosilicate and requires conditions of high pressure at modest temperature to form. Such conditions only occur where Earth's oceanic plates converge and dive (are subducted) beneath island chains (island arcs) and continental margins. All jadeitite deposits are found where such convergent boundaries have been unearthed. Jadeitite is extremely rare, so finding other indicators of convergent boundaries and rocks associated with jadeitite is a profitable strategy for finding jade deposits. Jadeitite forms from deep hydrous fluids that also react with Earth's mantle, which is composed of very magnesian rock (peridotite). The product is serpentinite, a rock dominated by serpentine, particularly the mineral antigorite ($Mg_3Si_2O_5(OH)_4$. Jade is always found in the context of much larger amounts of antigorite serpentinite. Other rocks formed at high pressure by subduction include blueschist (named for the blue amphibole glaucophane) and eclogite (green and red garnet omphacite rock). These rocks are also more abundant than jade, so, are important indicators.

X-Ray Diffraction on jade - possibilities and limits

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Rocks are in a great majority of cases made of crystalline minerals. This is the case also with jade, a stone preferred for the preparation of stone axes. The method predominantly used for the identification and characterisation of crystalline substances is the X-Ray Diffraction (XRD). As rocks are polycrystalline and typically multi-mineral materials, the XRD technique used for their characterisation is Powder XRD (PXRD) for which the material is grinded to a fine powder to assure a statistical orientation of crystals in a sample, necessary for a reproducible result. For the analysis of valuable objects, extracting of a part for analysis is not possible and instead the stone axis has to be inserted in the instrument if possible. Many rocks do not satisfy the requirements of an ideal powder sample and would give poor data, but the jade and some other rocks used for stone axes do have characteristics that give usable results. We shall present the challenges of this technique and illustrate them through analyses of selected stone axes and jade rocks from Syros and North Italy.

Fingerprinting the provenance of Jade axes through in-situ laser ablation ICPMS and SEM geochemical analyses

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Laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) and Scanning electron microscopy (SEM) is analytical techniques typically used to obtain chemical information on a micrometre scale of the materials being analyzed. For jade axes, LA-ICPMS and SEM can be used to get detailed information of e.g. rock chemistry, mineralogy, and geological age. This information can help fingerprint the provenance of the axes, and thus to identify axe manufacturing source regions (or indicate potential unknown sources), and in turn, prehistoric meeting places and exchange networks, trading paths and routinization of pathways within jade exploiting cultures. We present here a combined SEM and LA-ICPMS analytical approach that can help further progress in the study of provenance of ancient jade axes.
Chemical characterization of the jade axes and rock chips from known jadeite quarry localities using a SEM mineralogy mapping approach provides information about the mineral distribution and mineral proportion in the axe rock material. Such mineral maps can also be used to analyze (by LA-ICPMS) the minerals jadeite and omphacite (sensu lato) for their trace element chemistry, and to locate and date minerals like zircon, titanite and apatite by U-Pb geochronology. Combining the information obtained from the SEM and LA-ICPMS constitutes a powerful mineralogical, elemental, and isotopic data set that can be used to improve the provenance fingerprinting of the jade axes.
In this on-going study, we are using this analytical approach to characterize jade axes bought by a private Danish collector in 1887 as well as jadeite-bearing rock material collected from their potential exploiting source localities. For Europe, jadeite source quarry sites for axe manufacturing are relatively few, occurring only in Greece, the Alps, the Ural Mountains and in Iran. Data is thus acquired from these potential source locations and compared to data obtained on jade axes from the Aegean region. Further details of the approach and some preliminary results are presented at the meeting.
To further constrain the geographical origin of the jade axes, the mineral-chemistry data obtained by this analytical approach can potentially also be used for P-T thermodynamic calculations or single mineralogy geothermobarometry (e.g. phengite) occurring in the jadeite-bearing rocks.

