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Research Article

Characteristics of Jet in Phu Quoc island, Kien Giang province, Viet Nam

Le Ngoc Nang[1,2,*], Nguyen Thanh Tri[2], Lam Vinh Phat[2], Le Huu Tuan[1], Pham Minh Tien[2]

ABSTRACT

Jet is a special case of fossilized wood found in the northwest of Phu Quoc Island. By applying standard gemological methods and advanced analysis, including EDS, Raman, and FTIR spectroscopy, this paper aims to determine the identifying characteristics and gem quality of the jet from Phu Quoc Island for jewelry manufacturing. Jets from Phu Quoc display a gorgeous black color, opaque appearance, black streak, greasy to subvitreous luster, and a glossy fracture. The measured gemological indices include specific gravity - 1.24; refractive index - 1.66; inert under UV light; and isotropic. The deformed wood grain texture is visible under a microscope (400x and 100x). Chemical compositions are mainly carbon, oxygen, hydrogen, and nitrogen using EDS and Raman Spectroscopy. FTIR diagrams indicate that jet samples originated from the deformation of organic material, such as an ancient tree, with distinctive peaks at 2900 cm-1 (C-H), 1640 cm-1 (C-C), and 1200 cm-1 (C-O). The results show that the Phu Quoc jet is classified as a saltwater jet or hard jet. Hence, the jet from Phu Quoc is of good quality to be made into valuable ornaments and pieces of jewelry.

Key words: Jet, Phu Quoc, hard jet, organic gemstone, characteristics

INTRODUCTION

Jet is known as a black or brown organic material fossilized from the trunk of ancient trees. Commonly, people use this material as a gemstone for jewelry and ornamental pieces[1,2]. All over the world, sources of jets are mainly found in England with the famous Whitby jet[3], followed by Turkey with the Oltu Stone jet (natural black carbon)[4] and some other nations, including Russia (Tumble jet), France, Germany, and Spain. However, jet mining in these countries has been restricted and no longer exploited due to the depletion of jet products. In the late 18th century, the Vietnamese jet from Phu Quoc Island was extracted through open pits, as recorded by My and Linh, 2005[5]. Between 2017 and 2018, the jet from Phu Quoc was exposed greatly at 15 to 20 m depth and accumulated in Neogene sandstone at some construction sites in Phu Quoc (Figure 2A). These new outcrops were estimated to have considerable reserves with relatively good quality. However, the Phu Quoc jet has yet to be described in detail and evaluated scientifically, especially in terms of gemology. This article focuses on the characteristics and gemstone quality of the Phu Quoc jet to clarify the potential value of this distinctive organic gemstone.

LOCATION

Phu Quoc Island is situated in southwestern Vietnam, approximately 45 kilometers west of Ha Tien city. The entire area of the island is 124 km^2. The terrain is mainly mountains, with the highest peak at 607 m above the mean sea level. The research location is distributed in the northern part of the island, where the transportation system is accessible (Figure 1).

GEOLOGICAL SETTINGS

The geological formation of Phu Quoc Island is mostly sandstone, siltstone, sand, and silt that occurred from the Neogene to Quaternary periods (Figure 3). The Neogene sedimentary formations include two sections: the lower part is conglomerate interbedded with sandstone and gray–green siltstone, distributed on the eastern margin of the island, and the upper part is jet-bearing quartz sandstone with a cross-bedding structure, covering most of the northern Phu Quoc island, and is unconformably overlain by Holocene sediments[7,8] (Figure 2B and Figure 2C). The Phu Quoc jet is found as a slab form in the north center of the island, positioned in gray to whitish-gray and small to medium-grained sandstone[5]. In particular, the jet-bearing sandstone is situated at a depth of approximately 15-20 m and is approximately 30 m thick. The composition of the jet-bearing sedimentary rocks under the microscope is quartz sandstone with >90%

[1]*University of Science, Viet Nam National University Ho Chi Minh City*

[2]*LIU Gemological Research and Application Center*

Correspondence

Le Ngoc Nang, University of Science, Viet Nam National University Ho Chi Minh City

