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Mineralogical evidence from Bukit Bunuh impact crater and its contribution to prehistoric lithic raw materials

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Abstract: The Centre for Global Archaeological Research (CGAR), USM has conducted a geoarchaeology research at Bukit Bunuh, Lenggong since 2008, and has proven that the site is an *in-situ* Paleolithic and meteorite impact crater. Recent studies and researches in geology and geophysics have also proven that Bukit Bunuh is a meteorite impact crater. The evolution of archaeological studies in Lenggong valley had made it being listed as one of UNESCO world heritage sites on 30 July 2012 through its chronology and importance to the country and world. The evidence of handaxe embedded in the suevite with the dating 1.83 million years shows a clear connection between archaeology and geology at Bukit Bunuh. The Paleolithic humans at Bukit Bunuh had chosen different raw materials to be used as stone tools and their equipment. Most of the stone tools were from cherty metasediment and quartzite, while some were made from suevite and quartz. The Planetary and Space Science Center (PASSC), based at University New Brunswick, Canada, has listed six criteria for indentifying an area as a recognized meteorite impact area. One of the criteria is the presence of high pressure mineral polymorphs within *in situ* lithologies. This mineralogical research focused on identifying high pressure minerals. Samples taken in this research was heavy minerals. The samples were collected using panning method at Bukit Bunuh, Lenggong and its vicinity. Sampling was done in three phases and 51 samples were analyzed using XRD. As a result, the analysis indicates the presence of high pressure mineral polymorphs in the samples such as stishovite, coesite, akimotoite, ringwoodite, reidite and wadsleyite. This may be the main reason why the edges of the stone tools, especially the flake tools and chunk tools mostly show that they have not been retouched. In addition, the identification of these minerals has proven that the rocks at Bukit Bunuh were good raw materials in terms of strength and durability compared to other types of rocks. Interpretation of lithic industry technology at Bukit Bunuh shows that manufacturing technology by Paleolithic humans are advanced with their raw materials.

Keywords: Heavy minerals, high polymorph minerals, raw materials, Bukit Bunuh

INTRODUCTION

This mineralogical study was made at Bukit Bunuh, Lenggong and its vicinity. The study was made to identify high pressure polymorph minerals as the evidence of the existance of an impact crater. Polymorph minerals are two or more minerals that have the same chemical composition but different atomical arrangement and crystal structure. High pressure polymorph minerals are formed from the shock pressure by the shock wave of a meteorite impact. These minerals formed naturally when the original rocks recrystallize at high pressure and temperature. Polymorphism is the ability of a particular chemical composition to crystallize in the form of minerals depending on temperature and pressure, or both (Rafferty, 2012). For example, the polymorph minerals coesite and stishovite belong to high pressure silica polymorph that is formed due to shock pressure. Despite its simple chemical composition, silica shows rich polymorphism at elevated pressure and temperature (Hemley *et al*., 1996; Stöffler & Langenhorst, 1994; Teter *et al*., 1998). A variety of dense polymorphs of elements, oxides and silicates have been found by laboratory high-pressure experiments. In nature, shocked meteorites are the most important source of high-pressure minerals, in addition to impact crater rocks, mantle xenoliths, inclusions in diamond, and ultrahigh-pressure metamorphic (UHP) rocks. It is not easy to fully characterize such high-pressure minerals because of their very small grain size and low abundance. However, state-of-art equipments such as electron microscopy, X-ray diffractometry, and micro-Raman spectroscopy enable the identification of such small crystalline grains (Tomioka, 2011; Miyahara & Tomioka, 2012). Textures, crystallography and chemical properties of a natural high pressure minerals not only provide us with information to understand the impact of meteorite events but also clues on the structure and dynamics of the Earth's depth. The Planetary and Space Science Centre (PASSC) that stores the database on impact cratering on Earth has listed the criteria to identify the impact structure, and one of the criteria is the presence of high pressure mineral polymorphs within *in situ* lithologies (microscopic evidence and requiring proof via X-ray diffraction, etc.). Therefore, this research was conducted with the aim to identify the high pressure minerals based on presence of heavy minerals and its relationship with the raw materials of stone tools. Quantitative and continuous approaches are more apparent through the diversity of physical properties of lithic raw materials and its type. The discovery of stone tools can be seen as a unique combination of raw material structure, composition and morphology. Hardness and surface roughness provide a broader view by providing the detailed information to complete the research (Lerner *et al*., 2007).