Geochemical characterisation of circum-caribbean jadeitite sources: implications for provenance studies

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Jadeitite was used for tools and adornments throughout the Greater Caribbean since initial inhabitation. Regionally, jadeitite sources are only known in Guatemala, north and south of the Motagua Fault Zone (GM, NMFZ and SMFZ), eastern Cuba (CU) and the northern Dominican Republic (DR). The distribution of jadeitite artefacts establishes exchange and transport over vast distances and provides fundamental information about former trading and mobility networks between different islands and the mainland. Despite general geological similarities among the jadeitite source rocks, different ages, protoliths, P-T conditions of jadeite formation and (re-)mobilization of different fluid compositions offer the potential to geochemically discriminate the sources. Parent-daughter isotope ratios in the source rocks are, however, variable such that the Sr-, Pb- and Nd-isotope ratios of the source rocks generally overlap. Different trace element compositions are preserved apparently due to regional differences in metamorphic fluids. This study reports a rigorous statistical analysis to assess the ability to geochemical fingerprint Caribbean precolonial lithic artefacts, thereby providing a provenancing method to quantify regional exchange networks. The first approach was to assess 3 jadeitite source regions (DR, CU, GM) based on trace element ratios and isotopic compositions and subsequently see if it was possible to resolve 4 (DR, CU, GM NMFZ, GM SMFZ). The results of the statistical algorithm establish that there is > 95% discrimination between the 3 and 4 source. The technique can therefore be applied to artefacts of jadeititic composition of unknown provenance in the Greater Caribbean.

Jade artefacts in the Hatt Collection

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In the Hatt Collection, held at the National Museum of Denmark, a large number of suspected jade artefacts from the pre-Columbian Caribbean Islands was tentatively identified in 2012. This was significant, as no jade sources were known on the Virgin Islands from where the majority of the jade artefacts had been excavated. At the time, no well substantiated theory existed about the possible trade or exchange routes that brought these jade artefacts to Virgin Islands, but as jade is a rare resource it could possibly be used to establish a well-argued theory on the pre-Columbian jade trade or exchange routes over a diachronic time-frame.
A few jade resource areas were known in the Caribbean Area in 2012, these were: The Motagua Fault-line in Guatemala, the Rio San Juan Valley in northern Dominican Republic and the Sierra del Convento mélange in eastern Cuba, approximately: 3000, 600 and 1000 km away from the Virgin Islands respectively. A visual examination by geologist Peter Toft and archaeologist Lasse Sørensen in early 2016 enhanced the suspicion that a significant proportion of especially the stone axes in the Hatt Collection had been made out of jade. The theory was further strengthened in mid-2016 when geologist Michel Errera and archaeologist Pierre Petrequin used Raman Spectroscopy on 42 artefacts and identified 10 of these as either possibly, probably or positively jade artefacts. However, Raman spectroscopy is a form of remote sensing and just as visual examination not conclusive proof of the jade nature of the artefacts. Thus, a collaboration with the NEXUS 1492 project was established in 2017, as a sub-project in NEXUS 1492 sought to develop a portable Laser Ablation sampling method (pLA) using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). An initial sampling of 36 axes or pendants was conducted using pLA after an initial visual examination of several hundreds of rock artefacts to exclude non-jade artefacts.
The results thus far have shown that no jade artefacts can be proven in the Archaic period (2000 B.C. to ca. 1 A.D.) in the Hatt Collection, but from the latest phase of the Saladoid period (500 B.C. to 600/850 A.D) and the earliest phase of the Ostionoid period (600/850 A.D. to 1500 A.D) jade artefacts are relatively common either in the form of thick-butted petaloid shaped axes, short thick-butted petaloid axes, petaloid axes reused as hammerstones or grinders, or more rarely as nephrite looking jade pendants. It is also interesting that there is a high degree of uniformity shape wise among the sampled jade axes in the Hatt Collection without consideration to their excavation location: being it either in Cuba in the west, the Virgin Islands in the northeast or St. Vincent in the southeast of the Caribbean Islands. This could indicate a common source area of the thick-butted petaloid jade axes, where Cuba and Dominican Republic are considered less likely, as the jade sources on these two Islands where outside or in the periphery of the transitional phase between the Saladoid and Ostionoid Cultures. Thus, the farthest away jade source in Guatemala is presently considered more