LIU Gemological Research and Application Center

Email: nang@liulab.edu.vn

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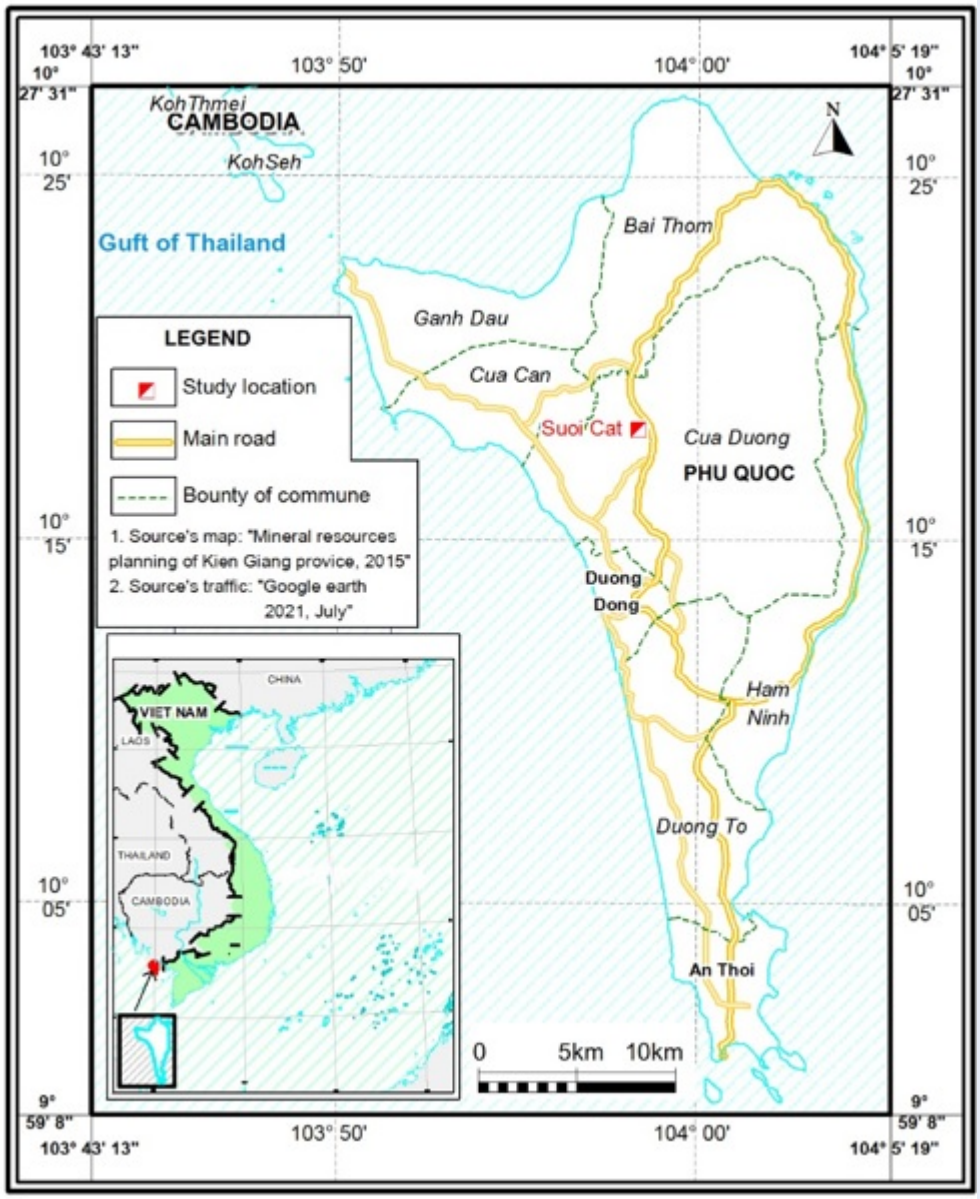

Figure 1: The study location is in the north-center of Phu Quoc Island. Prepared by Nguyen Thanh Tri (after Mineral Resources Planning of Kien Giang, 2015 and Google Earth, July 2021)

quartz and <10% cement (sericized clay minerals).

MATERIALS AND METHODS

After collecting several specimens, we selected 12 samples for gemological analysis and quality evaluation. The samples were described, processed, and prepared properly for testing (Figure 4 and Table 1). The size of each specimen ranged from 2 to 20 centimeters, approximately a few grams to more than a kilogram. We chose five raw samples with a homogenous color and less fracture. Six finished lapidary samples were worked at the Liu Gemological Research and Application Center, including 01 Buddha sculptures, 01 beaded bracelets, 02 small carvings, and 02 cabochons (Table 1). For structure and petrological analysis, we prepared a sample to process a thin section at the University of Science. The advanced methods were conducted at the Institute of Chemical Technology — Vietnam Academy of Science and Technology. We observed and described all samples before and after processing under a daylight bulb. We also identified the specimens' specific gravity and refractive in-

Figure 2: The research areas are located in a building stone quarry, where the authors found jets in splitting boulders (A). Veins of black jet are hosted in sandstone (B). Jet deposits in a split-open boulder (C). Photos by Le Ngoc Nang and Lam Vinh Phat [6].