STUDY AREA

Bukit Bunuh impact structure (c. 100°58.5′E, 5°4.5′N) is a complex crater. Bukit Bunuh lies between Banjaran Titiwangsa and Banjaran Bintang. Geophysical method proved that the study area is underlain by highly fractured granitic bedrock with a depth of 5-50 m from the ground (Rosli, 2016). The study area covers Bukit Bunuh and its vicinity. The discovery of handaxe embedded in suevite rocks has shown the earliest signs of human living in Southeast Asia with the dating of 1.83 ma. The excavations that was done in 2001 to 2003 and 2008 to 2010 had exposed evidence that Bukit Bunuh is an *in-situ* Paleolithic workshop and were used from time to time.

The Paleolithic humans had populated continuously at Bukit Bunuh more than 1.83 million years ago, 500,000 years ago, 270,000 years ago, 40,000 years ago and 30,000 years ago based on the excavation records. Among the artifacts found are stone tools and tools such as cores, choppers, handaxes, flake tools, pebble tools, anvils and debitages from a variety of rock types and clear of the association. The early population had used suevite, cherty metasediment, quartz and quartzite as their raw materials (Mokhtar, 2006; Mokhtar, 2010; Nor Khairunnisa *et al*., 2016). In general, Bukit Bunuh is a Paleolithic Complex with different raw materials at different time scale. Bukit Bunuh also revealed the use of raw materials from impact meteorite rocks to make stone tools and equipment in lithic industry.

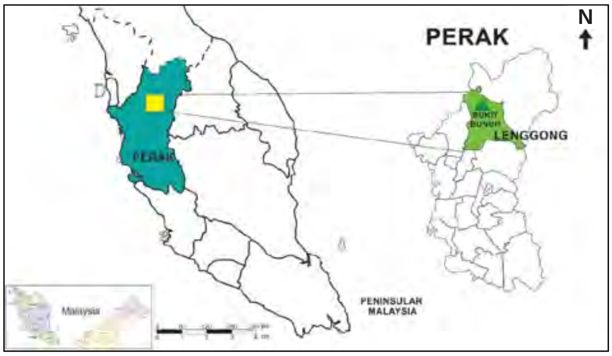

Figure 1: Location of Bukit Bunuh.

METHODOLOGY

Samples were collected from Bukit Bunuh streams and its vicinity, corresponding to the area of Bukit Bunuh impact crater. The samples taken in this research are heavy minerals. Heavy minerals is a class of mineral deposits with a density more than 2.8 g/cm^3 (Stendal & Theobald, 1994). The samples was obtained by panning process in the field using the standard gold pan and heavy minerals separation using Bromoform in the laboratory. The minerals are present in small quantities in sediments, especially sand, but they represent the variety of mineral classes from different geology units (Morton, 1985). Most of these minerals are very specific, limited and have their own paragenesis where some information cannot be provided by other methods. By using the geochemical data, we can determine the origin of minerals using mineral composition, structure and crystal morphology as an indicator of petrogenesis (Lihou & Mange-Rajetzky, 1996; Mange & Maure, 1992; Mertie, 1954; Morton, 1991; Morton & Hallworth, 1999; Morton *et al*., 2002). In geochemical exploration, the use of heavy minerals has a crucial role in detecting anomalous halos around mineralization (Gandhi & Sarkar, 2016). Thus, XRD analysis was made to identify the presence of polymorph minerals in the heavy minerals, which is based on the chemical composition of minerals. The analysis was carried out using an automatic horizontal diffractometer, rotating anode generator, with CuK*a* radiation operating at 40 kV and 40mA at the Earth Material Characterization Laboratory, Centre for Global Archaeological Research. These samples were analyzed by XRD on D8 Advance Bruker machine. We conducted XRD analysis by using full and slow scanning technique. The slow scanning technique was adopted to give more exposure of the X-ray to the samples with small angles. The step size of 0.008° and scan range from 28-32° 2ϴ/sec was used as the parameter for slow scan.

