Characterisation and Geological Provenance of Jasper that was Used for *Debitages* in the Archaeological Site of Tabon Cave, Philippines

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Abstract

The upper Pleistocene site of Tabon Cave yielded traces of Homo sapiens that are among the earliest on the Philippine Islands. Studying the geographical and geological provenance of the raw material that was used for the production of lithic tools could help us to understand the behaviour of early Homo sapiens who settled in insular Southeast Asia. Excavations in the cave have unearthed a lithic industry produced in radiolarian jasper. The present research paper aims to find potential provisioning sites for this jasper. It also attempts to reconstruct some of the decisions that were made during the raw-material supply. The studied corpus contains nine flakes, exhumed by archaeological excavations, and forty jasper samples that were collected in the surroundings of Tabon Cave. The study is based on mineralogical determinations and geochemical analyses of the jasper. Energy dispersive x-ray spectroscopy and chromatic spectroscopy, complete and align with infrared spectroscopy in order to bring a first schema of raw-material supply into being. The genesis of these silicifications is studied for the purpose of determining its influences on their homogeneity. It is shown that the selection by man depended on this homogeneity. The results of these methods suggest that the early man, who inhabited the Tabon Cave, supplied himself with jasper from the Panitian River and its confluent, Malatgao River. A distance of around 8–9 kilometres had to be covered in order to find raw-material with an adequate quality for knapping. The study also explains one of the idiosyncrasies of Tabon Cave's reduction chain: the

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absence of unaltered raw materiel lumps in archaeological sediments. The absence of unaltered raw-material being transported into the cave seems to be due to the specific fracture patterns, created by the intense tectonisation of the jasper. A first knapping had to be done on the raw-material bearing locus in order to separate these patterns. The study of the jaspers from Tabon Cave confirms and complements some hypotheses that have remained unproven since the 1970s. The circulation schema, issued by the study of raw-material supply, may contribute to the better understanding of early Homo sapiens in insular Southeast Asia.

Introduction

Tabon Cave lies in a limestone formation in the southwestern part of Palawan Island, Philippines. The cave opens to the South China Sea. The first excavations, in the 1960s, yielded human fossils (*Homo sapiens*) and a flake industry made from “chert.” Five ^{14}C dates indicated an upper Pleistocene age (Fox, 1970). Works on Tabon Cave were picked up in 2000. Excavations between 2000 and 2007 yielded new artefacts and first U/Th dating of human fossils confirmed the upper Pleistocene age of the site (Détroit et al. 2004). Given these dates, the site could be one of the earliest occurrences of *Homo sapiens* in insular Southeast Asia. The present research paper tries to decode parts of the behaviour of this group of early man through the study of their raw-material provisioning. Robert Fox (1970) supposed that the lithic raw material came from the neighbouring rivers of the site. In order to verify and affine the provenance of the chert, we ask ourselves the questions: Where is the exact provisioning location? Is it in the rivers around the cave? If so, which distance had to be covered along these rivers in order to find adequate raw material for the *debitages*? Moreover, can we infer some choices that were done during the provisioning from the patterns observed on the raw material?

Geological environment

The southern part of Palawan is dominated by the outcropping of a cretaceous ophiolitic sequence called *Palawan Ophiolite*. The top part of the Palawan Ophiolite, called *Espina Formation*, consists of late cretaceous pillow lavas associated with radiolarian chert (Aurelio and Peña 2004; JICA-MMAJ 1988). After sampling and analysing chert from the ophiolite, we adopt the more precise definition of ‘radiolarian jasper’ for these rocks, in order to specifically name them within the large boundaries of the term ‘chert’. It is this jasper that corresponds to what Fox (1970) described as chert for Tabon Cave. These sedimentary silicifications are usually associated with ophiolitic sequences. Lucien Cayeux (1929) defined jasper as marine sedimentary silicification containing clay minerals and iron oxides that contain large numbers of radiolarians that were deposited in the formation area. The iron oxides are responsible for the colour of the jasper. The present analyses of the Palawan jaspers show them to fit this definition. The geological setting is shown in Figure 1.

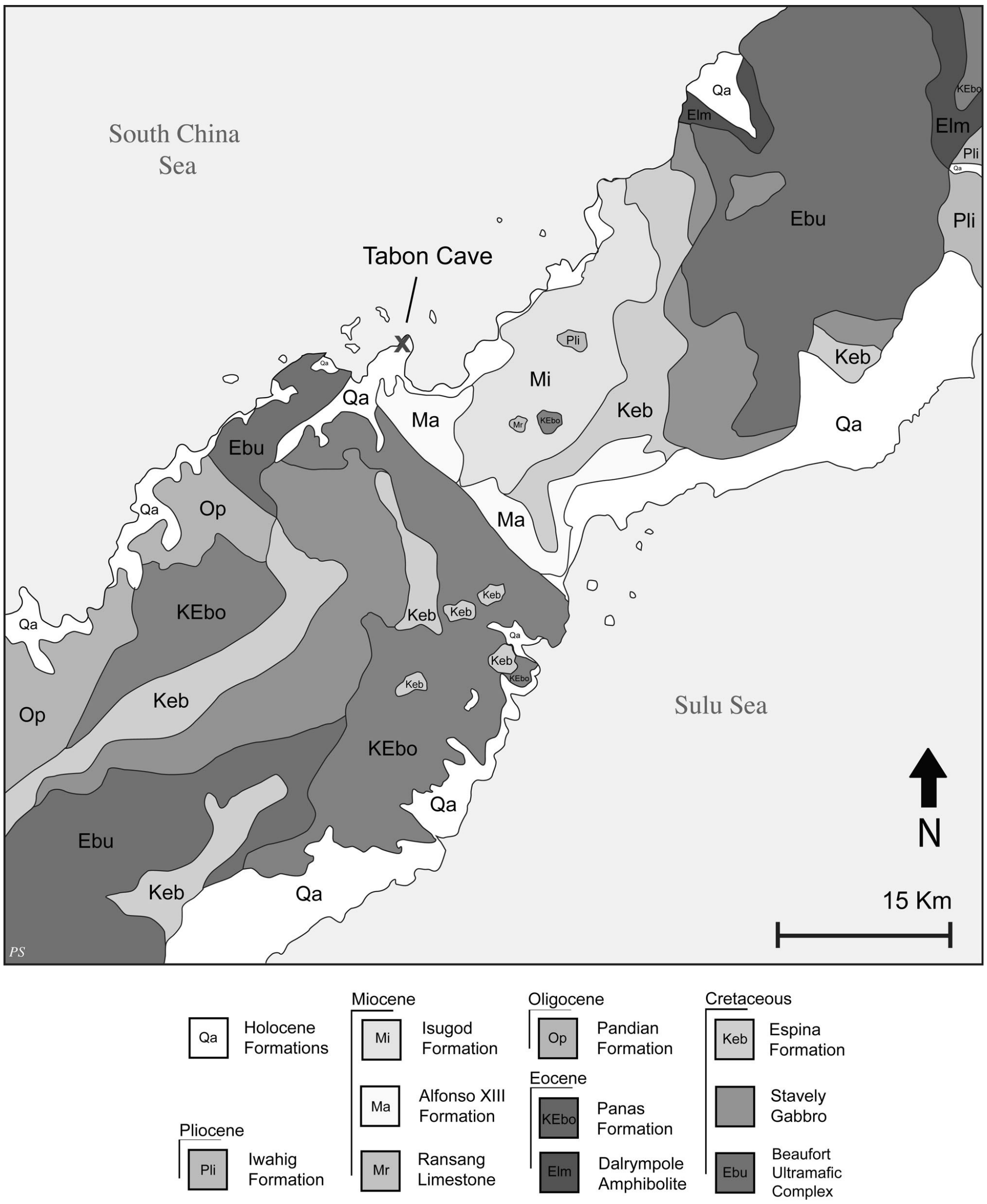


Figure 1. Geological map of Tabon Cave's surroundings (synthesis between JICA -MMAJ 1988 and Aurelio and Peña 2004)

