Detecting microscopic aspects of Late Pleistocene to Early/Mid Holocene lithic technology in Island Southeast Asia: Perspectives from North and Central Sulawesi

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2. Summary

Late Pleistocene lithic assemblages from North (Leang Sarru) and Central Sulawesi (Topogaro) were subjected to multi-stage use-wear analysis. This study provides new perspectives on seemingly simple flaked tools from Island Southeast Asia (ISEA). The results indicate the production of specialised organic-based technologies and varying technological developments on different locations c. 35kya. Analysis of stone tools from Leang Sarru have micro traces indicating intensive plant working while animal bone processing was more evident in Topogaro. Furthermore, evidence of composite tool technology using amorphous flakes as hafted implements, plant processing (polish and plant residues), and deliberate tool modification to create concave notched working edges indicate a complexity that is in contrast to previous assessments of stone tool technology as being undeveloped and stagnant. Current perspectives on amorphous expedient technologies should be reassessed, particularly since microscopic use-wear analysis clearly shows the potential to address issues on the lithic technology in ISEA that might have been missed by techno-typological approach, such as multi-functionality and variability of tool use. This research complements previous studies on amorphous flake tools, provides new significant results from a functional perspective, and scrutinises established but poorly substantiated concepts such as ‘unchanging technology’, ‘bamboo technology’, and ‘smash-and-grab’ strategy in the framework of a more encompassing traceological identification of prehistoric activities.

Zusammenfassung

Diese Forschungsarbeit stellt die erste mehrstufige Gebrauchsspurenanalyse von Steingeräteinventaren aus zwei Fundstellen aus Nord- und Mittel-Sulawesi dar, Leang Sarru und Topogaro. Die Ergebnisse dieser Untersuchungen werden dabei mit bereits durchgeführten Studien von Inventaren von den nördlich von Sulawesi gelegenen Philippinen verglichen. Diese Dissertation eröffnet neue Perspektiven hinsichtlich der scheinbar einfachen und unentwickelten Steingeräte, die typisch für die Inselregion Südostasiens (ISEA) sind. Die Ergebnisse zeigen unterschiedliche technologische Entwicklungen innerhalb der Region ab ca. 35.000 Jahre vor heute. Die Steinwerkzeuge mit Gebrauchsspuren aus Leang Sarru weisen überwiegend Spuren intensiver Pflanzenbearbeitung auf. Demgegenüber war in Topogaro die Verarbeitung von Tierknochen, vermutlich zur Herstellung von Werkzeugen und Geräten, stärker ausgeprägt. Beiden Standorten gemeinsam ist das Vorhandensein deutlicher Hinweise auf Technologien, die auf organischen Materialien basierten. Darüber hinaus fanden sich Hinweise auf Kompositgeräte, wobei einfache amorphe Abschläge als Werkzeuge in Schäftungen eingesetzt wurden, sowie eine ausgeprägte Verarbeitung pflanzlicher Materialien, insbesondere phytolithenreicher Gräser (Mikropolituren und Pflanzenresiduen). Dies und die systematische Anfertigung gekerbter Arbeitskanten lassen eine funktionale Komplexität aufscheinen, die im starken Gegensatz zu früheren Betrachtungen der Steinwerkzeugtechnologie in dieser Region als rückständig und unentwickelt steht. Derartige noch immer etablierte Ansichten müssen daher unter funktionalen Gesichtspunkten neubewertet werden, besonders, da die Methoden der mikroskopischen Gebrauchsspurenanalyse Sachverhalte und Fragestellungen der Steingerätetechnologien in ISEA in umfassenderer Weise angehen können als die traditionell angewandten techno-typologischen Methoden. Diese besitzen gegenüber der Gebrauchsspurenanalyse klare Schwächen beim Erkennen komplexer technologischer Aspekte wie Multifunktionalität und Variabilität beim Gebrauch von Steinwerkzeugen. Diese Forschungsarbeit stellt nicht nur eine Ergänzung früherer Studien über einfache Abschlaggeräte dar, sondern liefert neue und forschungsrelevante Ergebnisse aus funktionaler Sicht. Sie hinterfragt etablierte, aber wenig fundierte Konzepte wie "unveränderte Technologie", „Bambustechnologie" und "Smash-and-Grab"-Strategie im Kontext

einer umfassenderen Gebrauchsspuren-Identifizierung prähistorischer Aktivitäten innerhalb Südostasiens. Darüber hinaus werden in dieser Arbeit auch Quantifizierungsmethoden von Gebrauchsspuren als Möglichkeit zur weiteren systematischen Behandlung der Schlüsselfragen der prähistorischen Technologie im Bereich des insularen Südostasiens behandelt.

3. General introduction

A. Late Pleistocene modern human migrations towards Wallacea

Migrations of anatomically modern humans towards Sahul during the Late Pleistocene is one of the most important issues in Island Southeast Asia. These early movements reflected the technological and behavioural adaptation of modern humans to island environments. Early open water crossing in ISEA by modern humans 50,000 years ago is evident in the permanent colonization of Sahul (Australia and New Guinea) (O'Connor, 2010). A group of islands located between Sahul and Sunda (mainland Southeast Asia), Wallacea is a hotspot for movements, material exchanges, and evidence for adaptations of AMH during the past 35-50kya. Open water voyages could have been possible due to technological capabilities of the first groups who were able to cross through Wallacea during periods of lowest sea levels (Fox, 1970; Pawlik and Ronquillo, 2003; Piper et al., 2008, 2011; O'Connell et al., 2010; O'Connor et al., 2011; Porr et al., 2012; Pawlik et al., 2014; Robles et al., 2014; Bird, 2019; Pawlik and Piper, 2019; Roberts and Amano, 2019)**.** At the centre of current research in early modern migrations is the region called Wallacea, a biogeographical region between Sunda (mainland Southeast Asia including Palawan and Borneo. Theories regarding human migrations through Wallacea proposed two main routes – the Northern Route through Sulawesi towards Papua and the Southern Route passing through Java through Flores and towards North Australia (Birdsell, 1977; Kealy et al., 2017; Bird et al., 2019). Several key sites along the Southern Route, including Liang Bua, Jerimalai Cave, and Laili Cave, provided fossil artefact records associated with AMH (Moore et al., 2009; O'Connor et al., 2011; van der Bergh et al., 2009; Sutikna et al., 2016; Marwick et al., 2016; Hawkins et al., 2017).

Current research on sea level rise and sea crossings in the region also indicates that sea crossings along the Northern Route had probably a higher rate of success (Kealy et al., 2016). The Northern Route would have led human migrations from Borneo to the western coastline of Sulawesi (Kealy et al., 2016). Although there are currently no fossils reported in Sulawesi, archaeological evidence such as rock art and stone tools indicate the arrival and colonisation the island of AMH of the region at around 40kya in the southwestern section of Sulawesi (Aubert et al., 2014; Brumm et al., 2018). The central and northern sections of the island have been studied and explored since the 1970s (Bellwood 1976), however Pleistocene deposits were only discovered in the 1995 with the excavation of Leang Sarru (Tanudirjo, 2001, 2005), which was reopened in 2004 (Ono et al., 2010). Our current project involving two sites in North and Central Sulawesi indicates human occupation of cave sites beginning around 35-30 kya (Tanudirjo, 2001, 2005; Ono et al., 2010, in preparation). In this research use-wear analysis of lithic artefacts from two sites, Leang Sarru in North Sulawesi, and Topogaro in Central Sulawesi, was conducted. These sites produced the earliest evidence of human activities at c. 35-30kya in Central and North Sulawesi. This study provides new perspectives on the behavioural and technological adaptation to insular and coastal environments.

Leang Sarru is a rockshelter situated in Salibabu Island, at the Talaud Islands in North Sulawesi. It was excavated in 1995 (Tanudirjo, 2001, 2005) and 2004 (Ono et al., 2010, 2015), revealing four main occupation phases (Ono et al., 2010). Stone tools made of chert were recovered from Leang Sarru indicating human presence as early as c. 35kya with the production of unretouched tools using hard hammer direct percussion technique. Morphological analyses were conducted by Tanudirjo (2001, 2005) and Ono et al. (2010, 2015), describing the presence of gull wing flakes that were produced with repeated strikes on the same spot (on the core) resulting in negatives on the ventral face of the flakes. Retouched ‘scrapers’ recovered during the 2nd phase (LGM) were also identified. Overall, the lithic technology in Leang Sarru can be categorised as similar with amorphous flake traditions in the region but with few retouched pieces. On the other hand, Topogaro 1 and 2 were excavated in 2016 (Ono et al., *in preparation*) and is an ongoing collaboration between Pusat Penelitian Arkeologi Nasional (ARKENAS, National Archaeology Research Centre, Jakarta, Indonesia), Balai Arkeologi (BALAR) Sulawesi Utara (Manado, Indonesia) and the National Museum of Ethnology (Osaka, Japan). Excavations in Central Sulawesi are still ongoing and so far, Topogaro 2 has C14 dates of c. 30kya at three meters below surface level while Topogaro 1 has first occupation layers dated to c. 10kya. Initial results of the research indicate the arrival of AMH in the ‘north route’ (Birdsell, 1977; Bird et al., 2019) at least c. 30kya (Ono et al., *in preparation*).