RESULTS AND DISCUSSION

The number of samples for the heavy mineral separation and XRD analysis are 51 out of the 95 samples collected. Some of the samples were too small to be analyzed. After heavy mineral separation, these samples were ground before the XRD analysis. Based on the XRD analysis, Bukit Bunuh and its vicinity is shown to be dominated by zircon, quartz, ilmenite, rutile, anatase and schorl minerals. These minerals are also representing or indicator of a class of high polymorph minerals. The analysis also showed the presence of high pressure polymorph minerals, which is coesite (Figure 2), stishovite (Figure 3), akimotoite, ringwoodite, wadsleyite (Figure

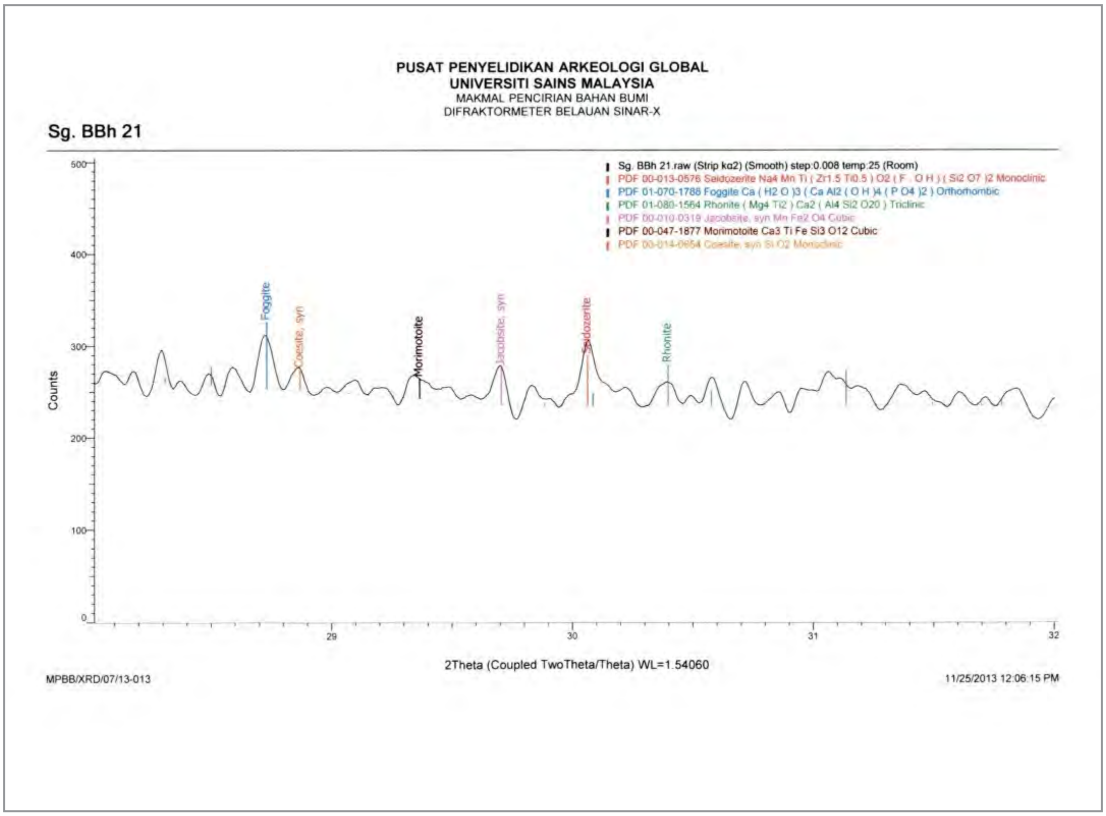

Figure 2: XRD pattern shows the occurrence of coesite mineral in Sg. BBh 21 sample.