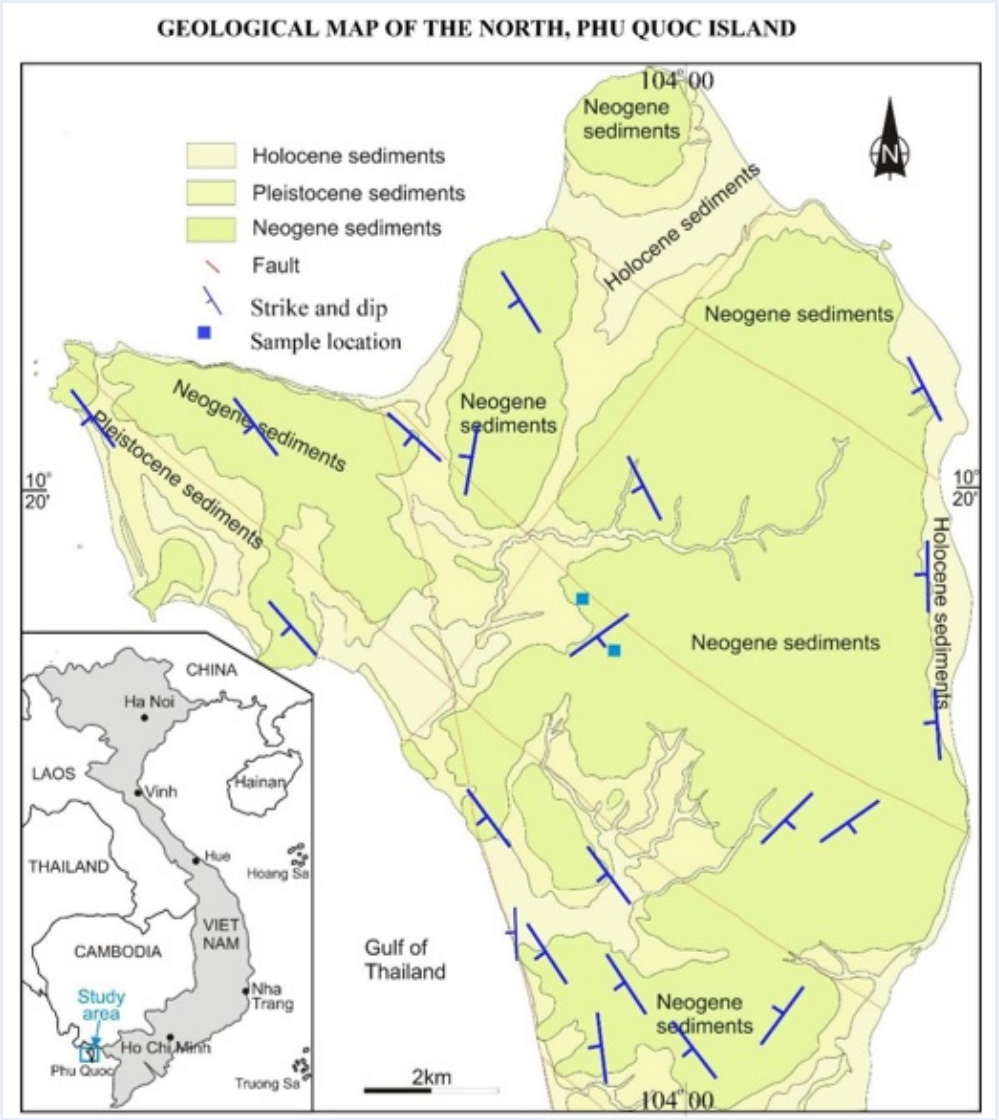

Figure 3: The geological map of northern Phu Quoc Island includes sedimentary formations of the Neogene and Quaternary periods. Made by Truong Cong Duong *et al.*, (1998). Modified by Le Huu Tuan (2021) [7].

Figure 4: Jet samples taken from Phu Quoc Island and processed in Ho Chi Minh city: raw samples (J-P01 to J-P03 & J-P10, J-P11), carved samples (J-P04, J-P05 & J-P09), cabochons (J-P06 & J-P07), a beaded bracelet (J-P08), and a thin section (J-P12). Photos by Pham Minh Tien

dex by the hydrostatic weighing system and a standard gemological refractometer, respectively. Fluorescence was observed under longwave (LW-365 nm) and shortwave (SW-254 nm) ultraviolet light (UV). Texture and inclusion features were determined using a gemological microscope and a polarizing microscope.

Fourier transform infrared spectroscopy (FTIR) analysis, which detected the vibrational points of chemical bonds in terms of elements, was conducted by a Bruker Tensor 27. Spectral range 4000 – 400 cm^{-1}. Resolution 1 cm^{-1} Scanning time 3. Scanning speed 3 velocities, 2.2 – 20 kHz (1.4 – 12.7 mm/sec OPD). Samples compressed with KBr.