Corpus

The study is based on a corpus of nine flakes that were unearthed in 2001. The artefacts were found in the squares S_7W_1 and S_8W_2. These two squares did not exhibit a clear stratigraphy. The original cave sediments had been disturbed by treasure hunters before they where excavated in 2001 (Orogo 2001). A clear attribution of the studied corpus alluding to one of Fox's lithic assemblages is therefore not possible. In order to compare the artefacts to a geological corpus, 40 samples were taken from the surroundings of the site during two sampling campaigns in the Summer of 2007 (Figure 2). The sampling sites were chosen along the rivers: Panitian River, Malatgao River, and Alfonso VIII Creek. One sample was taken at the southern margins of Palawan. Sampling sites commence with "L" in addition to the sampling site number (Table 1). A roman numeral indicates the sampling campaign (I or II) and an Arabic numeral indicates the sample's number (e.g., L3-I- 2 and L7-II-2).

Localities L1, L2, L3, L5, and L7 yielded only small blocs (>10 centimetres). L4 exhibits jasper lumps of 10–15 centimetres. Blocs with diameters of 30–40 centimetres were found at L8 and L9. We observed jasper blocs with a diameter of more than 2 meters at locality L6.

Methodology and techniques

There are multiple benefits for archeological research in working on raw-materials. Three kinds of information about the behavior of early man can be assessed by the study of the raw-material they used in their reduction chains. (1) In the case of nomadic hunter-gatherers and early sedentary groups, the territories that were occupied and actively exploited by these groups can be estimated by observing the distances these people used to cover for the requisitioning of goods they needed for their subsistence. (2) In the case of migrating groups, the diffusion of these populations can be retraced through the observation of the distances and directions in which objects were transported during migration. (3) Thirdly, some of the choices that were made during the raw-material requisitioning can be appreciated, which leads to further understanding of the population under study.

Lithic material is especially well suited to such analyses, for it generally does not suffer much from aggressive taphonomic influences that affect the preservation of other materials such as bone or wood. The study of lithic raw-material can therefore be adapted to most

Table 1. Coordinates and local names of the sampling sites

Site	Name and description	Coordinates
L1	Eastern branch of the Panitian River.	N 09°13,083′ E 117°56,382′
L2	Eastern affluent of the Panitian River.	N 09°12,664′ E 117°56,541′
L3	Eastern branch of the Panitian River.	N 09°12,331′ E 117°56,951′
L4	Dam on the eastern branch of the Panitian River.	N 09°10,202′ E 117°57,236′
L5	River close to the southern coast of Palawan that crosses Isumbo village.	N 90°08′ E 180°06′
L6	Western affluent to the eastern branch of the Panitian River called *Tabud River.*	N 09°08,051′ E 117°58,892′
L7	Alfonso XIII Creek.	N 09°13,274′ E 117°58,923′
L8	Southern affluent to the eastern branch of the Panitian River called Malatgao River.	N 09°10,646′ E 117°55,162′
L9	Southern affluent to the eastern branch of the Panitian River called Malatgao River.	N 09°11,462′ E 117°55,436′

archaeological cases, regardless of their age and taphonomical condition (with the exception of some aggressive environments that even affect certain kinds silica rocks). Sedimentary silicifications, such as jasper that is studied in this paper, are therefore perfect objects for the study of the behavior of archaeological populations. In order to judge distances on which rock material circulated, it is crucial to precisely determine the geological origin of these rocks. This determination can be attempted through the characterization of the formation and geological history of rocks (petrography), their mineralogy or the occurrence of trace elements that are specific to certain formation environments. In this study, we try to solve the question of the Palawan jasper's geological and geographical origin by means of the methods described below. This methodological corpus constitutes an *ensemble* that should facilitate an understanding of