B. Informal expedient lithic technology in ISEA

The absence of formal tools has led researchers in ISEA to propose alternative views on the development of stone tool production in the region. Plant-based technology is one theory, supported mainly by the presence of use-wear traces attributed to contact with phytolith-rich plant species (e.g. Mijares, 2007; Lewis et al., 2008; Brumm et al., 2018). However, experiments are limited to prove or disprove this claim. Direct evidence such as plant cells, fibres, and tissues from bamboo or grass families are rarely preserved on stone tools in the region. Another is the presence of organic technology, mainly bone tools, that have been recorded in some sites in ISEA, mainly Niah Cave, Borneo with evidence of hafted bone tools from the Late Pleistocene (Barton et al., 2009)**,** Jerimalai, East Timor with shell fish hooks directly-dated between ~23 and 16kya (O'Connor et al., 2011), and sites in Mindoro, Philippines that delivered polished bone tools and shell adzes, a fishing gorge and flaked shell tools (dated to c. 30kya) (Pawlik et al., 2014, 2015; Pawlik and Piper, 2019)**.**

Morphological analysis has been ineffective in identifying trends in the development of lithic technology in ISEA, often anchored on the premise that formal tools are absent in the region, implying 'stagnated' stone tool traditions (Movius, 1948; Coutts, 1983; Patole-Edoumba, 2012). Based on traditional techno-typological cultural periods in Europe and Africa, the lithic industries in Wallacea are a dilemma because these do not fit the definitions of lithic technologists (Haidle and Pawlik, 2009; Pawlik, 2009). This expedient technology from Late Pleistocene to historical period, has the same form and did not change even with the arrival of Austronesians and ceramic technology (Coutts and Wesson, 1980; Pawlik and Ronquillo, 2003; Mijares, 2007; Pawlik, 2009, 2010; Fuentes, 2015). It is further argued that the absence of formal tool types was the result of production and use of an organic- or plant-based technology. The bamboo hypothesis has been proposed to have existed in the region because of the ubiquity of bamboo species (Solheim, 1972; Pope, 1989; Bar-Yosef et al., 2013) and also based on ethnographic and experimental studies (Xhauflair, 2014; Xhauflair et al., 2016, 2017). So far, this ongoing debate on whether plants replaced or complemented lithic materials in ISEA failed to point out complexity in uses and functions of lithic materials. Borel et al. (2013) addressed the problem of studying flaked tools from the Early Holocene period of ISEA by combining data from use-wear and geometric-morphometric analyses of lithic assemblage from Song Terus (Java, Indonesia). The results suggest that form is not the main criterion in production and selection of stone tools rather it is the suitability for particular tasks (Borel et al., 2013). Formal tool types during the Late Pleistocene and Early Holocene are rare in ISEA. An example is the Toalean lithic industry or the Maros points, recovered from South Sulawesi. Maros points refer to the small, hollow-based point that are usually with saw-tooth margins (Mulvaney and Soejono, 1970; Glover, 1976). This absence of formal tools, at least to standards applied to sites in Europe and Africa, led to a dilemma on how to categorise technology in the region (Pawlik, 2009).

C. Use-wear analysis and typology dilemma

Use-wear analysis is founded on the premise that certain traces on the surfaces of stone artefacts are caused by contact with certain types of materials (Semenov, 1964; Keeley and Newcomer, 1977). In fracture mechanics, this is more commonly known as tribology, the science of rubbing surfaces. In archaeology, the actors include the artefact (stone tool) and the worked object (Yamada and Sawada, 1993). The same concept is being followed for the analysis of both experimental and actual prehistoric stone tools. Distinct use-wear traces are formed because of contact with different types of materials (e.g. Semenov, 1964; Tringham et al., 1974; Odell, 1977; Hayden, 1979; Keeley, 1980; Anderson-Gerfaud, 1981; Kamminga, 1979, 1982; Keeley, 1980; Odell, 1981, 1996; Vaughan, 1985; Unrath et al., 1986; Beyries, 1988; van Gijn, 1989, 2014; Pawlik, 1992, 1995, 2001, 2009; Anderson et al., 1993). Knowledge of use-wear traces is vital in the identification of prehistoric stone tool use, thus replicative experiments are necessary (Semenov, 1964; Keeley and Newcomer, 1977). Action-oriented experiments focuses on the development of use-wear traces in a controlled setting while goal-oriented approach aims to understand the development of use-wear traces vis-à-vis the end product or goal (Vaughan, 1985; Unrath et al., 1986).

Two main approaches in lithic use-wear analysis developed through time – low power (examining scarring and rounding) and high power microscopy (examining surface alterations, polish, and striations) (e.g. Keeley, 1976, 1977, 1978, 1980; Keeley and Newcomer, 1977; Odell 1977, 1979, 1981; Hayden, 1979; Odell and Odell-Vereecken, 1980; Kamminga, 1982). The low-power approach applies magnifications below 100x to identify edge scars and rounding. Vaughan (1985:10-11) outlined the main classes of use-wear traces, which include microchipping - the scars along the edges of stone tools caused by intentional utilisation or in some cases non-use damage mechanisms (edge scarring – Odell, 1975; microflaking – Tringham et al., 1974; utilisation damage – Keeley and Newcomer, 1977; edge damage – Keeley, 1980; *micro-esquillement* and *ébréchures* – Dauvois 1977; retouche d'utilisation – Brézillon, 1977; and *micro-écaillures* – Anderson-Gerfaud, 1982: 25). Rounding or smoothing of the working edges can also be observed in lower magnifications (Pawlik, 1992). In high-power approach, tool surfaces are observed using a modified reflected light microscope with differential interference contrast (DIC) at optical magnifications of 100-500x Odell, 1979; Keeley, 1980; Kamminga, 1982; Vaughan, 1985; Odell, 1996; Pawlik, 2001). Higher optical magnifications allow researchers to identify striations and polishes. Striations indicate the direction and type of motion while micropolishes indicate which type of contact materials were processed in the past (Semenov, 1964; Keeley, 1974; Hayden, 1979; Kamminga, 1982; Newcomer et al., 1986; Vaughan, 1985; Unrath et al., 1986; Fullagar, 1991; Pawlik, 2001, 2017).

The processes of polish formation are still debated among use-wear analysts and three main theories emerged from this. The abrasion model (e.g. Crabtree, 1974; Dauvois, 1977; Diamond, 1979: Kamminga, 1979; Masson et al., 1981; Meeks et al., 1982) suggests that “polish is produced by the gradual loss of surficial material (wearing down) and smoothing of those surfaces” (del Bene, 1979:172 as cited by Vaughan, 1985:13). The friction-fusion model proposes that the intense localised frictional heat in the main contact area of the stone tool causes silica to melt and fuse. This is the mechanism behind the formation of sickle gloss (Witthoft, 1967). The amorphous silica gel model suggests that silica and precipitates in an amorphous gel-like state and appears as highly reflective polish. Furthermore, it causes particles of the worked material to be embedded in this gel (Anderson-Gerfaud, 1981, 1982). Vaughan (1985) outlined three stages of development of polish in experimental tools. First, generic weak refers to the dull polish, which is, nonetheless, somewhat brighter than the natural reflective background of the flint, yet less reflective than a well-developed polish on the same surface. Smooth-pitted refers to the individual small polish components, with smooth surfaces, formed on the higher points of the microtopography of a generic weak polish contact area. The components of the polish can be said to be incompletely linked, thus there are numerous darker interstitial spaces between the polished sections referred to as micropits. The final stage in polish formation, called well-developed, is characterised by the increase in intensity of reflection and increase in linkages between the affected areas (Vaughan, 1985:29-30).