All gemological experiments and FTIR spectroscopy were performed and recorded at the Liu Gemological Research and Application Center.

Energy dispersive X-ray spectroscopy (EDS) and Raman spectroscopy analyses were employed to detect the existence of major elements such as C, O, N, and metal elements. The EDS method was operated by a JEOL JSM-IT200 device, with a magnification of 500x, live time of 30 s, and count rate of 885.00 cps. Raman spectroscopy was performed on an Xplora One instrument in the range of 0 - 3750 cm^{-1} with *an a*cquisition time of 15 s, 2 accumulations changing, laser lines at 532 nm, Spectro 1991.53 cm^{-1}, using 900 g/mm grating, 50x objective, filter 50%. EDS and Raman spectroscopy were implemented at the Institute of Chemical Technology — Vietnam Academy of Science and Technology.

RESULTS

Appearance

The jets were pure black under daylight bulb, opaque, had greasy to subvitreous luster, and a black streak. Raw materials generally had tabular form, whose size varied from a few centimeters up to 30 centimeters.

Gemological properties

The gemological properties of the Phu Quoc jet are shown in Table 2 as follows:

Refractive Index (RI): eight samples measured by the refractometer showed single refraction (represented isotropic material). The highest index of 1.67, the lowest index of 1.65, and average index of 1.66 (Table 2) are consistent with the RIs of the jet [1,9].

Specific gravity (SG): Using the hydrostatic weighing method, SGs recorded for six samples were 1.21, 1.25, and 1.24 for the lowest, highest, and average, respectively (Table 2). The SGs of the samples are within the range of jets [1,9].

Optical properties: Observing thin sections of sample J-P12 under the polarizing microscope showed that the jet is isotropic [1].

Structure: Under 400X magnification of the polarizing microscope, innumerable distorted oval shapes

Table 1: The parameters and physical appearance of Phu Quoc jet

No.	Sample	Weight	Size (cm)	Shape	Color	Transparency	Luster
1	J-P01	515 g	20.0-9.0x3.5	Tabular	Black	Opaque	Greasy
2	J-P02	223.79cts	7.5-4.0x2.0	Tabular	Black	Opaque	subvitreous
3	J-P03	271.94cts	6.0-5.5x3.0	Tabular	Black	Opaque	subvitreous
4	J-P04	40.53cts	3.6-2.6x1.2	Buddha sculpture	Black	Opaque	subvitreous
5	J-P05	29.88cts	3.5-2.4x0.8	Bodhisattva sculpture	Black	Opaque	subvitreous
6	J-P06	11.48cts	1.9-1.2x0.9	Round -cabochon	Black	Opaque	subvitreous
7	J-P07	2.19cts	1.2-0.9x0.4	Oval - cabochon	Black	Opaque	subvitreous
8	J-P08	80.45cts	0.8 (diameter)	Beaded bracelet	Black	Opaque	subvitreous
9	J-P09	720 g	19.0-18.0x4.0	Buddha sculpture	Black	Opaque	Greasy
10	J-P10	298 g	-	Tabular	Black	Opaque	Greasy
11	J-P11	301 g	9.0-8.0x5.5	Mass	Black	Opaque	Greasy
12	J-P12	-	-	Slice	Brown	Translucent	Greasy

of wood cells were compressed extensively (Figure 5-left). While determined by the gemological microscope at 100X magnification, thousands of directional xylem tissues were packed together (Figure 5-right).

Analysis of EDS

Six measured points were selected. According to the analyzed data, the jet composition mainly contained carbon and oxygen. Specifically, the percentage by mass of carbon fluctuated from 82.47 to 84.16% and oxygen from 15.84 to 17.53%, while the atomic percentage of carbon and oxygen ranged from 86.24-87.62% and 12.38-13.76%, respectively (Table 3). Meanwhile, hydrogen and nitrogen were missing due to the limit of detection (Figure 6).

Raman spectroscopy

The results given by Raman analysis presented some typical absorption peaks in the spectral range from 1200 to 2000 cm^{-1}. Those peaks in particular were 1372, 1440, 1598 and 1793 cm^{-1} (Figure 7).

FTIR analysis

Statistics recorded by FTIR spectroscopy indicated significant absorption peaks including 1118, 1384, 1458, 1620, 2338, 2360, 2866, 2923, 3445, 3674, 3749 and 3839 cm^{-1} (Figure 8).