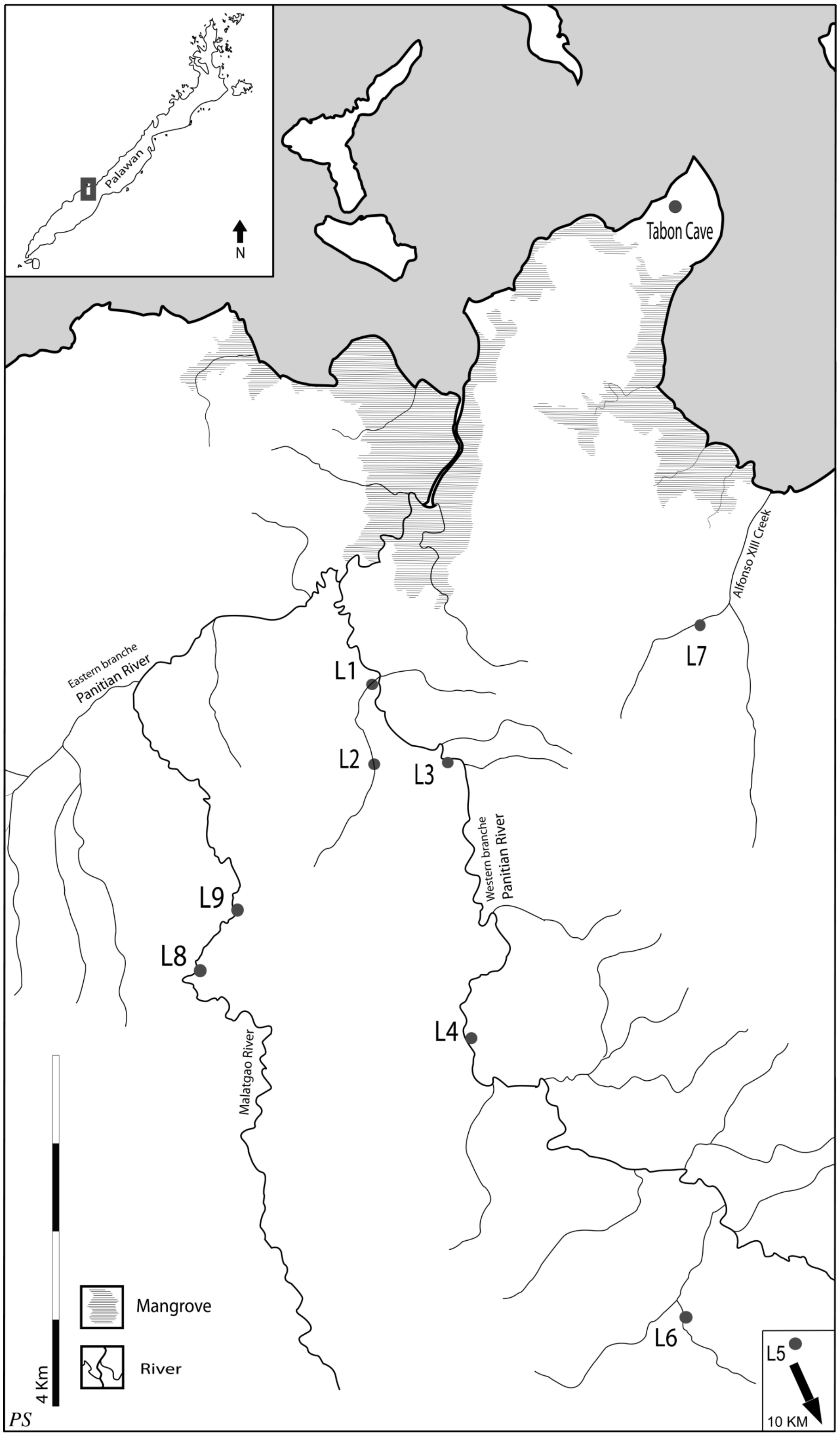


Figure 2. Sampling locations

the formation parameters of the jasper, its mineralogy and its chemical constitution.

Six methods were used in characterising the jasper and comparing the archaeological samples to the geological samples. The following analytical methods were used:

1. *Macroscopic descriptions*: Observations were made on the surface of the samples by using a hand loupe with a magnification of 10x. Twenty characteristics (e.g., presence of hollow parts in the matrix of the jaspers and joints filled by quartz) were taken into account and interpreted. These, concerning colour, surface aspect, fracture patterns, and transparency of the jasper, are compared to each other in order to discriminate similarities between artefacts and geological samples.

2. *Chromatic spectroscopy*: In order to compare the colours of the artefacts and the geological samples, we used a Techkon, Spektralphotometer SP820 λ in the *Centre infrarouge* of the *Muséum National d'Histoire Naturelle* (MNHN). The observable colours of the surfaces of each sample were analysed. The comparison of the colours, observed on the artefacts and the geological samples, was done in the $L^*a^*b^*$ colour space. This colour space was chosen because it displays different colours in a three-dimensional space. In this space, the linear distances between two different colours are based on how the human eye perceives the differences between these two colours.

3. *Infrared* (*IR*) *spectroscopy*: The measurements were mainly made in (non-destructive) specular reflectance mode on the surface of the samples. A Brucker, Vector 22 Fourier transform spectrophotometer was used in the *Centre Infrarouge* of *MNHN* in Paris, France. The parameters were a resolution of 2 cm^{-1} and 32 repetitions in order to reduce the background noise. The non-destructive method aliened to the classical transmission method (using KBr pellets, the preparation was made like described in (Fröhlich, (1993)). The destructive analyses aimed to interpret some of the spectra and were only made on geological samples so that non-destructivity of the archaeological corpus was maintained.

4. *Energy dispersive x-ray spectroscopy* (*EDX*): A Philips EDX sensor that was attached to a scanning electron microscope was used for these analyses in the *Centre de Recherche Préhistorique de Tautavel*, *Tautavel*,

France. The measures were taken on the surfaces of the samples. A surface between 200 square micrometres and 1 square millimetre was measured. The percentages of each element, found in the jasper samples, will be compared in Table 4.

5. *Petrographic analyses*: Forty microscope thin sections (thickness of 30 micrometres) were cut in the *Punto Terra* laboratory in Rome, Italy. Ten microscope rockslides were cut in the National Institute of Geological Sciences in Quezon City, Philippines. The observations were made at magnifications between 125x and 312x, using a Zeiss *Standard* polarizing microscope equipped with Zeiss Neoflur P lenses (*Centre Infrarouge* of the MNHN, Paris). The percentages of the jasper composing minerals were evaluated by using a percentage comparison chart like in Rothwell (1990).

6. *X-ray powder diffraction*: A small series of tests was run on four geological samples. A Siemens D500 diffractometer was used in the *Département de l'Histoire de la Terre* of the MNHN. These destructive analyses were made on geological samples in order to attempt to better characterise the composition of the jasper.

Results

Macroscopic analysis

The characteristics that were observed on the samples are resumed in Table 2. The macroscopic observations discriminate two groups within the geological samples. (1) One part of the jaspers is extremely tectonised. The fracture patterns point to multiple periods of pressure that was applied to the rocks from different directions. (2) Fracture patterns are almost absent on another part of the jaspers found in the rivers. However, Tabon Cave inhabitants do not seem to have preferred the non-fractured jaspers over the fractured ones. The nine flakes show the same fracture patterns as the geological samples.

All characteristics (within the 20 defined criteria) observed on the analysed Tabon Cave artefacts are also present on the geological samples. It is, thus, possible that the flakes were made on jasper that was transported through the rivers. On the other hand, the geological samples exhibit the following five characteristics that are absent on the artefacts: "white quartz inclusions", "black natural splitting surfaces", "white quartz veins", "damageable when touched", and "hollow parts in the matrix." The last four of these characteristics affect the homogeneity of the material and implicate a less regular conchoidal fracture. The absence of these characteristics seems to translate some of the choices that were made during the raw-material acquisition. Furthermore, black natural splitting surfaces and hollow parts are not observable on the surface of unfractured jasper lumps. The blocs must be fractured in order to evaluate the presence of these characteristics. From the point of view of a raw-material collector that means that unaltered, freshly picked, jasper lumps cannot be transported into the cave in order to process them on the habitat, for they might exhibit these two characteristics that make them useless to knapping. The raw-material collector has to perform a first knapping on the collection site in order to evaluate the quality of the jasper regarding its *debitage*.