Residue analysis is one of the main components of use-wear approach (e.g. Anderson, 1980; Vaughan, 1985; Kooyman, 1992; Loy, 1993; Loy et al., 1992; Pawlik, 1995, 2004a, 2004b; Jahren et al., 1997; Atchison and Fullagar, 1998; Dominguez-Rodrigo et al., 2001; Rots, 2002; Wadley et al., 2004; Lombard and Wadley, 2007; Xhauflair and Pawlik, 2010; Pawlik and Thissen, 2011). Residues refer to deposits of a former contact material on artefact surfaces. Initially, only organic residues that can be removed using hydrochloric acid but are not washable by soap and water, alcohol or acetone, were considered (Keeley, 1980; Vaughan, 1985). However, inorganic residues from hematite and ochre (e.g. Wadley, Lombard, and Williamson, 2004) or pyrite (Pawlik, 2004b; Sorensen, 2014) associated with tool use have also been analysed. Prehistoric hafting technology can be reconstructed based on the locations of residues on the tool surface (Keeley, 1980; Anderson-Gerfaud, 1981, 1982; Vaughan, 1985; Pawlik, 1995, 2004; Rots, 2002; Pawlik and Thissen, 2011, 2017). Current use-wear analysis techniques such as surface metrology, geographic information systems (GIS), three-dimensional microscopy, and micro-residue analysis are being employed to obtain data with higher resolution and a more standardised approach (e.g. Barceló, Pijoan, and Vicente, 2001; González-Urquijo and Ibáñez-Estévez, 2003; Evans and Donahue, 2008; Bird, Minichillo, and Marean, 2007; Macdonald and Wilkins, 2010; Schoville and Brown, 2010; Macdonald, 2014; Stemp et al., 2015; Bordes et al., 2018; Prinsloo and Bordes, 2018).

Use-wear analysis is a suitable method to address particular issues of lithic technology in ISEA and in other regions with informal flake assemblages. Pawlik

(2012) proposed a microscopic approach in dealing with lithic technologies in the Philippines due to similar types of lithic artefacts recovered from the Late Pleistocene to the Holocene and even until the historical period. He further analysed artefacts from Ille Cave, Palawan (Philippines) and inferred use as of unretouched lithic flakes as composite tools. It shows possibilities with use-wear analysis rather than employing technological approaches in creating a chronological sequence of technological development in the region. The same dilemma occurs in most sites in the Philippines and ISEA (Haidle and Pawlik, 2009). The North and Central Sulawesi assemblages are also composed of unretouched flakes, however, retouching was present especially during the transition to the Holocene period. Similar use-wear approaches were used for both unretouched and retouched stone tools.

Multistage use-wear analysis has its limitations, thus, for future research the following should be addressed particularly for ISEAn assemblages: 1) increasing sample size across several sites, 2) recording all the anomalies and not only dependent on key traces that were previously mentioned (e.g. plant polish associated with bamboo and rattan working, 3) extensive taphonomic experiments, and 4.) consider complex technologies such as hafting and intentional retouching in tool interpretations. These suggestions could alter interpretations and provide a more accurate picture of the prehistoric lithic technology in the region. Although, the development of hafting and formal tool technology during the Pleistocene is not yet fully understood, future studies can address these more sufficiently.

4. Objectives and expected output of the thesis/ doctoral research

This research contributes to our understanding of the development and variability of lithic technology in ISEA through a multi-level comparative analysis of stone tool assemblages from Indonesia. Second, we aimed to integrate state-of-the-art technology of microwear analysis to fundamental archaeological research by examining lithic artefacts to determine their actual uses, especially in cases not suitable with techno-typological approach. This is the first application of use-wear analysis to the study of lithic assemblages from North and Central Sulawesi. This researcher conducted a morphological-technological classification of the samples, utilised use-wear analysis to identify the tool functions, and inferred the activities carried out at Leang Sarru and Topogaro throughout their occupation sequences. Overall, the comparison of prehistoric stone tool functions of the assemblages from North and Central Sulawesi allowed us to understand technological development in island setting during period of drastic environmental change.

The outcome of this study is a significant contribution to the reconstruction of human behaviour and the responses to a changing palaeoenvironment in Wallacea from the Terminal Pleistocene to the Holocene. The identification of former tool uses and the different activities carried out with these stone tools shed light on the cognitive and behavioural abilities of prehistoric humans, their subsistence strategies, and interaction with a tropical rainforest environment. The research outputs were submitted to international peer-reviewed journals for publication and results were presented in international conferences, highlighting themes such as prehistoric technology and maritime interactions ISEA. The researcher also established collaborations with institutions in Germany, Japan, Philippines, and Indonesia, for future research.

5. List of publications

A. Accepted papers

1. **Fuentes, R.** and Pawlik, A.F. **In press.** *Not formal but functional: Traceology and the Lithic Record in the Philippines*. In Hunter-gatherers tool-kit: a functional perspective. Edited by Gibaja, J., Clemente, I., Mazzuco, N., Marreiros, J. Cambridge Scholars Publishing.
2. **Fuentes, R.**, Ono, R., Nakajima, N., Nishizawa, H., Siswanto, J., Aziz, N. Sriwigati, Sofian, H.O., Miranda, T., and Pawlik, A.F. **2019.** Technological and behavioural complexity in expedient industries: the importance of use-wear analysis for understanding flake assemblages. Journal of Archaeological Science.

B. Submitted manuscripts

1. **Fuentes, R.**, Ono, R., Carlos, J., Kerfant, C., Sriwigati, Miranda, T., Aziz, N. Sofian, H. O., and Pawlik, A.F. **Under review**. *Stuck within notches: direct evidence of plant processing 22,000 years ago in North Sulawesi*. Proceedings of UISPP Sessions XII-1 and XII-2 on Functional Studies. Journal of Archaeological Science: Reports.

C. Manuscripts ready for submission

1. Ono, R., **Fuentes, R.**, Pawlik, A.F., Sofian, H.O., Sriwigati, Aziz, N., Alamsyah, N., and Yoneda, M. *Island migration and foraging behaviour by anatomical modern humans during the late Pleistocene to Holocene in Wallacea: New evidence from Central Sulawesi, Indonesia.*
2. **Fuentes, R.**, Ono, R., Sofian, H.O., Aziz, N., Sriwigati, Alamsyah, N., Faiz, Miranda, T., and Pawlik, A.F. *Microscopic traces on tools used by anatomically modern humans in Central Sulawesi 30 thousand years ago*.
3. **Fuentes, R.**, Ono, R., Sriwigati, Aziz, N., Sofian, H.O., Miranda, T., and Pawlik, A.F. *Missing or undetected? A review of microwear traces on composite prehistoric lithic tools from ISEA.*

D. Manuscripts being prepared (abstracts)

1. Quantification of polishes on unretouched flakes from Island Southeast Asia
2. A technique for quantification of polish bevel from plant working

6. Results and discussion

A. Typology dilemma in ISEA – cases from the Philippines

Amorphous lithic tools that are prevalent in ISEA are often categorised as expedient lithic tools, showing little to no change from the Pleistocene until Holocene and even until the Metal Age. This unchanging technology has been documented in several studies, proving previous claims that the lithic technology in the area stagnated (Fuentes and Pawlik, *in press*; see Appendix A.1). This research did not include artefacts from the Philippines due to access with excavated materials, which are currently being studied or were already analysed by other researchers - Ille Cave and Rockshelter, Callao Cave, and Tabon Cave (Mijares, 2007; Lewis et al., 2008; Xhauflair, 2008; Pawlik, 2010). However, this researcher is collaborating within the Mindoro Archaeological Research Project and participates in the technological and functional analysis of lithic artefacts from three sites investigated within the project. The Mindoro Archaeological Research Project is a long-term multidisciplinary research initiative that investigates early migration and maritime adaptation of the first modern humans reaching the Philippines (Pawlik et al., 2014, 2015; Neri et al., 2015; Carlos et al., 2018; Boulanger et al., 2019; Pawlik and Piper, 2019). Other researchers in the Philippines are already currently working on lithic assemblages similar in radiometric dates to Leang Sarru and Topogaro. These include Tabon Cave in Palawan (Xhauflair, 2008; Xhauflair and Pawlik, 2010; Xhauflair et al., *in review*) and Callao Cave in Northern Luzon (Mijares, 2007). Those assemblages have the same context with the sites from Central and North Sulawesi, however, these are already being studied by other lithic analysts. The researcher was able to study Neolithic tools from Vito Cave in Northern Luzon and addressed the issue of appearance of pottery-wielding groups or the so-called Austronesians (Fuentes, 2015), which was previously addressed by Mijares (2007). Pawlik (2009, 2012) argued for the possibility of more complex functions of amorphous flakes with the identification of hafted tools from the Terminal Pleistocene in Ille Cave, Palawan From the 1980s and until the establishment of the Lithic Studies Laboratory in the Philippines in 2001 (Dizon and Pawlik, 2001), the main research themes underwent the same typology dilemma observed in other Palaeolithic sites in ISEA. Furthermore, the pursuit of characterising the so-called bamboo technology led researchers to conduct more detailed plant-working experiments, coupled with ethnographic field research (Xhauflair, 2014; Xhauflair et al., 2016, 2017).