likely with regards to axes. Whereas comparable jade pendants in other collections and Museums appear to be concentrated around the Guyana's area in north-eastern South America, which could indicate a possible fifth presently unknown jade source area.
Finally, the pLA and ICP-MS analysis methods can possibly also be used to establish a kind of "finger-print" of source rock material, if this proves to be the case, then the certainty of the previous results and conclusion will be further enhanced and the diachronic long-distance mobility of the Amerindians of the Saladoid and Ostionoid periods will be much better understood.

Provenance analyses of raw materials from Çukuriçi Höyük, Western Anatolia

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Çukuriçi Höyük is a multi-phased prehistoric site situated at the central Aegean coast of Anatolia. The settlements have been inhabited in Neolithic, Late Chalcolithic and Early Bronze Age 1 periods, covering a time from early 7th to the early 3rd millennium BC.
The lithic assemblages from Çukuriçi Höyük consist of a considerable variety of small finds, grinding stones as well as chipped stone tools. The high variability of raw materials within the categories of tools is remarkable. Beside tools manufactured of rocks from sources in the immediate vicinity of the settlement (i.e. mica-schist, limestone, marble, amphibolite, serpentinite) others are produced of rock types which indicate a regional origin like grinding stones or chipped stone tools made of chert. Moreover, the supra-regional procurement of a distinct rock type is attested by the exceptional high amount of Melian obsidian found at Çukuriçi Höyük. These far-reaching procurement strategies are also indicated by small stone axes presumably made of jadeite from the Greek island of Syros. Further analyses of these axes are planned.
The interdisciplinary study of the excavated stones with various methods (i.e. thin section analyses, XRF, NAA, LA-ICP-MS) offers new primary data about the procurement strategies of prehistoric societies in diachronic perspective illustrating the high efforts were undertaken to supply the settlement with carefully selected raw materials or finished goods procured from distinct rock sources as early as the Neolithic period

Jadeitite occurrences in Syros island, Aegean Sea, Greece: Petrographic remarks and implications for early exploitation

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During the Neolithic age jadeite was used in most European countries, primarily for axes, scrapers and weapons. There is clear archaeological evidence that Europeans were the first to do so. The largest known jadeite source in the Aegean is located on the Cycladic island of Syros, mainly at Kefalos hill and Kampos area. They are found in the form of isolated jadeitite blocks in metamorphosed basic and ultrabasic lithologies. We have collected samples from Kampos area, which have been studied by optical microscopy and analyzed by the X-Ray Diffraction method. All examined samples display common petrographic characteristics: Their texture is granoblastic/lepidoblastic and they comprise prismatic crystals of jadeite and omphacite. Minor chlorite or amphibole (actinolite), especially in the periphery of the pyroxene crystals, or along cleavage plains were also observed. Other phases include feldspar (albite), titanite (locally including jadeite and omphacite), epidote and minor zircon, white mica and opaque phases (rutile). The strong bonding of the crystals of the studied jadeitites give the rock a characteristic resistance, while their hardness allows relatively easy processing for curving useful items (e.g. axes). This fact along with the discovery of man-crafted stone relicts in the Kampos area, indicates that Syros was an important jadeitite producer during the Neolithic period.