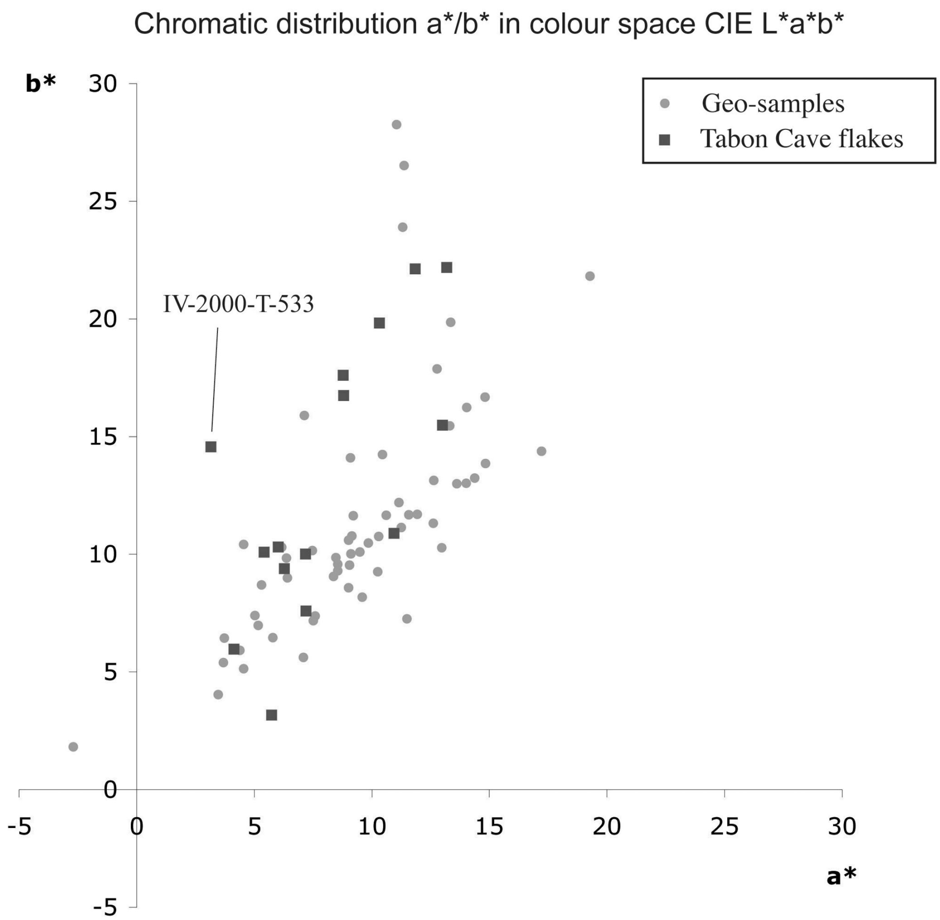
Chromatic spectroscopy

The values of the measured colours are located (with one exception) on the positive sector of the *a** axis and the *b** axis in the three dimensional L*a*b* color space (red and yellow). Values between 25 and 50 on the *L** axis define the samples as reddish brown to yellowish brown. L4-I-6 is an exception with its greenish colour.

The scatter plots (Figure 3) of the Tabon Cave flakes are more or less congruent with those of the geological samples. The plots of the colours of the artefacts are located within the circumference of the plots that correspond to those of the geological samples. Two exceptions are IV-2000-T-533 and IV-2000-T-450. The measures of IV-2000-T-533 indicate a higher clarity (*L** axis) and a slightly lower value on the *a** axis. IR and EDX spectroscopy indicate an integration of gypsum/anhydrite in the surface of the jasper (*cf. infra*). It is thus probable that the brighter colour corresponds to a taphonomic patina. One spot on this flake does not exhibit the bright colour but a darker reddish brown colour (region where the patina is absent). The value of the reddish brown colour is congruent with the plots of the geological samples. The differential colorimetric values of the patina of IV-2000-T-533 are due to a differential taphonomic history of the flake. They are not due to differential geological origins of the jasper. IV-2000-T-450 exhibits a little higher luminance than the majority of the scatter plot. This value indicates a slight difference for this artefact.

Table 2. Characteristics observed during the macroscopic analysis

Accession number	Shiny aspect of surface	Colour stains	Colour bands	Stratification visible	Visibility of grain	Microscopic colour spots	Manganese stains	White quartz inclusions	Formation bed limit	Fractures (joints/faults)	Black natural splitting surface	Black veins	White quartz veins	Black tectonisation fracture marks	Irregular natural splitting surfaces	Typical conchoidal fracture	Transparency	Damageable on contact	Hollow parts	Geodes
Tabon Cave flakes																				
IV-2000-T-533		X	X	X		X			X	X					X		X			
IV-2000-T-540	X	X		X			X			X							X			
IV-2000-T-489		X		X	X					X										
IV-2000-T-468		X					X			X		X				X	X			
IV-2000-T-485	X	X				X				X					X	X				
IV-2000-T-629	X									X				X			X			
IV-2000-T-450		X	X	X	X				X						?	X	X			X
IV-2000-T-535			X	X	X				X						?	X				
IV-2000-T-815	X				X	X	X								?	X	X			
Geological samples																				
L6-II-1	X					X		X	X	X	X	X	X	X	?	X				
L6-II-2										X	X	X	X							
L6-II-3	X	X	X	X			X	X		X			X			X	X			
L6-II-4	X	X								X	X		X		?					
L7-II-1		X			X					X	X		X	X						
L7-II-2		X			X			X	X	X						X				
L7-II-3	X									X			X		?				X	X
L3-II-1	X	X								X					?			X	X	
L3-II-2	X		X	X			X		X	X					?	X	X			
L3-II-3	X		X							X					X	X	X		X	
L3-II-4	X		X						X	X			X		X	X	X			
L9-II-1										X	X		X	X	X	X				
L9-II-2	X															X	X			
L9-II-3	X								X	X					?		X	X	X	
L9-II-4		X			X					X	X		X	X	X	X			X	
L9-II-5		X	X	X	X			X	X	X			X	X	X	X				
L9-II-6	X	X						X	X	X					x	X	X			
L8-II-1	X					X			X	X		X			?	X				
L8-II-2	X	X		X					X	X			X	X	?	X	X			
L8-II-3	X	X	X	X											X	X				X
L8-II-4										X	X		X		?					
L8-II-5	X	X	X	X					X	X		X				X			X	
L8-II-6							X			X			X		?	X	X			
L8-II-7	X	X	X	X	X				X	X					?				X	
L8-II-8	X					X		X		X	X				X	X			X	
L8-II-9			X	X		X				X	X					X			X	
L8-II-10	X					X		X		X				X	X	X			X	
L8-II-11	X								X	X			X		X		X		X	
L8-II-12	X	X	X	X				X		X			X			X				
L8-II-13										X					?				X	
L1-I-1	X						X	X		X	X					X	X		X	
L1-I-2					X	X			X	X	X				X	X			X	
L2-I-3	X	X				X				X					X	X			X	
L2-I-4										X		X			X				X	
L2-I-5						X		X		X					?	?				
L4-I-6	X	X				X				X		X			?	X	X		X	
L4-I-7							X			X		X	X		?	X		X	X	
L3-I-8						X				X		X	X		?					X
L3-I-9										X		X				?				
L5-I-10		X				X				X					?	X				