Techno-typological evaluation of the analysed samples from Leang Sarru and Topogaro indicate production and use of unretouched flakes from c. 35kya until the Metal Age (Fuentes et al., 2019, *under review, in preparation).* This seemingly unchanging technology did not cover the production and use of retouched tools and hafting as part of the amorphous lithic package, and thus needs to be further studied. Tool modification and technologies that were not previously described within lithic studies for the region were identified through use-wear analysis. The researcher was able to detect traits, such as hafting technology and intentional production of 'formal' tools, previously considered to be rare or even non-existent in the region (Pawlik, 2012). These results are relevant not only to amorphous lithic assemblages in ISEA, but to other regions that encounter the same typology dilemma, previously outlined by Pawlik (2010). Expedient technology, previously thought to be 'backwards', 'stagnated' or even 'culturally retarded' (Movius, 1948; Mijares, 2002) can be better appreciated within the overall debate of appearance of technologies such as formal and composite tools. The status of use-wear analysis in the Philippines greatly reflects the specialisation in ISEA as most of the premise and literature in the discipline were mostly produced from sites in Luzon and Palawan (Koenigswald, 1958; Fox ,1970; Pawlik and Ronquillo, 2003; Lewis et al., 2008). Thus, to understand prehistoric technology and functions in the northern part of Wallacea and ISEA, the approach needs to be applied to adjacent sites south of the Philippines to have comparisons and discuss amorphous lithic technology in the larger context and targeting locations within the most possible routes of AMH towards from Southeast Asia to Sahul (Kealy et al., 2016). To address this issue, we analysed stone tools from Leang Sarru rockshelter (N=182) in North Sulawesi and Topogaro caves (N=173) in Central Sulawesi. Both sites have produced archaeological sequences beginning from c. 35-30kya and continued until the Holocene and Metal Age with majority of stone tools considered as unretouched with few samples that can be categorised as retouched lithics.

B. Traceology of lithic assemblage from Leang Sarru, North Sulawesi

This is the first multi-stage use-wear analysis of Palaeolithic artefacts from Leang Sarru, since the it was excavated in 1995 and 2004 (Tanudirjo, 2001, 2005; Ono et al., 2010, 2015). The researcher analysed 183 artefacts from four main cultural phases (and samples from the 'Modern Period') in Leang Sarru (Fuentes et al., 2019*,* see Appendix A.2; Tanudirjo, 2001, 2005; Ono et al., 2010). The implications are discussed within the framework that form does not follow function in ISEA, previously addressed by Borel et al. (2013) with the analysis of early Holocene assemblage from Song Terus through a combination of geometrics-morphometrics and use-wear analyses. Interpretation of stone tool functions in ISEA has been limited due to few experiments conducted only recently often pointing to production of organic technology that might have played a role during the Late Pleistocene. Bamboo technology is being proposed as an alternative to the supposed backwardness of lithic technology in the Philippines and in the region in general. It has been the accepted notion, thus, most studies focused on this aspect of expedient lithic technology in ISEA (Mijares, 2007; Xhauflair et al., 2016).

A clear indication of plant use during the Terminal Pleistocene is the presence of well-developed sickle polishes on unretouched flakes in processing phytolith-rich plants. Intensive polishes were identified along the working edges, creating undulating flat polishes and bevel (Fuentes et al., 2019, see Appendix A.2). Transversal striations and scarring were also formed on polished surfaces where polishes developed indicating repetitive scraping action. No bone artefacts were recovered at the site, which also suggests dominantly plant processing. Polish formation is characterised by undulating smooth areas emanating from the edge outline then transitioning to smooth-pitted and generic-type polishes, at the inner part of the edge. The traces indicate higher working angles that can be interpreted as scraping action for smoothing through repeated motion. This is probably due to lesser contact on sections away from the working edge outline. The main contact sections can be inferred following the segments showing concentration of polishes at the centre of the working edge outline, which slowly fades towards the left or right lateral section of the working edge. This indicates transversal action especially scraping, as opposed to parallel motion. Polish bevels were also identified on unretouched flakes indicating steep working angles up to 90 degrees (see Appendix A.2), which is preferred for thinning or smoothing actions (based on experiments conducted by the researcher). This type of polish can be formed through consistent and continuous contact with phytolith-rich plants, indicating activities such as thinning for basketry (Xhauflair et al., 2016). These intensive plant polish formation has often been suggested as the main indicator of the so-called bamboo technology in the region. The results suggest contact with phytolith-rich plants, however, this may not necessarily point to bamboo-working. The study concluded that these were phytolith-rich plants but identification to the species level is difficult to impossible due to the diversity of flora in the region. Previous researches that supported bamboo- or rattan-working based their interpretations on very limited experimental database (Teodosio, 2006; Mijares, 2007). Quantification methods might aid in the identification of ‘plant species preference’, however, more relevant issues such as which parts of plants were processed, what were the desired end products, and what was their role in the prehistoric toolkits of the early islanders must be addressed.

Other than indirect evidence in the form of use-wear traces (polishes), our research also found direct material evidence. Plant remains were identified on the artefacts even after mild cleaning (Fuentes et al., *under revie*w, see Appendix B.1). These were recovered were recovered from the c. 22kya, and as old as 35kya, until the Holocene. These include plant cells and tissues, raphides, starch, fibre, and decaying or indistinct plant cells which are comparable to those identified on archaeological sites in Wallacea and Sahul (Kononenko, 2011; Torrence and Barton, 2016). These were deposited on both the unretouched and retouched flakes, on the working and non-working sections. Plant cells, especially parenchyma, were deposited throughout all the occupation phases. It was only during the Early Holocene when starch and raphides were identified, and during the Metal Age when fibre was preserved. Plant processing was therefore aimed at producing binding for attachment on shafts. The absence of bone points (as well as animal bones) further supported our view that intensive plant working was conducted as adaptation to available resources while at the same time tool modification became a specialisation in order to process hard materials through scraping activity (Fuentes et al., 2019; Fuentes et al., *under review,* see Appendix B.1).

Retouching through direct percussion was applied to create ‘notched’ concave working edges. Plant working was not only conducted with unretouched flakes but also with notched tools. Activities such as scraping and smoothing are more efficient with the use of blunt concave tools, the retouched notched in the case of Leang Sarru. Intentional retouching began to be recorded in layers dated from the Terminal Pleistocene. Flakes were modified through repetitive striking on one part of the proximal base, usually at its thickest section, to create a concave section. The researcher conducted replication experiments and was able to reproduce similar concave edges through direct percussion technique (Fuentes et al., *under review*, see Appendix B.1). These tools have steep edge angles, usually greater than 45 degrees. Plant working should not be perceived as an end point in understanding the prehistoric technology in ISEA. It is rather just a facet in the technology previously thought to be simple and stagnated. As a result, plant remains were deposited within the retouched sections of these notched tools and identification of these residues provided direct evidence of plant working in the site.

In order to test our hypothesis that retouching played a vital role in the deposition and preservation of the plant remains, experiments were conducted at Talaud Islands in North Sulawesi using local chert materials and plants. Although the experiments are still limited, the documentation of residues indicate that 1.) step and hinge scars on the retouched sections acted as catchments for plant residues regardless of activity, but more apparent when processing fresh plants 2.) physical angle of plant preservation must be looked upon to understand why plant preservation on stone tool surface is rare in ISEA 3.) future research should address the phenomenon of fungal growth on plant remains deposited on stone tools and its role in either the hastening or slowing down of decomposition (Langejans, 2010; Fuentes et al., *under review,* see Appendix B.1).

The results provide evidence for plant processing using unretouched and retouched tools in Leang Sarru during the Pleistocene to Holocene. Hafted lithic technology was also documented in this study, which is still rare in Late Pleistocene sites in Island Southeast Asia (Pawlik, 2012). Complex hunter-gatherer behaviour can be revealed through microscopic study of simple flake tools. Furthermore, use-wear analysis could assist in redefining expedient lithic technology in ISEA. Technological traits not detectable through macroscopic approaches can be detected through microscopic use-wear analysis. The state of the art of use-wear analysis in the region focuses on identification of simple tasks such as cutting, scraping, or chopping which limits interpretations of lithic technology in the region. Although the number of artefacts displaying complex activities were limited, through use-wear analysis the researcher was able to identify traces that indicate production and possible use of hafted tools, especially unretouched ‘blades’. By utilising published materials on hafted composite tools, the researcher was able to document scalar scars, hafting polish, impact scars, and tar residues pointing to production and possible use of unretouched tools to create composite tools (Fuentes et al., 2019).