DISCUSSION

Characteristics of the appearance, gemological properties, and microscopic features

The appearance features of some Phu Quoc jet specimens, such as plant traces of bark, knot, and wood grain, were relatively well preserved. However, most of the Phu Quoc jets suffered from high pressure and high temperature over very long geological periods, and these primary features were no longer recognizable. Therefore, the remaining physical form and traces on the jet's surface are insufficient to determine the initial plant species.

The essential gemological properties for jet identification include the refractive index, specific gravity, and optical properties [1,9]. However, when compared to the others, such as the Whitby jet (England) (SG 1.32) and Oltu stone jet (Turkey) (SG 1.30) [12,13], the specific gravity of the Phu Quoc jet was much lower (average SG 1.24). This low specific gravity is explained by the pure, homogenous composition of the Phu Quoc jet without the heavy impurity of other elements such as silicon, iron, and sulfur.

Under the magnification of 100X on the raw surface and 400X on the 0.3 μm polished thin section, the

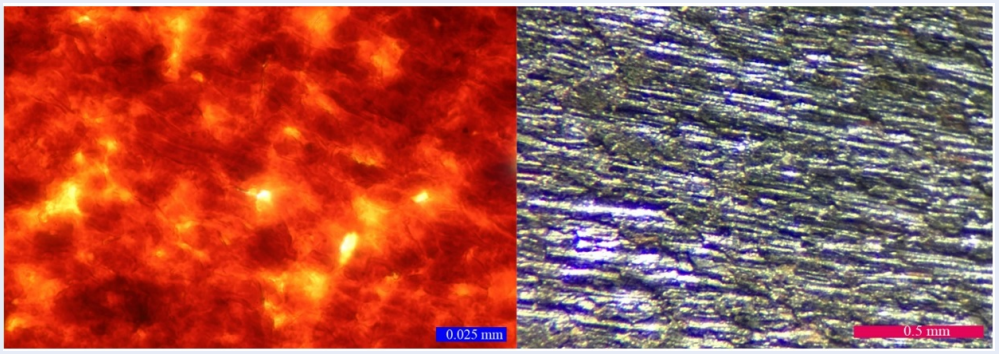

Figure 5: Microscopic structure of the Phu Quoc jet. The compressed wood cells, magnification of 400X (left). The packed xylem tissues, magnification of 100X (right). Photomicrographs by Le Ngoc Nang

Table 2: The gemological properties and structures of jet samples taken from Phu Quoc

No.	Sample	RI	SG	Structure	Micro-Structure (Magnification of 100x and 400x)	Optical properties
1	J-P01	-	-	Woodgrain structure and traces of wood bark present on the rough surface.	In the woodgrains, vascular bundles of xylem tissues connect continuously	Not available
2	J-P02	1.66	1.25			
3	J-P03	1.665	1.24			
4	J-P04	1.66	1.21	Not available		
5	J-P05	1.65	1.24	(Polished, the structure is faded)		
6	J-P06	1.67	1.24			
7	J-P07	1.66	1.25			
8	J-P08	-	-			
9	J-P09	1.65	-	Woodgrain structure and traces of wood bark present on the rough surface.		
10	J-P10	1.66	-			
11	J-P11	-	-			
12	J-P12	-	-	Not available	Wood cells	Isotropic

structure of wood cells and xylem tissues is visibly observed [14]. This structure is critical evidence that the jet is fossilized from woody material, different from coal or black carbon [3].

Chemical elements

The elemental composition of the Phu Quoc jet was determined using EDS (quantitative) and Raman (qualitative) methods. The EDS analysis only determined two elements, carbon and oxygen, without detecting metal elements, neither hydrogen nor nitrogen, because of the detection limit. For Raman spectroscopy, Figure 7 illustrates the absorption peaks of the Phu Quoc jet positioned at 1372 cm-1 for CH_3, 1440 cm-1 for N=N bonds, 1598 cm-1 for C-C bonds, and 1793 cm-1 for C=O bonds [10,11]. Combining both methods concludes that carbon, oxygen, hydrogen, and nitrogen are the four main fundamental elements