Jade and jadeite in Turkey

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Jadeite is a rare mineral, which occurs in eclogite and blueschist facies, high pressure – low temperature metamorphic rocks. A wide variety of eclogite and blueschist facies rocks crop out in Turkey with documented metamorphic ages of Neoproterozoic, Triassic, Early and Late Cretaceous and Eocene. Among these high pressure, metamorphic belts, the largest and best preserved is the Tavşanlı Zone, which includes both continental and oceanic sequences metamorphosed under blueschist and eclogite facies conditions during the Late Cretaceous (ca. 80 Ma). The metamorphism was related to subduction of a passive continental margin in an intra-oceanic subduction zone.
Jadeite and jadeites occur mainly within the metamorphosed continental sequences of the Tavşanlı Zone. At the base of the continental sequence, called the Orhaneli Unit, there is a micaschist series, over 1000 m in structural thickness. Clastic zircon ages indicate a Triassic and younger depositional age for the micaschists. In the western part of the Tavşanlı Zone, the micaschists contain regionally distributed jadeite, which coexists with chloritoid, glaucophane, lawsonite and quartz giving metamorphic P-T conditions of 24 kbar and 450° C. Metaaplitic veins of unknown age, a few tens of centimeters thick, cut the micaschists and are made up of quartz and jadeite. The micaschists also contain Ordovician metagranitic bodies, several hundred meters large, consisting mainly of jadeite and quartz.
Jadeite is rare in the oceanic crustal lithologies of the Tavşanlı Zone due to unfavorable rock composition. The bulk of the oceanic crustal rocks are represented by sodic amphibole and lawsonite assemblages. Jadeite is restricted to the few acidic metavolcanic rocks, which consist of quartz, jadeite and minor lawsonite. Jadeite in these rocks makes up over half of the rock.
Apparently the only "jade" occurrence in Anatolia is the purple jade from northwest Turkey. It is a fine-grained phonolite, metamorphosed in blueschist facies. Some of the primary magmatic minerals, including aegerine, and magmatic textures, including the outlines of former nepheline crystals, are preserved. The blueschist facies mineral assemblage is represented by jadeite, lawsonite and K-feldspar giving metamorphic P-T estimates of 8 kbar and 300° C. Jadeite usually makes over half of the rock and occurs both as individual grains and as overgrowths on the magmatic aegerine. The purple jade is found as loose blocks in the late Tertiary continental sedimentary rocks. The jade blocks, along with blocks of serpentinite, were brought to the basin by rock avalanches.

The Polished Stone Axes, Adzes and Chisels , “In Izmir’s Prehistoric Settlement Area-Yeşilova Höyük”

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The Yeşilova Höyük is under a thick alluvium layer in the middle of the Bornova Plain in Izmir. It is known that many different cultures lived within the Yeşilova Höyük spreading area from the Neolithic Age to the Roman Period. First settlements in the Höyük began during the Neolithic Age, at least 8-9 thousand years before our time. The 4rd layer is the longest standing and thickest cultural layer of the Yesilova Höyük. Usually stone and pottery workshops were discovered in the structures. We can be see important elements of daily life such as stone workshops that were used for making axes from stones. The Neolithic community of Yeşilova employed a wide variety of rock types (Serpentinite, Gabbro, Basalt, Hematite, Andesite…) for their stone tool technology. The evidence from the Neolithic site of Yeşilova are important technological and social significance of stone tools and related edge tools in Western Anatolia. The Yeşilova tools material characterization and raw materials reveal that these were far from mundane artefacts.

Preliminary notes on the prehistoric marble and magnesite bracelet-bangle production in Anatolia

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In Turkey, bracelet finds from Chalcolithic and Neolithic sites made from different metamorphic and sedimentary rocks are ample. However, studies on their raw material preferences, their typology and their possible quarry localities are not. Here we try to give some preliminary notes on the production scale, typo-technological and typo-chronological details on bracelet and bangle finds obtained from the prehistoric site of Kanlıtaş near Eskişehir, Turkey. Kanlıtaş mound is a Chalcolithic settlement dating between 5700- 5000 BC. The site has an intensified activity with traces of marble and magnesite bracelet, armlet and bead production reflecting a specialised settlement on these end products. The location of the site is intentionally chosen to be near to the geological marble and magnesite outcrops in the vicinity.
Keywords: Chalcolithic Anatolia, Kanlıtaş Höyük, bracelets, armlets, prehistoric marble, magnesite production.