In general, the lithic technology in Leang Sarru can be characterised by intensive plant working using unretouched and retouched flakes. Overall, in terms of morphology, it is similar with other assemblages in ISEA, however, upon closer inspection, cultural traits previously rare in the region were identified – possible hafting and retouching to create formal tools. These technological innovations are uncommon in the region and often been justified or explained by the seeming dependence on organic plant-based technologies. Through use-wear analysis, minute details of complex activities using simple tools can be identified. The same approach should be utilised in addressing the question on the absence of technological development of stone tools in ISEA. The results show that unmodified flakes were utilised in a similar manner as retouched tools - an aspect of lithic technology in ISEA that still needs to be properly documented.

C. Stone tool functions at Topogaro Caves, Central Sulawesi

This is the first multi stage use-wear analysis in the region and could provide clues in the earliest lithic technologies in Central Sulawesi or the so called North Route as outlined by Birdsell (1977) and Bird (2019), so far the only site with radiocarbon dates 30kya or older. The overall results of material analysis, radiocarbon dating, and interpretation of site occupation for the Topogaro sites are being prepared (Ono et al., *in preparation*, see Appendix C.1). Techno-typological analysis of all lithic artefacts from both Topogaro 1 and 2 are still ongoing and in this research the researcher presents the initial results from use-wear analysis of samples from layers dated to c. 30kya until the Metal Age.

One hundred seventy six artefacts from Topogaro 1 and 2 in Central Sulawesi undergone multi-stage use-wear analysis. The artefacts were sampled from excavations conducted from 2016-2017 (Ono et al., *in preparation*). The assemblage was collected through dry-sieving and recovered in situ. Impact scars with secondary edge rows indicate bone chopping from c. 30kya, the oldest-dated layer of Topogaro 2 so far (Ono et al., *in preparation*; Fuentes et al., *in preparation*). Activities from this period were carried out using chert flakes. One tool displayed step- and hinge-terminated scars along the working edge, and was recovered in the same context with animal foot bones (Ono et al., *in preparation*). These technologies not only utilised chert tools but also limestone and silicified chert with generally smaller dimensions. These were possible microliths made from limestone were recovered from c. 30kya. Chert materials based on initial surveys were generally available at the periphery of the site, along streams and at the main river system (Ono et al., *in preparation*). Analysis is still ongoing but initial assessment indicate production of small triangular limestone flakes (c. <3 cm in length). Further analysis and comparisons with other lithic technological traditions in Sulawesi and Wallacea needs to be conducted to place the stone tool traditions into their proper context.

Tool retouching using direct percussion technique was identified on stone tools from the LGM layers in Topogaro 2. A unifacially retouched chert flake indicates possible production of points. Through microscopic analysis the retouched point displayed MLITs with longitudinal orientation – evidence of use as projectile (Fuentes et al., *in preparation,* see Appendix C.2). These belong to the techno-typological classification of points with unifacial retouching to create a formal tool. During the Holocene similar points were observed but produced with soft hammer percussion technique as shown by shallow and feather scarring, initiated from both dorsal and ventral face. Replicas of these tools were reproduced through direct percussion technique with the use of hammerstones c. 5cm in diameter.

Bone points were recovered from Topogaro 1 and are associated with notched scrapers. Retouched notched tools feature a single notched retouched from either the ventral or dorsal face, characterised by shallow and feather terminated scars. Retouched tools display concave edges produced with direct percussion technique. These were recovered with bone points and are associated with bone processing.

Furthermore, unretouched flakes indicate polishes from contact with bones, especially scraping. The researcher hypothesise that bone processing was conducted using retouched tools. On the other hand, polishes formed through contact with bones were also identified within the same assemblage. Production of bone tools involved several stages and notched scrapers where thought to have been used in roughing the bone fragments before actual bone smoothing. Throughout Holocene and even the latter periods of Holocene, these two artefact types were recovered and creates a clear demarcation of intensive bone tool production in the sites, which was limited to absent in Topogaro 2.

Evidence of presence of AMH at the oldest layers of the site indicate stone tools and animal bones were recovered in the same context. Stone tools recovered from 30kya layers, classified as ‘large’ flakes were manufactured using chert. Limestone was also used in producing large flakes and possibly microliths (Fuentes et al., in *preparation*, see Appendix C.2). Tool retouching was identified on tools from the LGM at Topogaro 2 while it was observed on notched scrapers in Topogaro 1 beginning the Holocene period. Future techno-typological research in the sites can provide more clues to the technology of AMH who crossed from Sunda to Sulawesi. The results of use-wear analysis indicate direct evidence of human presence in the island and intentional production of stone tools c. 30kya, with evidence of tool retouching to create notched scrapers later during the Holocene. The availability of resources around the site (Ono et al., *in preparation*) indicate the availability of good quality chert very similar to what were used in the past.

D. An experimental database for North and Central Sulawesi

Although still ongoing, this research also included an experimental database, which is the first extensive one to be developed solely for the purpose of addressing prehistoric use of stone tools associated with early movements of AMH in North and Central Sulawesi. Surveys were conducted to identify possible raw material sources for production of stone tools. Knapping was conducted at BALAR Manado to produce unretouched flake. The experiments were aimed at creating a use-wear database, testing the functionality of notched tools, production and use of hafted tools, and polish development on unretouched flakes for quantification of polishes. A database is necessary for the island and this is to be pursued for future research and as reference for other researchers.

Although unpublished yet, we observed specific traces on each experiment that might be applicable to other sites dealing with unretouched lithic flakes. On the notched tool experiments the following has been recorded on both experimental tools and artefacts - plant cells and tissues, tuber sap forming circular patterns, fungal growth on the residues, fibres, starch grains, and stomata. The samples resemble those documented from Leang Sarru and could explain why retouched tools were present in the assemblage from the LGM (Fuentes et al., *under review*, see Appendix B.1). Retouching was closely associated with plant working in the archaeological materials thus the researcher hypothesise that it was intentional retouching and specifically for the purpose of smoothing and roughing plant materials. The preservation of residues still needs to be addressed in future research. The role of fungal growth in the decomposition or preservation of organic residues on these tools, and contamination of both experimental tools and artefacts are issues that also needs clarification.

The ongoing project in Topogaro, Central Sulawesi provides an ideal venue for testing and addressing polish formation on plant and bones because of the recovery of bone points and unretouched flakes which indicate plant processing. The results are not published yet and documentation is ongoing. Based on initial analysis the following trends were observed: 1) experiments using notched tools resulted in deposition of residues on the retouched working edges, a possible explanation of preservation of plant residues on the artefacts. 2) plant polish formation or sickle gloss formed after experiments with phytolith rich plants with unretouched flakes and are ideal for testing quantification techniques using laser scanning confocal microscope. 3) retouching can be conducted through direct percussion technique to replicate the morphology of the artefacts.

E. Current techniques in use-wear and potential for future research

We also partly tackle issues that need to be addressed in future research in Pleistocene sites in ISEA. First, is the presence of hafted tools using both unretouched and retouched flakes. We utilised experimental results from previous research (Rots, 2003, 2014, 2016; Rots et al., 2011; Rots and Plisson, 2014), in the meantime because of limited or non-existent published results on projectile technology in ISEA. To address this issue, a robust experimental database catered for ISEA needs to be developed (see Appendix C.2). Hafting technology, indicating technological complexity can be detected through use-wear analysis. Plant working is an important issue but other questions such as the presence of complex tools (such as projectile points) and intentional tool retouching seem to be overlooked in ISEA. Another issue is the absence of extensive comparative experimental database of raw materials from Sulawesi. The researcher began an experimental program, designed to answer provide qualitative and quantitative database for future use-wear analysis of assemblages in the island and in ISEA, in general. More than the pursuit of plant working and identification of plant species, focus should be given to detection of more advanced technological innovations such as hafting and production of composite tools. The presence of hafting technology was previously addressed by the analysis of unretouched flakes from the Terminal Pleistocene and Early Holocene layers of Ille Cave, Palawan (Pawlik, 2012). Amorphous expedient technology can also be used as possible hafted tools without further modification. Tool retouching is an integral component of composite tools and we observed this in the case of Topogaro 2, Central Sulawesi on tools that possess unifacial and bifacial retouching similar to technique used in making backed blades in Europe. We might have overlooked something and some traces were not even mentioned in previous literature in ISEA, for tools that were possibly hafted. These traces need to be checked in the literature and also in use-wear analysis in the future. The traces include micro linear impact traces (MLIT), impact scars at the proximal tip of the artefact, scalar scars located on the left and right lateral sections, presence of organic residues (Fuentes et al., *in preparation*, see Appendix C.3).