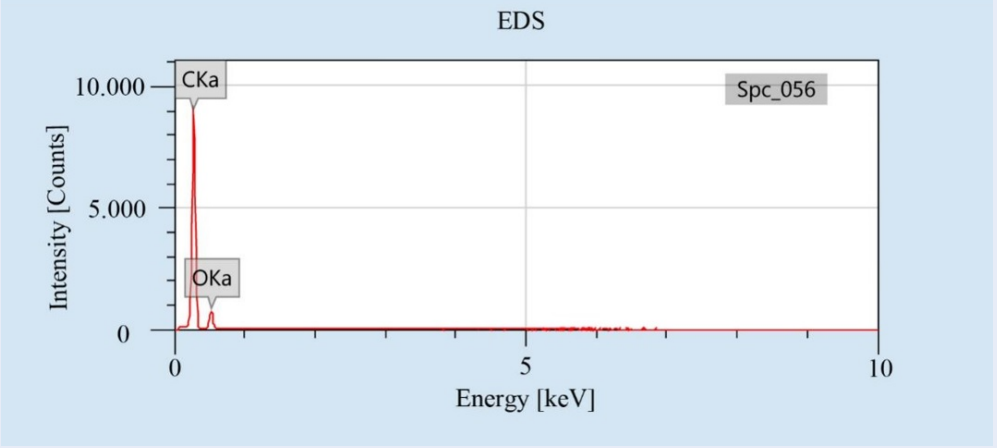

Figure 6: The EDS features at the measured point (No. 56) only exhibit two peaks of carbon and oxygen.

Table 3: Element composition of Phu Quoc jet determined by EDS

Measured point	Composition			
	Mass (wt%)		Atoms (at%)	
	Carbon	Oxygen	Carbon	Oxygen
56	83.28±0.20	16.72±0.25	86.91±0.21	13.09±0.19
57	84.16±0.21	15.84±0.26	87.62±0.22	12.38±0.20
58	84.05±0.22	15,95±0.26	87.53±0.22	12.47±0.21
59	84.03±0.25	15.97±0.30	87.51±0.26	12.49±0.24
60	83.31±0.21	16.69±0.26	86.92±0.22	13.08±0.20
61	82.47±0.21	17.53±0.27	86.24±0.22	13.76±0.21

of the Phu Quoc jet, as well as the ancient wood. Indeed, the transition from wood into jet is caused by geological compression and temperature for a long time, which modifies the chemical bonds from organic to inorganic bonds[3].

Additionally, neither method can detect other elements, such as silicon and sulfur, although these elements commonly exist in almost any jet in the world with considerable content[15]. The depositional environment is responsible for the amount of silicon and sulfur in the jet during formation. As a result, the absence of silicon and sulfur in the Phu Quoc jet claims that its forming environment is distinct and different from other jets[16]. This environment results in the purity and uniformity of the jet's appearance and composition, increasing the durability of materials. These significant factors make the Phu Quoc jet suitable for general use in jewelry.

FTIR analysis

The absorption features depicted in Figure 8 show various bonds of carbon, oxygen, and hydrogen. First, the 2900 cm^{-1} region recorded a pair of strong bands at 2923 cm^{-1} and 2861 cm^{-1}, assigned to C-H stretching. Second, the absorption of free O-H content was relatively weak at peaks 3674, 3749, and 3839 cm^{-1}. Third, two strong bands at 2361 cm^{-1} and 2338 cm^{-1} were related to the double bonds of carbon dioxide (O=C=O). All bands mentioned above are associated with organic compounds, which confirms the origin of the jet, which is derived from wood materials[14]. Furthermore, we observed a broad band centered at 3445 cm^{-1} due to the stretching vibration mode of N-H, indicating a saltwater environment[17]. This feature explains the fossilized condition of the Phu Quoc jet in saltwater. Technically, the jet deposited in this environment is called a hard jet[4].

Quality. The quality standard of the Phu Quoc jet to be used as a gem material is evaluated based on the criteria of homogenous color, free of fracture, uni-