Asian jade sources: Petrological diversity of jadeite jade

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It has been well known that a jadeitite (jadeite jade) culture existed in a variety of places in prehistoric Japan. Jadeitite artifacts have been found at numerous tumuli from the middle Jōmon period (~5000–3500 BSE) up to the Kofun period (~250–400 CE). The beauty and preciousness of gem-quality, semi-translucent varieties of jadeitites led to the recent designation of jadeitite as the national stone of Japan. Also the jadeitite known as 'feicui' from Myanmar has begun to attract the wealthy families of the Qin Dynasty in the late nineteenth century of China, and some jadeitite in the present-day Chinese gem and jewelry market are more precious and valuable than diamond.

Localities of jadeitite, consisting of jadeiteic clinopyroxene (NaAlSi2O6), have been reported in Phanerozoic orogenic belts in Central Asia (Kazakhstan and Central Russia), Southwest Asia (Myanmar), and Northeast Asia (Japan and Far East Russia). All localities are situated in serpentinite-dominant geotectonic unit or body. Because of the rarity of jadeitite, petrological and mineralogical features in each locality might help to explore the provenance of archaeological artifacts. In this contribution, we provide an overview of Asian jadeitite; in particular we focus on petrological diversity of jadeitite in Japan.

The exchange and use of jadeitite jade in prehistoric Japan

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Jadeitite was a highly valued lithic resource among hunter-gatherer communities during the Jōmon period in Japan. Its source, Itoigawa in Niigata prefecture on the Japan Sea Coast, was discovered by 6000BP; finished objects circulated outside of the immediate source area by 5500BP. These jadeitite objects, characterized by a drilled hole, are defined as "pendants" or "beads"; their use is regarded as prestigious and/or magic ornaments, worn by leaders or shamans.
However, this presentation will discuss the regional and temporal variability in function and social value of Jōmon jades, arguing that even within a certain phase and/or regional cultural sphere, such interpretations may be overly concentrated on 1) a specific type; 2) discoveries from mortuary contexts, 3) assumptions of a universal and singular use. Nevertheless, during the later phases, jadeitite may have played a role in (slightly) increasing social differentiation.
Although the circulation of jadeitite objects eventually spread throughout Jōmon Japan (including isolated islands from Hokkaidō to the Ryūkyū Islands) by 3000BP, neither raw material nor finished goods reached the continent. Thus, exchange networks involving jadeitite did not incorporate contemporaneous communities in the Korean Peninsula; and among the more socially complex Neolithic cultures in China, nephrite jade already fulfilled the role of highly valued ornaments and symbolic objects.
While nephrite also occurs in Japan, during the Jōmon it was used for (functional) polished axes, as recent research by Iizuka has demonstrated.

Non-invasive mineralogical study of nephrite jade objects in Southeast Asian prehistory:
Implication for jade exchange network and their sources.

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Nephritic jade artifacts are commonly found in prehistoric sites in East and Southeast Asia. Since nephrite deposits only occur rarely in nature, geochemical and mineralogical analysis are available to use for sourcing of specific quarries. Both portable XRF and low-vacuum (LV) type SEM-EDS are powerful and non-invasive (completely non-destructive) to study for stone artifacts. The p-XRF is handy and suitable to material identification, and the LV-SEM-EDS technique can be used not only for sample surface observation, but also workable to quantitative analysis for precious artifacts. These techniques combined with EPMA (electron microprobe) method for natural rocks are applying to prehistoric jade objects in Taiwan and Southeast Asia. Significantly, results indicate that Taiwan (Fengtian) nephrites were transport to islands of the Philippines in Neolithic, and were still carried to western Borneo, central-southern Vietnam and the Peninsula Thailand in their Metal Age. And results are also suggested that some potential nephrite sources have existed in the Mainland Southeast Asia.

Geological sourcing, Nephrite jade, p-XRF, SEM-EDS, Non-invasive analysis, Southeast Asia

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A Nephrite jade – prehistoric timescale

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The presentation investigates different nephrite sources and exploitation on a global scale.