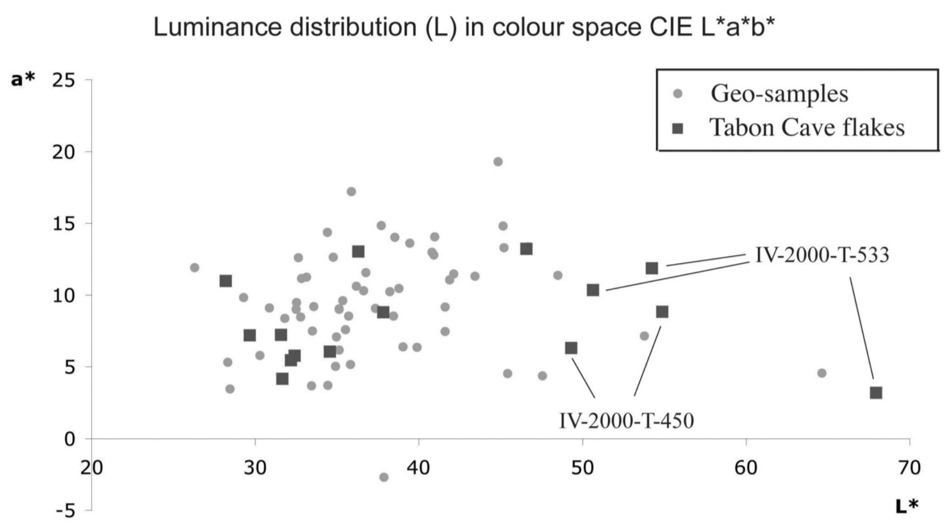


Figure 3. Scatter plots of the observed colours on the samples

Infrared spectroscopy

The infra-red spectra show the typical absorption bands for quartz. The triply degenerated ν Si-O (1050-1200 cm^{-1}) and δ Si-O (400-550 cm^{-1}) absorption bands indicate the SiO_4 tetrahedron. Absorption bands at 692 cm^{-1} and at around 797 and 778 cm^{-1} indicate ν_s (Si–-O–-Si) vibrational modes of the α-quartz unit cell [concerning these absorption bands, *cf.*: Farmer (1974); Etchepare (1974); Pettinari and Santini. 2000]. Absorptions around 536 cm^{-1} observed (in reflectance spectra) in the majority of the samples could be caused by the presence of chalcedony. Badia and Fröhlich (1975) showed absorption at 555 cm^{-1} in transmission IR spectra to be due to the presence of chalcedony in flint. As the frequencies of absorption bands that are observed in IR transmission spectra tend to shift towards lower frequencies in specular reflectance spectra (Spragg 2000;), the 546 cm^{-1} absorption observed in the Palawan jasper's reflectance spectra seems very likely to be equivalent to this 555 cm^{-1} absorption. Microscopic evaluations (petrographic microscope, *cf. infra*) corroborate this hypothesis by showing that the jasper samples that contain high percentages of chalcedony exhibit the 536 cm^{-1} absorption band to be more important than samples that do not contain chalcedonic quartz. It seems therefore that the band corresponds to the presence of chalcedonic quartz *s.l.* in the jaspers.

Weak absorption bands were observed at 600–606 cm^{-1} and at 666 cm^{-1} in some specular reflectance spectra. The occurrence of absorptions at these two frequency ranges in IR spectra can be attributed to gypsum ($CaSO_4 \cdot 2H_2O$), bassanite ($CaSO_4 \cdot ½H_2O$), or anhydrite ($CaSO_4$) (Farmer 1974; Marel and Beutelspacher 1976, database of the *Centre Infrarouge* MNHN). Concerning the 600–606 cm^{-1} range, gypsum and bassanite show absorption bands at slightly lower frequencies than anhydrite (Farmer 1974). Thus, a possible attribution of the 666 cm^{-1} band is that its coincidence with the 600 cm^{-1} band is caused by gypsum/bassanite, whereas its coincidence with the 606 cm^{-1} band is caused by anhydrite. However, this hypothesis remains unconfirmed because of the rather high detection limit and the poor signal-to-noise ratio of the non-destructive reflectance method.

Another absorption band appears between 416 and 418 cm^{-1}. Due to its weak intensity and its isolated appearance, the exact interpretation of this single band is not possible. However, its occurrence suggests the presence of other components in the jaspers. The database of the *Centre*

Infrarouge (MNHN) shows absorption bands at this frequency to be present in various clay minerals.

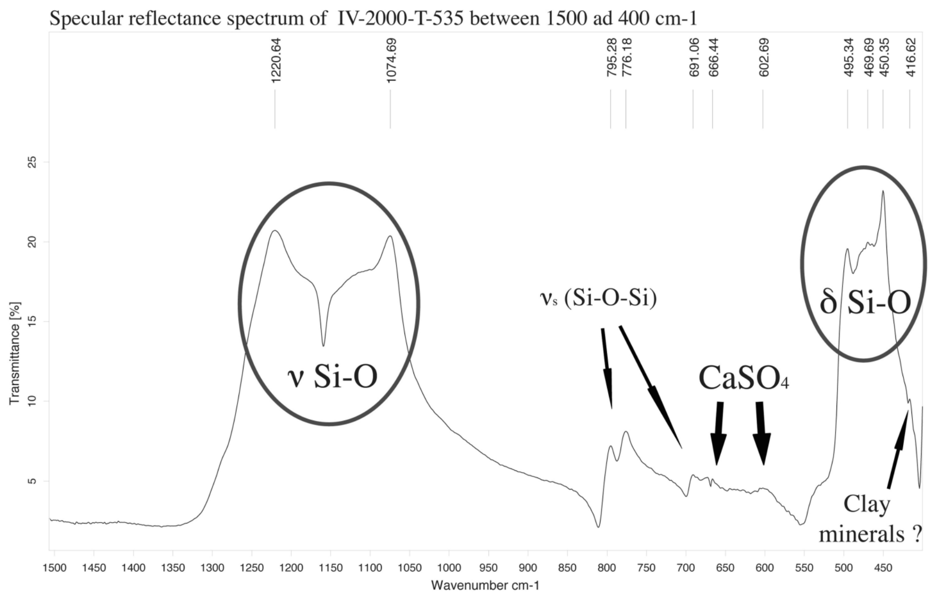


Figure 4. IR spectrum of a flake showing the characteristic absorptions

Comparison between artefacts and geological samples

The specular reflectance spectra exhibit identical quartz and chalcedonic quartz absorption bands in the geological samples and in the Tabon Cave flakes. However, the frequency at which the triply degenerated ν Si–O absorption band occurs seems to indicate a difference between artefacts and geological samples. It is located between 1079 and 1072 cm^{-1} for the archaeological flakes and between 1109 and 1080 cm^{-1} for the geological samples. A series of Scanning Electron Microscope (SEM) observations were conducted in order to interpret this phenomenon. The results indicate that the frequency shift could be caused by the different surface aspects of the two groups. The spectra of the artefacts were recorded on conchoidal fracture negatives, whereas those of the geo-samples were recorded on surfaces that were cut during the manufacturing of thin sections (for fracture negatives were not present on the surface of all geo-samples). In order to verify the attribution of the frequency shift to the surface aspect of the samples, specular reflectance spectra were recorded on conchoidal fracture negatives of some geological samples. These spectra showed the ν Si–O absorption band to be located between 1079 and 1072 cm^{-1} similar to those of the artefacts. Thus, we find the frequency shift not to be relevant to the comparison between artefacts and geological samples.

The 416–418 cm^{-1} absorption is present in the spectra of the artefacts and the geological samples. The gypsum/bassanite/anhydrite absorption bands are unequally present in the two groups. The 666 cm^{-1} band is present in seven out of nine flakes but only in three out of 40 geo-samples; the 600 cm^{-1} band is present in four flakes and one geo-sample. Additionally, the latter appears at 606 cm^{-1} in the geo-sample. Additional transmission spectra of four geological samples that were recorded for the purpose of interpreting the unequal occurrence of the bands show that the 666 cm^{-1} absorption is also present in the transmission spectra of jaspers for which it was absent in the specular reflectance spectra. We partially attribute the statistical difference of the occurrence of this absorption band to be due to the surface aspect of the samples and the high detection limit and signal-to-noise limitations of the specular reflectance method. Concerning the 600 to 606 cm^{-1} shift, it seems possible that the differential frequencies in the two groups are due to the differential presence on gypsum/bassanite and anhydrite. Cave sediments were sampled in the squares where the nine analysed flakes were unearthed. These IR analyses showed a considerable amount of gypsum (Gallet pers. comm. (2008) in prep.). It seems possible that the Tabon flakes integrated gypsum into their surfaces during their burial in these sediments. The presence of gypsum/bassanite in the Tabon Cave flakes could correspond to a taphonomic factor, whereas the presence of anhydrite in the geo-samples could correspond to an evaporite that is due to the jasper's marine formation. IR spectroscopy does not permit the conclusion of the presence of anhydrite in the matrix of the Tabon Cave flakes, for the taphonomically generated gypsum/bassanite signal overlays a potential anhydrite signal. The differential presence of these minerals in the two groups can, thus, not be taken into account for their comparison and the purpose of determining the origin of Tabon Cave raw material.