Second, is the identification of plant species through residue analysis. Although rare, residues from plant parts are still the most reliable and direct evidence of plant working. In the case of Leang Sarru, the researcher was able to identify plant remains as well as provide an explanation to why these were ‘preserved’ on the tools. Retouching aided in the deposition as well as preservation of the residues including plant cells/ tissues, raphides, starch, fibres, and sap. Further research is necessary to identify and understand the chemical component of residue preservation. Plant remains were associated with direct plant processing and at the same time for the first time documented to be directly associated with production of composite tools, and possible fibre extraction with presence or fibres on retouched tools**.** The plant species processed for consumption and production of other forms of technology were identified through residue analysis. Most were identified as monocots (e.g. palm trees, grasses), and could possibly explain the predominance of plant polishes associated with phytolith-rich plants.

Third, is the identification of plant species preference through quantification of polishes on the tool surface (see Appendices D.1 and D.2). These polishes served as proxy to which plant were processed and that could answer the question on whether bamboo was really preferred over other plants or there was no preference but rather plants that produce the needed materials were selected regardless of. In this research we are addressing one of the core issues of use-wear analysis – how to produce quantitative data that can be compared and can be repeated by other researchers through experiments. One technique being used in the past decade is laser scanning confocal microscopy and surface metrology. So far, researchers were able to at least distinguish between contact material types between condition (e.g. fresh versus dried plants) and types of contact materials (e.g. bone, wood, plant). However, no comparative data yet across sites due to differences in laboratory setup and equipment, and compartmentalised research questions. Two approaches are being explored – surface roughness measurement and profile sections of polish bevel. The potential of these techniques to go beyond the qualitative aspect of use-wear analysis will be pursued in future research.

F. Micro-traces and lithic traditions in ISEA – a conclusion

The results of this research indicate technological aspects amorphous of lithic technology in North and Central Sulawesi and in Wallacea that might have been missed. This warrants re-assessment of the current perspectives and views of how early AMH adapted and innovated their technology. The absence of formal stone tools for the Late Pleistocene until the Holocene may not be necessarily true as retouched tools resembling scrapers were already produced during the LGM in Leang Sarru and from the Early Holocene layers in Topogaro 2. The appearance of these retouched tools coincided with intense site occupation and use, which also indicated direct and indirect evidence of plant working. This is still a contentious issue in terms of lithic technological adaptation in the ISEA, due to the plant-based organic technology that is hypothesised as a reason why the lithics did not progress in morphology. Through low and high-power microscopy, the researcher was able to identify traces that indicate use of unretouched and retouched flakes for hafting or production of composite tools. These results offers alternative perspectives on the lithic technology of ISEA, as seemingly simple flake tools could be used in more advanced technologies. Previous use-wear studies in the region inferred plant working due to presence of polish on unretouched flakes. While our results also indicate intensive plant working, we propose that it was not the end goal to create plant tools but rather it was just a facet of their cultural and technological adaptation to island environments and to available resources.

Although the lithic traditions in Wallacea are often labelled as simple and unchanging, yet no extensive analysis addressed the presence of complex technologies such as hafting were conducted (Pawlik, 2010). We propose to determine technological traits, such as hafting and production of formal tool types, through microscopic analysis. This research provides new perspectives on the prehistoric activities during the Terminal Pleistocene in Wallacea, which are vital study in exploring aspects of amorphous flake technology that cannot be revealed through techno-typological approach. We hypothesise that plant working is one component (e.g. bindings from fibres, shaft for hafted tools) of prehistoric toolkits in the region, rather than the end goal itself. The comparison between stone tool traditions of North and Central Sulawesi provides a picture of the prehistoric technologies in regions vital to understanding early sea crossings of modern humans. Overall, this study indicate that unformal lithic traditions were used with and without modification and use-wear analysis can help reveal micro-traces of activities that do not follow standard techno-typological classifications.

Use-wear analysis is an effective tool in detecting evidences of prehistoric stone tool functions. Debates and issues in ISEA revolving around prehistoric production of unformal flake tool tools as evidence of an underdeveloped lithic technology could be addressed through careful microscopic analysis. The study sites are the oldest C14-dated cave and rockshelter in North and Central Sulawesi. These region are vital to understand human presence during prehistoric migrations to Sahuland through Sulawesi. The technologies that we identified implies a variety of strategies and reflects the intuitiveness of those prehistoric populations in producing cultural material made from both lithic and organic objects. Complex technologies such as hafting which constitutes parallel technologies with craft making, especially with the use of binding, could lead us to future research question to tackle which material culture and technologies made the sea-crossings possible.

Advancements in surface metrology is being incorporated in lithic use-wear analysis and this is beginning to be applied to assemblages in ISEA. Surface roughness measurement demonstrated distinction between several types of contact materials and would be apt for unretouched tools in ISEA with sickle polish. With enough data from an extensive set of experiments, issues such as the presence of bamboo technology and plant preference, in general, can be addressed. Databases from the region can also be compared with results conducted elsewhere because similar and standardised microscopes and protocols are employed by use-wear analysts. Addressing prehistoric-plant working in ISEA through more advanced methods should still be based on extensive experiments and basic use-wear analysis due to limited samples and the problem of over simplification of interpretations in the region. As described in this research, morphologically-similar technologies with the same functions can exist in two distant locations but due to differences in resources, these traditions differ in terms of micro traces as outcome of actual functions.

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8. Appendices

A. Accepted papers

1. **Fuentes, R.** and Pawlik, A.F. **In press.** *Not formal but functional: Traceology and the Lithic Record in the Philippines*. In Hunter-gatherers tool-kit: a functional perspective. Edited by Gibaja, J., Clemente, I., Mazzuco, N., Marreiros, J. Cambridge Scholars Publishing.

2. **Fuentes, R.**, Ono, R., Nakajima, N., Nishizawa, H., Siswanto, J., Aziz, N. Sriwigati, Sofian, H.O., Miranda, T., and Pawlik, A.F. **2019.** Technological and behavioural complexity in expedient industries: the importance of use-wear analysis for understanding flake assemblages. Journal of Archaeological Science.

CHAPTER FIFTEEN

NOT FORMAL BUT FUNCTIONAL: TRACEOLOGY AND THE LITHIC RECORD IN THE PHILIPPINES

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1. Lithic Assemblages and Technology in Prehistoric Philippines – The Missing Types Problem

Lithic technologies appear, at face value, to have remained remarkably uniform from the Late Pleistocene to mid-Holocene in Southeast Asia until the introduction of fully ground stone tool technologies at c. 4500-4000 cal. BP or even later. In the Philippines, as in most parts of prehistoric Island Southeast Asia, flaked stone tools were generally manufactured using rather simple production techniques, applying mostly direct and/or anvil percussion, and going without elaborate core preparation. There is hardly any convincing evidence for the deliberate production of formal tools and advanced knapping technologies such as Levallois and blade core preparation, with the exception of a small assemblage from Arubo in Central Luzon that included a bifacial handaxe, cleaver, unifacially modified artefacts, and several cores showing different reduction techniques (Pawlik, 2002, 2004; Pawlik and Ronquillo, 2003; Dizon and Pawlik 2010). Although the site remains undated, morphological similarity with several early Palaeolithic artefacts from sites in mainland and Island Southeast Asia suggests a Middle Pleistocene age (Pawlik, 2009).