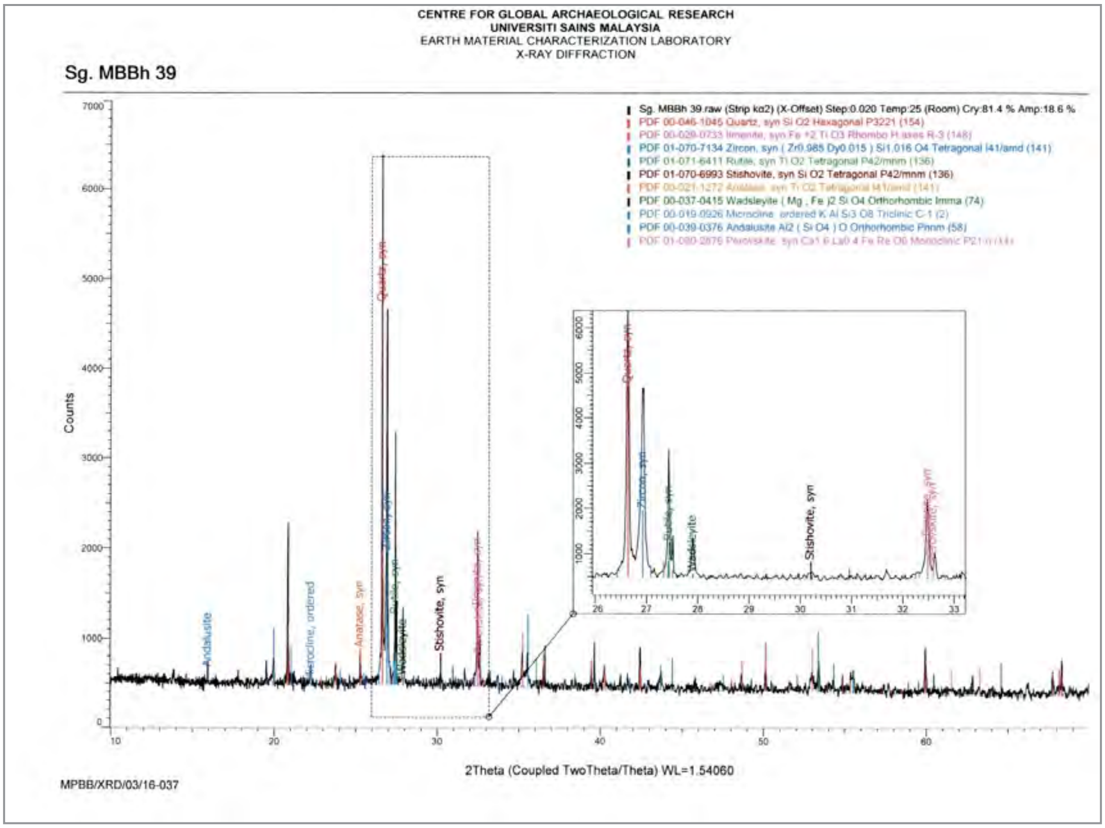

Figure 3: XRD pattern shows the occurrence of stishovite and wadsleyite minerals in Sg. MBBh 39 sample.

3) and reidite. Coesite and stishovite are the polymorphs of silica (SiO_2) group and these minerals have high Mohs scale with conchoidal fracture (Akhavan, 2014; Chao *et al*., 1960; Chao *et al*., 1962; Stishov & Popova, 1961).