EDX spectroscopy

The following elements were found in the jaspers: silicon (Si), oxygen (O), iron (Fe), aluminium (Al), sodium (Na), potassium (K), magnesium (Mg), chlorine (Cl), calcium (Ca), titanium (Ti), manganese (Mn), sulphur (S), and phosphorus (P). Due to a carbonate impurity in/on the spectrometer's detecting sensor, the element carbon (C) could not be detected by the used spectrometer. This technical problem hinders the determination of calcite and other carbonates, which would be expected on the surfaces of the cave artefacts. We mainly attribute Si and O to the SiO_4 tetrahedron. X-ray diffraction analyses suggest Fe to be present in the form of hematite Fe_2O_3 (*c.f. infra*). Ca and S are interpreted as gypsum ($CaSO_4 \cdot 2H_2O$), bassanite ($CaSO_4 \cdot ½H_2O$), or anhydrite ($CaSO_4$). [Hydrogen (H) cannot be detected in EDX spectroscopy. The $CaSO_4$ minerals cannot be further determined here.] Na and Cl could be present as halite (NaCl). The presence of halite and anhydrite could be attributable to the marine formation of the jasper. It is thought that some of the listed elements may concomitantly be present in some other (non-determinable) minerals in the jaspers. Phosphorus, being exclusively present in the cave artefacts, is attributed to the abundance of bat guano in the cave sediments (Fox 1970). The presence of P is interpreted as a taphonomic incorporation and is, therefore, not relevant to the present comparison of the artefacts with the geo-samples. The elements K, Mg, Al, Mn, and Ti can constitute several minerals. The presence of clay minerals was suggested by IR spectroscopic analyses. The determination of their exact nature was not possible with the spectroscopic methods that were employed.

Comparison between artefacts and geological samples

All of the elements that were observed in the Tabon Cave flakes were also found in the geological samples (with the exception of P, which is caused by differential taphonomy of the cave artefacts). Some geo-samples contain exactly the same elements as the flakes. Thus, it is possible that at least parts of the geo-samples consist of the same jasper as the artefacts. In order to narrow the choices of a potential raw-material *locus*, we divided the geological samples into five geographical groups. The averages of each element within these groups are compared to the averages of the same element in the Tabon Cave flakes (see Table 3). The groups "Panitian River headwaters," "Panitian River outflow," and "Malatgao River" show relative percentages of the elements to be the most similar to the Tabon Cave flakes (Ti and Mg are not taken into account, for their presence is sporadic in both groups and the employed method does not permit analyses fine enough to access these elements) The jaspers from the Alfonso VIII creek, approximately 25 kilometres away from Tabon Cave (indicated as L5 in figure 2), do not contain sulphur and chlorine. This shows a slight difference with the Tabon Cave jaspers. The sample from the southern coast of Palawan was also compared with these groups. The sample shows a chemical signature that is different from those of the jaspers that were sampled in the cave environment. Only the elements Si, O, and a rather small quantity of Al are present in this sample. These measures indicate that the jaspers, coming from a distance of more than 25 kilometres from the cave, do not have the same genetic history as the jaspers found more closely to Tabon Cave. However, with only one test sample taken at the L5 location, the differentiation of the southern coast of Palawan must be considered as an indication only. We noticed a slightly different chemical signature for IV-2000-T-485. The absence of all elements but O, Si, Al, and Fe could be a result of a different geological origin. This observation corroborates the assertion of the difference of this flake on account of its fine and homogenous properties that were observed during the macroscopic analysis.

Table 3. Percentages of elements observed during the EDX analysis

Accession number	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe
Tabon Cave flakes													
IV-2000-T-533	40,7	0,39		0,38	44,9	0,32		1,17	5,34	2,15	4,68		
IV-2000-T-540	58,2	0,32		0,63	35	1,57	0,85		0,41	2,17			0,85
IV-2000-T-489	50,28	0,71	0,63	1,87	37,75	2,5	0,39	0,39	0,78	0,76			1,35
IV-2000-T-468	46,29	0,86	0,7	1,15	46	1,12	0,74	0,71	0,84	0,91			0,68
IV-2000-T-485	48,05			0,94	50,74								0,27
IV-2000-T-629	53,11	0,46	0,32	0,93	43,81	0,55				0,82			
IV-2000-T-450	49,55	0,67	0,32	1,29	44,49	1,40	0,28	0,55	0,72	0,19	0,35		
IV-2000-T-535	48,9	1,25		1,61	32,8	3,63	2,92	0,75	1,38	3,94			2,43
IV-2000-T-815	53,35	0,99		1,17	39,29	1,73	0,72		0,67	1,01			1,07
Geological samples	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe
Malatgao River	49.4	0.38	0.55	1.39	46.7		0.17	0.15	0.46	0.35		0.45	1.08
Panitian River outflow	51.3	0.52	0.59	1.38	45.2		0.21	0.2	0.52	0.28			0.83
Panitian River headwaters	52.9	0.39	0.44	0.92	44.5		0.14	0.18	0.37	0.25			0.74
Alfonso VIII Creek	48.7	0.47	0.68	1.39	47				0.41	0.29	0.25		0.99
Southern coast of Palawan	53.9			0.84	45.2								

Petrographic analyses

The observation of the thin sections reveals the jaspers to be formed by micro-quartz, mega-quartz, and chalcedony. Within the limits of the present study, we understand the term chalcedony in its broadest sense as defined by Lacroix (1909), including all fibrous spatial arrangements of elongated quartz. Rather large domains of length-fast fibrous pseudo-chalcedonite without extinction banding have been observed. The geological and mineralogical implications are the subject of ongoing studies of the author but exceed the present demonstration.

An overview of 4 thin sections is shown in Fig 5. The evaluated percentages of micro-quartz, mega-quartz, and chalcedony in each rockslide are shown in Figure 6. The matrix mainly consists of micro-quartz and chalcedony. Macro-quartz was found as joint filling material. Chalcedony is shown to be rather abundant in the jaspers. The samples contain between 10 and 40 percent radiolarian microfossils. The microfossil's bodies are replaced by chalcedony, which left their limits to be generally very dull. An identification of the exact type of the fossils is, therefore, impossible. The majority of the joints show chalcedony filling. It is this abundance of chalcedony in the jasper that reconsolidated the rocks after tectonic fracturing. The controlled *debitage* of the jaspers would not have been possible without the crystallisation of cryptocrystalline chalcedony.