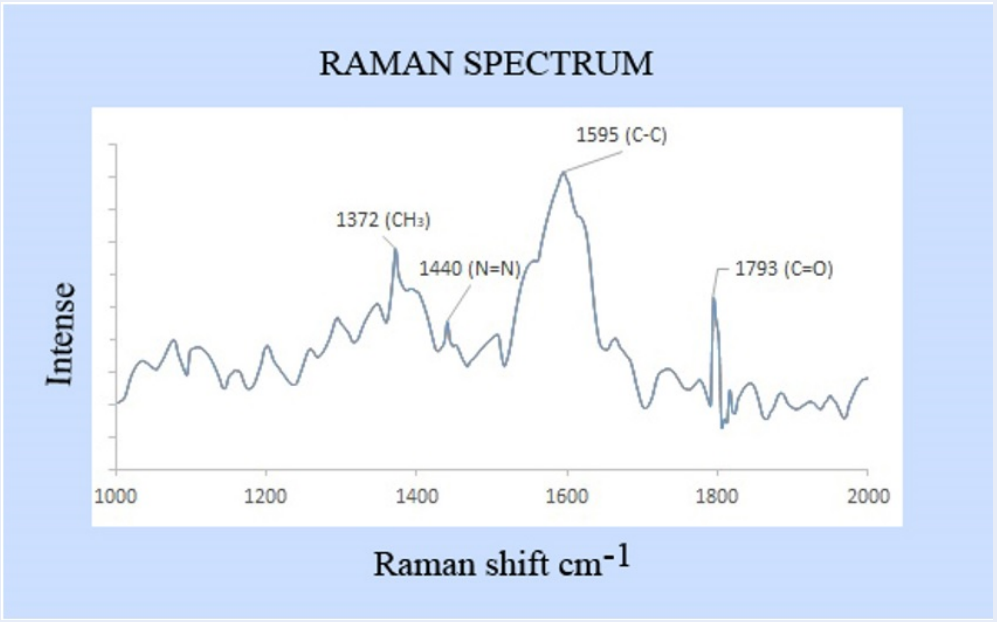

Figure 7: The Raman spectra of the Phu Quoc jet present some strong and medium bands with major peaks positioned at 1372, 1440, 1595 and 1793 cm^{-1} assigned to C-H, N=N, C-C and C=O, respectively (Kevin V. Hackshaw, 2020; Joseph B. Lambert *et al*. 2013) [10,11]

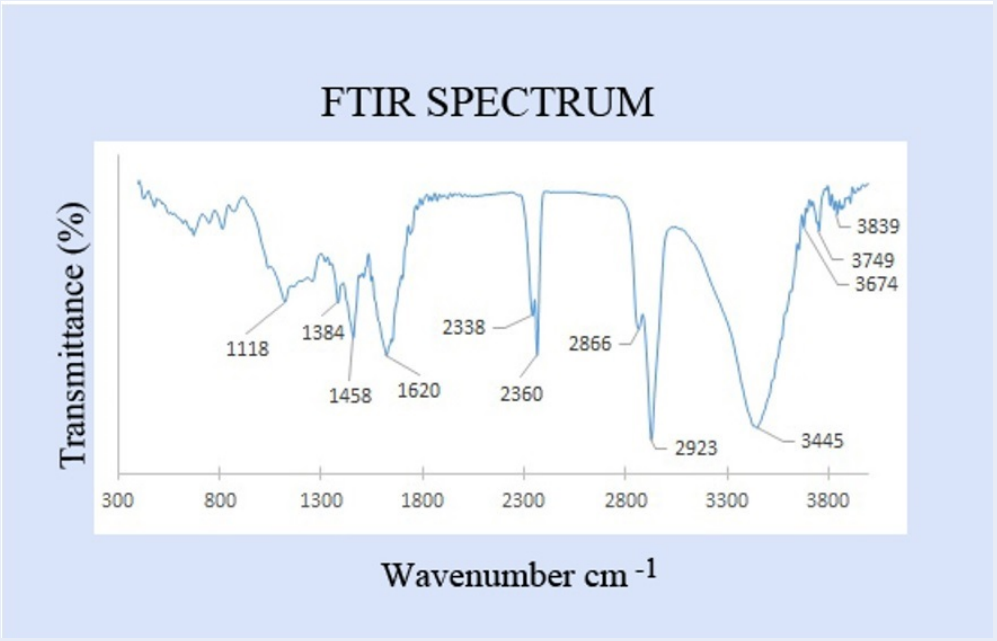

Figure 8: *FTIR spectra of the Phu Quoc jet. Absorption peaks* 2923 cm^{-1} and 2866 cm^{-1} relate to C-H stretching; 3674, 3749, and 3839 cm^{-1} are typical for O-H;2361 cm^{-1} and 2338 cm^{-1} are associated with O=C=O. 3445 cm^{-1} is typical of N-H

form texture, high luster, and lapidary ability. During the research, the authors slightly polished the samples, and the preliminary evaluation showed that all samples were suitable for jewelry and ornament manufacturing. Several products, such as cabochons, facets, carvings, and beads, were created based on the size and shape of the samples. As mentioned earlier, the Phu Quoc jet is classified as the saltwater jet or hard jet, which is appropriate for making jewelry and ornamental pieces to bring economic value [18].

CONCLUSION

Phu Quoc jet deposits in layers of quartz sandstone are distributed widely and concentrate mainly in the northern part of the island. The physical appearance is characterized by its pure black, greasy to subvitreous lustre, and opaque appearance. The standard gemological properties include SG 1.24, RI 1.66, and inertness under UV. Traces of wood cells after deformation are visible under the microscope. The elemental composition includes C, H, O, and N without metal or sulfur impurities. The Phu Quoc jet accumulated in a saltwater depositional environment and is classified as a hard jet. The gemstone quality of the Phu Quoc jet is qualified to make pieces of jewelry and ornaments. Further research is needed to propose appropriate ways for sustainable use and preservation of this gem material.

ABBREVIATIONS

EDS: Energy dispersive X-ray spectroscopy
FTIR: Fourier transform infrared spectroscopy
SG: Specific gravity
RI: Refractive Index
LW: Longwwave
SW: Shortwave
UV: Ultraviolet light

COMPETING INTERESTS

The authors have no competing interests.