Akimotoite is a polymorph mineral from the ilmenite group (Tomioka & Fujino, 1999) while ringwoodite and wadsleyite are polymorphs of olivine that formed during high pressure and temperature (Binns *et al*., 1969; Katsura *et al*., 2004; Kiefer *et al*., 1999). Reidite is zircon high pressure polymorph (Glass & Liu, 2001; Reid & Ringwood, 1969). The presence of these high pressure polymorph minerals proves that Bukit Bunuh is a meteorite impact site because these minerals are normally found in naturally occurring impact structures (astroblemes) and synthesized in experiments (Fel'dman *et al*., 2007). Most of these high pressure polymorph minerals have high density and Mohs hardness. Despite having the same chemical formula of SiO_2, their structural arrangement is different (Figure 4). Minerals with high hardness provide the rocks with more strength and toughness thus making it one of the important quality for stone tools production. The hardness property of the rocks and its fine texture were formed as the result of recrystallization of the regional rocks. Due to these advantages, this may be the main reason why the edges of most of the stone tools, especially the flake tool and chunk tool had not been retouched. This made the edge of the stone tools to be very sharp (Figure 5).

Thousands of artifacts such as pebble tools and flake tools were discovered on the surface of Bukit Bunuh site and during the excavation. More surprising is that some of these artifacts found were made using suevite as the raw material. Suevite is a rock that formed after an impact event, due to the high pressure and temperature. From excavation records, most of the stone tools found at Bukit Bunuh used quartzite, cherty metasediment, suevite and quartz as the raw materials (Table 1), compared to the other sites at Lenggong valley such as Kota Tampan, Lawin, Bukit Jawa and Temelong. Within these areas, quartz and quartzite are the main raw materials. The Bukit Bunuh site also revealed the different method to use the raw materials because the early humans here used rock cobbles from rock quarries. The other Paleolithic sites in the Lenggong valley however used pebbles directly from the rivers and streams.

CONCLUSION

The presence of high polymorph minerals at Bukit Bunuh has strengthened the evidence of Bukit Bunuh as an impact meteorite site. Based on the characterization

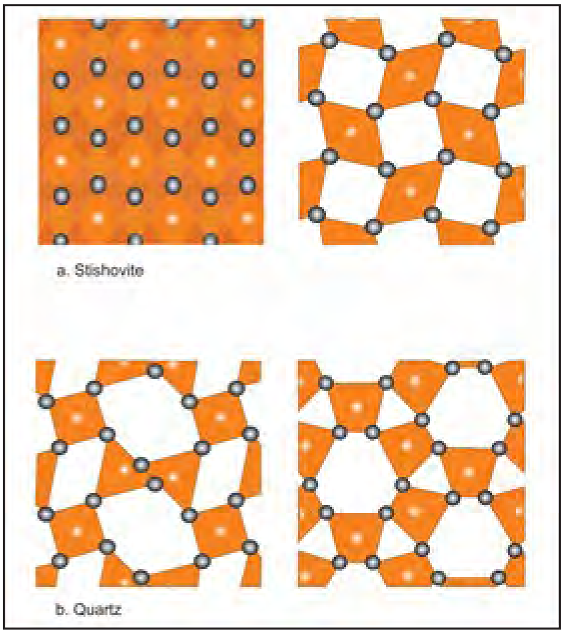

Figure 4: Crystal structures of stishovite compared to quartz (After Funamori *et al.*, 2015).

Figure 5: Edge of a flake tool that has not been retouched.

Table 1: Statistics of Bukit Bunuh raw materials. (Nor Khairunissa *et al*., 2016).

Raw Materials	Anvil	Core	Hammerstone	Flake tools	Pebble tools	Chunk tools
Quartz	2	229	37	21	9	133
Suevite	28	105	37	76	6	64
Quartzite	1	72	27	298	12	134
Cherty Metasediment	0	139	9	447	10	215

of these high polymorph minerals with high density and hardness indirectly give the advantage toward the raw materials at Bukit Bunuh. Hence, it has been advantageous to the selection of raw materials in terms of durability, compression and strength as well as describing the Paleolithic society of Bukit Bunuh were using the finest materials and knowing the appropriate materials in their vicinity to be used in the stone tools industry. Thus, this reveals that the Bukit Bunuh Paleolithic society acknowledged the best raw materials and shows that their technology was advancing.

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