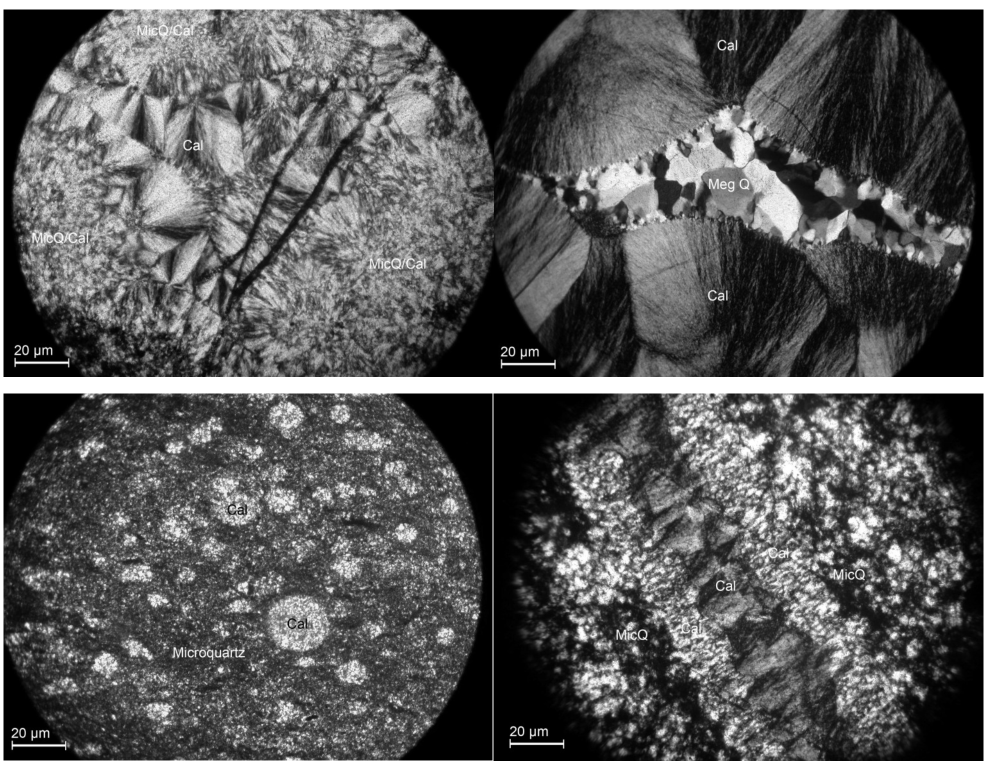
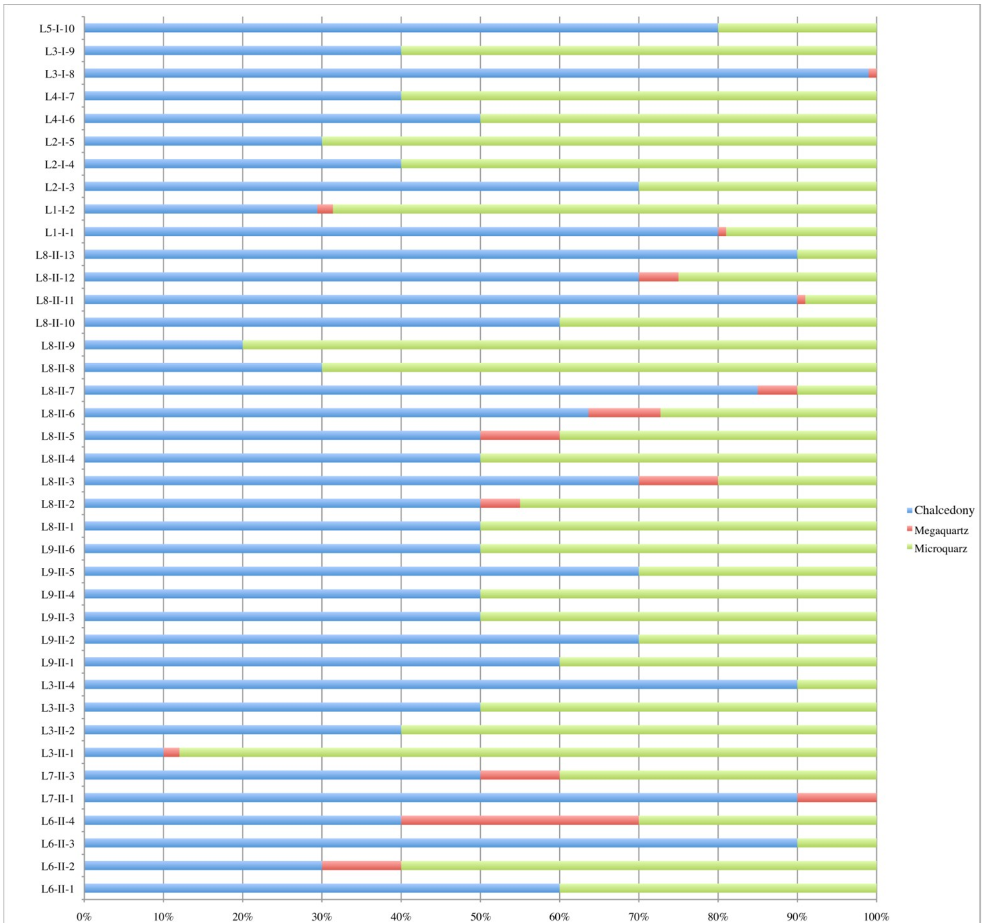


Figure 5. Micrographs of the observed minerals in the thin sections, where Cal is chalcedony *s.l.*, Meq Q is mega-quartz, and Mic Q is micro-quartz



	L6-II-1	L6-II-2	L6-II-3	L6-II-4	L7-II-1	L7-II-3	L3-II-1	L3-II-2	L3-II-3	L3-II-4	L9-II-1	L9-II-2	L9-II-3	L9-II-4	L9-II-5	L9-II-6
Chalcedony	60	30	90	40	90	50	10	40	50	90	60	70	50	50	70	50
Megaquartz	0	10	0	30	10	10	2	0	0	0	0	0	0	0	0	0
Microquarz	40	60	10	30	0	40	88	60	50	10	40	30	50	50	30	50

	L8-II-1	L8-II-2	L8-II-3	L8-II-4	L8-II-5	L8-II-6	L8-II-7	L8-II-8	L8-II-9	L8-II-10	L8-II-11	L8-II-12	L8-II-13
Chalcedony	50	50	70	50	50	70	85	30	20	60	90	70	90
Megaquartz	0	5	10	0	10	10	5	0	0	0	1	5	0
Microquarz	50	45	20	50	40	30	10	70	80	40	9	25	10

	L1-I-1	L1-I-2	L2-I-3	L2-I-4	L2-I-5	L4-I-6	L4-I-7	L3-I-8	L3-I-9	L5-I-10
Chalcedony	80	30	70	40	30	50	40	99	40	80
Megaquartz	1	2	0	0	0	0	0	1	0	0
Microquarz	19	70	30	60	70	50	60	0	60	20

Figure 6. Percentages of minerals found in the thin sections

X-ray powder diffraction

The diffractograms of four geological samples show the characteristic peaks for quartz. The quartz signature is dominant at greater than 95 percent in every case. Two peaks that are present in all four diffractograms (at 2.70393 and 2.52257 angstroms) show the presence of hematite (Fe_2O_3). It, therefore, seems that the iron (Fe), observed in EDX spectroscopy, is present as hematite. This hematite is likely to be the origin of the reddish to yellowish colour of the samples. The diffractograms do also indicate the presence of clay minerals. However, the concentration of these minerals is too weak to conclude on their precise identity.