Not many lithic assemblages that are clearly associated with the Pleistocene by absolute dates have been retrieved in the Philippines. Despite a somewhat problematic chronological record, the lithic assemblage from Tabon Cave in Central Palawan (Fig. 1) might be the oldest absolute-dated lithic artefacts in the Philippines and can at least be considered to be of a Terminal Pleistocene and early Holocene age with radiocarbon dates between 9250±250 uncal. BP or 11182-9768 cal. BP (UCLA-284) and 30500±1100 uncal. BP or 36731-31814 cal. BP (UCLA 958; Fox, 1970, 40-44). In the north of Palawan, a series of radiocarbon dates placed the cultural materials from Ille Cave to as early as ca. 14ka cal. BP (Lewis et al., 2008). In Callao Cave, Northern Luzon, a lithic assemblage has been retrieved from just above the layer where the oldest hominin fossils, dated to a minimum of ca. 67ka BP, respectively 50ka BP, were found (Mijares et al., 2010; Grün et al., 2014). The lithic materials were associated with a radiocarbon date on charcoal of 25968±373 uncal. BP or 30918-29334 cal. BP (WK-14881; Mijares, 2007). No lithic artefacts, however, were found associated with the possibly reworked human fossil remains. The few lithic assemblages that would date into the Terminal Pleistocene and early to mid-Holocene would not show a distinctive different morphology and technology and it seemed that lithic technology remained stagnated for the entire Palaeolithic until the Neolithic and introduction of agriculture in the Philippines (Mijares, 2002, 2007; Pawlik, 2010; Patole-Edoumba et al., 2012; Pawlik et al., 2014). Despite a rather early appearance of the remains of Homo sapiens in Island Southeast Asia (and Australia) at already 50ka BP, if not earlier, there is a remarkable absence of production of formal lithic tools throughout the Upper Pleistocene and even into the early/mid Holocene. Whether those lithic assemblages derive from the mainland Southeast Asia or were found in the region of Island Southeast Asia very few stone tool types like the so-called ‘Sumatraliths’ of the Hoabinhian technocomplex have been defined (Gorman, 1970).

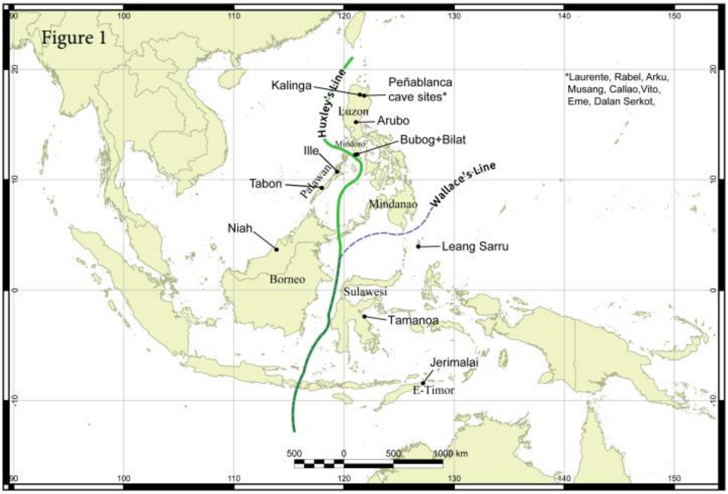

Figure 1: Geographical situation of the Philippines and relevant sites.

For African and European prehistory, cultural, cognitive or behavioural advancement have been connected to innovations in lithic technology, and the appearance of milestone indicators like specialised blade industries, geometric tools, burin technology, among other traits of the so-called "modern package" (e.g. Mellars, 1989; Bar-Yosef, 2002; Conard, 2007; Haidle and Pawlik, 2010). Such a 'package' of modern behavioural traits cannot be claimed for the Southeast Asia-Pacific region. Habgood and Franklin (2008) stated that this 'package' of cultural innovations did not exist as an entity from the beginning of Sahul settlement, and that its components were gradually assembled over a 30,000-year period. In a comprehensive examination of more than 200 Pleistocene sites from Australasia, Langley (2009; 2011) could not find evidence of cognitive modernity and cultural complexity, but identified effects of taphonomy and archaeological sampling on the nature and representativeness of the archaeological record in this region.

For Southeast Asia, it is quite remarkable that despite an early fossil evidence for the arrival of modern humans ranging back to 45-50ka BP, modern traits remain basically absent until the early Holocene and are still very rare until the Neolithic, with the exception of few finds of tools and points as well as fishing gear made of bone, shell, and stone predominantly in the coastal environments of Southeast Asia (Rabett, 2005; Pawlik et al., 2014, 2015). Several authors have argued that the simplicity of Southeast Asia's lithic industries and paucity of formal tools were caused by the scarcity of lithic raw materials in sufficient quality, and the abundance of various organic materials like bamboo, rattan, and other wood species (Narr, 1966; Solheim 1970; Hutterer, 1977; Pope, 1989; Schick and Zhuan, 1993; Mijares, 2002). For taphonomic reasons, those ‘vegetal industries’ remain, however, hypothetical. Tools made of bamboo and wood are not present in Pleistocene and early Holocene archaeological assemblages. Also, their production would still have required stone tools. The wood/bamboo tool hypothesis does neither consider factors of tool mechanics and uses nor does it deal with the fact that large lithic assemblages are present in the archaeological record (Pawlik, 2010). It can be certainly assumed that tools and utilitarian objects were made of vegetal materials including bamboo and wood but they were more likely an addition to the lithic toolkit rather than replacements, like the few bone tools found in Southeast Asia (Barton et al., 2009; Pawlik, 2009). Furthermore, the causality that the production of vegetal tools has led to a simplification of lithic industries has not been convincingly explained. Also, artefacts made of lithic materials possessing a sufficient knapping quality, for instance chert, jasper, or even obsidian are not uncommon in Southeast Asian sites (e.g. Beyer, 1947; Charoenwongsa, 1988; Pawlik, 2002, 2004a; Mijares, 2002, 2007; Neri et al. 2015), and long-distance exchange systems probably existed for obsidian since the Terminal Pleistocene (Neri et al., 2015).

While evidence for vegetal tools is missing in the Palaeolithic record of Southeast Asia, several use-wear analyses have indeed identified wear traces of working wood, bone and bamboo on stone tools (e.g. Bannanurag, 1988; Mijares, 2002; Pawlik, 2004, 2010; Teodosio, 2006; Barton, 2006; Xhauflair, 2014). Cutmarks found on animal bones from the 67ka layer of Callao Cave, Philippines have been investigated with optical and scanning electron microscopes (Manalo, 2011). Her comparative analysis with experimentally created cutmarks from various lithic and organic sharp-edged tools suggested the use of bamboo “knives” rather than the sharp edges of lithic flakes (Manalo, 2011).

However, explaining the paucity of formal and ‘modern’ lithic tool types with a supposed developed organic tool industry, that is even more absent in the archaeological record, might not be very helpful to argue for the existence of advanced and complex technologies in Southeast Asia. Instead, it is probably safer to say that tools made of vegetal material were complementing lithic tool kits in Southeast Asia when necessary rather than replacing lithic tools, like tools made of bone and shell (Pawlik, 2012; Xhauflair, 2014; Xhauflair et al., 2016). To overcome this “Typology Dilemma” (Haidle and Pawlik, 2009), functional analysis using microscopic use-wear and residue analysis was proposed as method for a more meaningful classification of stone tools based on actual tool uses rather than formal and typological criteria (Pawlik, 2009). In the Philippines, only a few sites produced bones tools, and preserved plant remains, although organic technologies have been more frequently recorded in other parts of Island Southeast Asia (Piper and Rabett, 2009; Barton et al., 2009). A reason might be the current state of research and the very few excavated and comprehensively analysed assemblages of Pleistocene and early Holocene contexts.

Although the overall absence of tool formality through time has nullified attempts at producing meaningful typological and technological classifications in the lithic record, traceological analysis of lithic assemblages in the Philippines and neighbouring regions confirmed the utilization of simple flakes for a variety of processes and activities. These evidences gave indications that complex technologies and use-contexts already existed by the Late Pleistocene, not unlike, for instance, the more formal prehistoric tools of the European Upper- and Epi-Palaeolithic (Mijares, 2002, 2007; Barton, 2006; Brumm et al., 2006; Barton et al., 2009; Pawlik, 2012; Xhauflair and Pawlik, 2010; Xhauflair, 2014; Fuentes, 2015; Xhauflair et al., 2016). For example, composite projectile technologies have been identified at Ille Cave in northern Palawan (Pawlik, 2012) and at Niah Cave in Borneo (Rabett and Piper, 2014), both associated with layers dated to c. 14–12ka cal. BP. Residues on the stone tips from Ille Cave are also similar in morphology to the resinous glue applied to the composite artefacts from Niah (Barton et al., 2009; Pawlik, 2012). Reynolds et al. (2013: 154) have argued that similar residues of resin observed on flake tools from Niah Cave suggested that they were used to work on resinous wood or pieces of tree resin, possibly in the manufacture of composite implements evident from at least the Terminal Pleistocene. The edge-ground shell adzes, polished bone tools, as well as flaked shell artefacts found at shell midden sites in Mindoro, dating to between 4ka and over 30ka cal. BP (Pawlik et al. 2014, 2015) might indicate that a range of tools made of organic material, particularly shell and bone, complemented the basic lithic toolkit.