AUTHORS' CONTRIBUTIONS

Le Ngọc Nang wrote and edited the first draft; Nguyen Thanh Tri was responsible for the geological settings section, Lam Vinh Phat collected materials and processed the sample; Le Huu Tuan performed the standard gemological methods, processed the statistics of FTIR, raman, and EDS after analysis; and Pham Minh Tien edited the draft, checked English.

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REFERENCES

1. Liddicoat RT. Handbook of gem identification. 12th ed. Gemological Institute of America; 1993. p. 192, pp 183-188;.
2. Çiftçi E, Selim H, Sendir H. Authentic semiprecious and precious gemstones of turkey: special emphasis on the ones preferred for prayer beads, 14th International Congress for Applied Mineralogy (ICAM2019); 2019;.
3. Carvalho LMd, Fernandes FM, Nunes MdF, Brigola J. Whitby Jet Jewels in the Victorian Age. Harv Pap Bot. 2013;18(2):133-6;Available from: https://doi.org/10.3100/025.018.0206.
4. Hatipoğlu M, Cesaro SN, Ajò D. Comparative Fourier transform infrared investigation of Oltu-Stone (natural carbon black) and jet. Spectrosc Lett. 2014;47(3):161-7;Available from: https://doi.org/10.1080/00387010.2013.785435.
5. My BP, Linh TH. On the stratigraphy and age of continental sediments in the Phu Quoc Island, Tho Chu and an Thoi archipelagoes, Kien Giang Province. J Geol. 2005:A/291;.
6. Le Ngoc Nang, Pham Trung Hieu, Lam Vinh Phat, Pham Minh Tien, Ho Nguyen Tri Man, and Ha Thuy Hang. Characteristics of newly discovered amber from Phu Quoc, Vietnam. Gems Gemol. Summer 2022;58(2):184-94;Available from: https://doi.org/10.5741/GEMS.58.2.184.
7. Truong Cong Duong et al. Report on the result of geological mapping and mineral exploration, Ha Tien - Phu Quoc map series, scale. Vol. 1:50.000. South Vietnam Geological Mapping Division, General Department of Geology and Minerals of Vietnam (in Vietnamese); 1998;.
8. My BP, Linh TH. On the stratigraphy and age of continental sediments in the Phu Quoc Island, Tho Chu and an Thoi archipelagoes, Kien Giang Province. J Geol. 2005:A/291;Available from: https://doi.org/10.1007/978-3-030-22974-0_42.
9. Johnson ML, McClure SF, DeGhionno DG. Some gemological challenges in identifying black opaque gem materials. Gems & Gemology. 1996;32(4):252-61;Available from: https://doi.org/10.5741/GEMS.32.4.252.
10. Hackshaw KV, Miller JS, Aykas DP, Rodriguez-Saona L. Vibrational spectroscopy for identification of metabolites in biologic samples. Molecules. 2020;25(20):4725;PMID: 33076318. Available from: https://doi.org/10.3390/molecules25204725.
11. Lambert JB et al. Organic structural spectroscopy. Pearson Education, Ltd; 2013;.
12. Hunter FJ, Mc Donnell JG, Pollard AM, Morris CR, Rowlands CC. The scientific identification of archaeological jet-like artifacts. Archaeometry. 1993;35:68-9;Available from: https://doi.org/10.1111/j.1475-4754.1993.tb01024.x.
13. Hurwit KN. Gem trade lab notes: carved jet. Gems Gemol. 1985;21(4):234-5;Available from: https://doi.org/10.5741/GEMS.21.4.232.
14. King H. Whitby. Jet A black organic gem material that is also a rock very similar to coal. 2019;Available from: https://geology.com/gemstones/jet/.
15. McMillan M. Whitby jet through the years. Whitby: Mabel McMillan; 1992;.
16. Gezici O, Demir İ, Demircan A, Ü. nlu¨, N; Karaarslan, M. Spectrochim Acta A. 2012. Subtractive-FTIR spectroscopy to characterize organic matter in lignite samples from different depths;96:63-9;PMID: 22652543. Available from: https://doi.org/10.1016/j.saa.2012.05.004.
17. Patty DJ, Loupatty G, Sopalauw F. Interpretation FTIR spectrum of seawater and sediment in the Ambon Bay (TAD). AIP Conf Proc (Vol. 1801, No. 1, pp. 060005-5 and 060005-6). 2017, January;Available from: https://doi.org/10.1063/1.4973109.
18. Muller H. Jet jewellery and ornaments. Shire Publication, Ltd; 2003;.