Discussion

The number of studied samples seems to be generally sufficient for the laws of statistics to be applied (number of greater than 31). However, precision seems to be somehow limited in some cases. The different sampling *loci* did not yield more than 31 samples each. The exact raw-material supply *loci* that have been established by this study must, therefore, be considered as indications only. Further studies that take into account a larger number of geo-samples are necessary in order to confirm these indications. It shall also be reminded that the results of the present research cannot be correlated with a specific stratum within the cave, for the studied material's archaeological context is unclear. The present results attempt to be a first general schema of Tabon Cave raw-material procurement.

The utilised methods suitably complement with one another in differentiating the Palawan jaspers. IR spectroscopy leads to the determination of the minerals composing the jasper. EDX spectroscopy complements the latter by establishing a list of percentages of elements that were found within different geographical groups. Inversely, the IR spectra and x-ray diffractograms helped in the determination of the minerals formed by these elements. These determinations shed light on the genesis of the Palawan jaspers as well as the taphonomic evolution of the cave artefacts. Concerning the jaspers' colour, Elekes and colleagues (2000) demonstrated in a study on radiolarian jasper from the Carpathian Basin that the colour of this jasper is not in correlation with its chemical composition. In the present context, however, chromatic spectroscopy reveals to be a powerful tool for the differentiation of radiolarian jasper. The emerged scatter plots clearly display analogies and differences of the jaspers' colours in a numerical and, hence, quantifiable way.

Jasper raw-material procurement was rather infrequent in prehistory, for these rocks (*associated with* ophiolitic series) are usually highly tectonised. The petrographic analyses showed that the high percentage of chalcedonic quartz reconsolidated the tectonic fractures of the Palawan jasper. The reconsolidating chalcedony was a condition for conchoidal fracturing. Another case of jasper utilisation for lithic raw-material procurement is the Brook Run site in USA (Monaghan *et al*. 2004). The study of this jasper quarry can be compared to the Tabon Cave raw-material procurement strategy because it demonstrates some similarities. Monaghan and colleagues (2004) depict raw-material procurement in erosional zones along the banks of local rivers. The simultaneous existence of an organised jasper quarry in the same region is specified. In view of this case, one might pose the question of the existence of a simultaneously exploited jasper-bearing locus within the outcrops of the Espina formation. Concerning the formation of the Brook Run jasper, Monaghan and colleagues (2004) proposed a model involving a population of bacteria that was enveloped by hematite *post-mortem* and then replaced by hydrothermal silica. The Palawan jasper is more likely to show a different genetic history. Neither optical microscopy nor scanning electron microscopy showed hematite covered elongated structures similar to those described for the Brook Run jasper (Monaghan *et al*. 2004). However, the presence of evaporites (anhydrite/halite) in the matrix of the Palawan jasper could point to a hydrothermal formation.

The slightly different chemical record of IV-2000-T-485 that was suggested by EDX spectroscopy might implicate that this flake was knapped on jasper that was picked on a different location from the rest of the flakes. Further studies by using different analytical methods and further sampling on Palawan Island might be more affirmative about the status of this flake.

The slightly different status of IV-2000-T-450 that was suggested by chromatic spectroscopy is partially corroborated by the fracture patterns and the colour stains observed on the flake. All of the other utilised methods do not confirm this status. Further analyses, using particle induced x-ray emission (PIXE) or (inductively coupled plasma mass spectrometry (ICP-MC), might allow us to affine the present results concerning this flake.

Concerning the first research question, if Tabon Cave man supplied himself with raw material from the rivers around the cave, the present research seems to be affirmative. These rivers transported jasper to places that are less distant from Tabon Cave than the physical outcrop of the Espina Formation. Macroscopic analyses show that the fracture patterns of the river jasper are the same as the ones on the artefacts. Chromatic spectroscopy shows that the colours of the cave flakes match those of the river jaspers. IR spectroscopy shows that the jaspers of these two groups contain identical major elements. Some of the minor elements are also shown to be identical. EDX spectroscopy corroborates these results. A general correspondence between Tabon Cave artefacts and jaspers that are transported by the rivers is affirmed. The analyses point to an even more precise raw-material provenance. EDX spectroscopy indicates that Tabon Cave men rather went eastwards from the cave then westwards. The jaspers sampled in the Panitian River and its affluent Malatgao River show the best correspondence with the cave artefacts.

Concerning the distances that the occupants of Tabon Cave had to cover, the field study indicates some results. A direct taphonomic evolution in the matrix of the jasper that could be attributable to the river transport does not seem to exist. However, it seems that the transport separates blocks of bigger dimensions out. The sampling *loci* in the river's outflows do not yield jasper lumps of sufficient dimensions for debitage as it was practised in Tabon Cave. The close *loci* (from Tabon Cave) that bear blocks of a sufficient size are L8 (8.5 kilometres in a direct line from the cave) and L4 (9 kilometres from the cave). These places are close to the physical outcrops of the *Espina Formation*. Thus, it seems that present-day rivers do not transport big jasper lumps far away from the place where they erode them. However, depending on the changing sea level at different periods and the reactions of the river beds to these changes, the transport potential of the rivers might have been different from today.

Concerning the choices that were made during the raw-material provisioning, the present research opens up some of the behavioural patterns of Tabon Cave man. The characters that were observed on the Tabon Cave artefacts seem to constitute a selection. The macroscopic analyses show that not all of the characters that can be found on the river jaspers are present on the artefacts. Some of the characters, due to tectonisation that worsen the homogeneity of the jasper, were sorted out during the provisioning. In order to evaluate the presence of these characters, the lumps must be broken. Thus, a model of raw-material provisioning that includes a first debitage on the provisioning *locus* is proposed. This model may explain the findings of Robert Fox (1970) that raw-material lumps were absent in the archaeological sediments.

Conclusion

Tabon Cave men supplied themselves with jasper raw material in the southeast of their site. The Panitian River and its affluent, Malatgao River, are the most probable *loci* for this provisioning. A distance of at least 8 kilometres was covered during these provisioning excursions. The actors of the provisioning made choices that translate a good acquaintance of the available raw material. The heterogeneity of this jasper and, therefore, the necessity of breaking the blocks in order to evaluate their quality for knapping explains the originality of Tabon Cave's lithic reduction chain: the absence of unaltered raw-material lumps in archaeological sediments.

The present research was done on a limited archaeological corpus. The author hopes that future researches will take into account a larger number of Tabon Cave artefacts from a clear stratigraphical context. The recent acquisition of Tabon Cave artefacts that were long time held back in the house of Robert Fox's widow by the National Museum is likely to help in the application of the results to the rest of the site.

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