2. Lithic Use-wear Studies in the Philippines: Functionality of a non-formal lithic tradition

The method of microscopic functional analysis became worldwide popular short after the English translation of Semenov’s (1964) ground-braking monograph “Prehistoric Technology”. However, in the Philippines until the 1980s, lithic studies focused mainly on identifying the technology or morphological characteristics and the application of attribute analysis. Initial studies applied the low power approach (Odell, 1981) on materials from several cave sites in Peñablanca, northern Luzon. Henson (1978) analysed artefacts from Laurente Cave using a combination of attribute and use-wear analyses and proposed that these were possibly used on bamboo and rattan (Henson, 1978). A similar combination of technological and functional analyses was applied by Ronquillo (1981) in his master's thesis for selected stone artefacts from Rabel Cave using a binocular microscope and magnifications of 10x - 40x (Ronquillo, 1981). Thiel (1990a, 1990b) studied wear traces on artefacts from Arku Cave und Musang Cave using hand lenses with magnifications of 2x, 10x, and 20x, and inferred that the artefacts were used as scrapers, spokeshaves, knives, grass-cutters, blades, gravers, drills, and saws. However, the studies conducted during this period had limitations in terms of optical techniques used as they mainly employed low power microscopy, and lacking in comparative use-wear experiments.

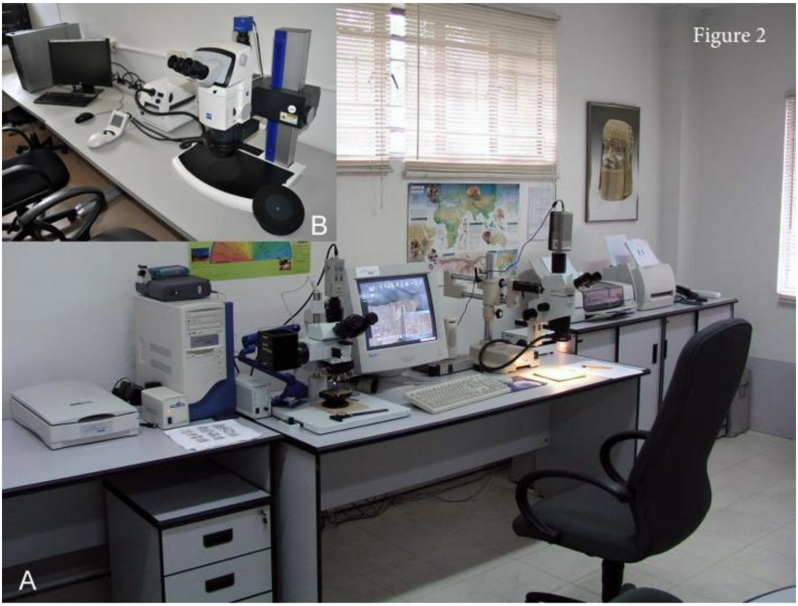

Figure 2: The University of the Philippines Lithic Studies Laboratory with microscopes for high and low power analysis. A) After the inauguration in February 2002. B) Fully motorized Zeiss SteREO Discovery V20 microscope acquired in 2013.

By the late 1990s and early 2000s, research on lithic artefacts involved now both low power and high-power microscopy. Pawlik (2001) provided an introduction and manual on the methods of use-wear analysis and its application to the study of flaked lithic technology in Southeast Asia. This was related to his establishment of the Lithic Studies Laboratory at the University of the Philippines (Fig. 2), as the first facility for technological and functional analysis in the Philippines (Dizon and Pawlik, 2002). Also, replicative use-wear experiments began to be integrated into traceological studies and several studies following current methods of traceological analysis were conducted, since (Mijares, 2002; Teodosio, 2006; Pawlik, 2002, 2006, 2012; Xhauflair & Pawlik, 2010; Xhauflair, 2014; Fuentes, 2015; Benz, 2016).

Another important aspect in use-wear analysis was testing the application to much older sites, as in the case of the Arubo artefacts. Analysis of potentially early Palaeolithic artefacts from Arubo in Central Luzon and Kalinga in Northern Luzon revealed that there was an industry in central Luzon where flakes and core tools were produced Pawlik (2002, 2004a; Teodosio 2006). Use-wear analysis of chopping tools, a handaxe, cleaver, spatulate, and large flakes show traces of use especially, but not limited to heavy duty activities such as butchering, and mostly on hard materials (Teodosio, 2006). Although the tools were from reworked contexts and there was absence of absolute dates, yet the study established that the artefacts were intensively used.

Traceological analysis was also applied on lithic assemblages from cave sites in Peñablanca, Northern Luzon. Mijares proposed in his analysis of the stone tools from Peñablanca, particularly Minori, Eme, Callao, and Dalan Serkot (Mijares, 2002, 2007) that an "expedient technology" (Binford, 1979) was present for prehistoric Philippines. This technology was seemingly unchanging during the entire Late Pleistocene until the mid-Holocene, with the use of simple technique of producing flakes through direct hard hammer percussion and without retouches (Mijares, 2005). He further argued that the expediency of the lithic technologies in Southeast Asia were not due to cultural stagnation, but represent an appropriate cultural adaptation by prehistoric people to their environment and resources (Mijares, 2003).

The continuation of this unchanging technology into the Late Holocene of northern Luzon was observed by Fuentes (2015) in his microwear analysis of lithic artefacts from pre-ceramic and pottery containing deposits from Vito Cave in Peñablanca. He demonstrated that except for the addition of pottery, human activities, behaviour and subsistence remained widely unchanged even after the introduction of agriculture in the region. The few pottery remains suggest contacts and some form of exchange of the upland hunter-gatherers with the newly arriving Austronesian-speaking farmers that settled in the lowlands along the Cagayan River at around c. 4000 BP (Bellwood, 2017; Piper et al., 2009). The archaeological record of Vito Cave also indicates that hunter-gatherer populations maintained their modes of life even after the arrival of sedentary Austronesian-speaking populations along the Cagayan River Valley and did not adopt this new form of subsistence and its technology. It further demonstrates that a clear distinction can be made between cave sites utilized by Neolithic populations for the burial of their dead, and sites used for habitation by forager groups, and that this distinction is fundamental in accurately reconstructing different modes of cave utilization by the various human populations that probably co-existed across Island Southeast Asia for extensive periods of the later Holocene.

Several microwear studies have been conducted on lithic artefacts coming from Ille Cave in northern Palawan. Throughout its layers, the lithic assemblage contained a high proportion of cores all reduced using bipolar techniques with effort to control the core face geometry. Some cores displayed even parallel longitudinal flake scars indicating the production of flakes with blade geometry (Lewis et al., 2008). However, blade-like flakes are not apparent in the assemblage but mostly un-retouched flakes. Use-wear analysis conducted by Barton (2006) revealed that a high proportion of the exhausted cores were subsequently used as tools as evidenced by micro-scarring, use polish, rounding and striations. A subset of six pieces had traces suggesting a specialised function, possibly the planing of siliceous plants, reeds or wood. Pawlik (2006) studied fully ground stone adzes from Neolithic burials at Ille. The adze blades had been intensely used and were multiple times resharpened. They showed traces of wood working and transverse hafting suggesting that they were tied on wooden shafts with phytolith-containing plant fibres, perhaps supported by glue-like resin. Use-wear analysis of artefacts from the lowest layers of Ille Cave, dated to 12-14,000 cal. BP, demonstrated that simple unretouched flakes served as hafted armatures of more complex multi-component tools and that composite technology has to be considered for the lithic technologies in the Philippines (Pawlik, 2010, 2012). Furthermore, unmodified flakes exhibited traces from processing shell, red pigments and resins, among bone and plants (Pawlik, 2012). The variety of tasks and activities carried out with unmodified flakes paints a picture somewhat different from a solely expedient technology and a dominant organic technology for Island Southeast Asia.

A detailed experimental referential database on microwear traces and residues from processing tropical plants from the Palawan uplands was produced by Xhauflair (2014) through the combination of traceological analysis with ethnoarchaeological and ethnobotanical field research in relation to archaeological sites in Palawan, mainly Tabon Caves, providing the first systematic and comprehensive reference collection for the identification of traces from plant processing for the region (Xhauflair, 2014; Xhauflair et al., 2016, 2017).

In an ongoing interdisciplinary and multi-regional research program, lithic artefacts from several sites in the Philippines and the neighbouring region of northern Sulawesi are undergoing traceological analysis. The main goal of the project is to identify early human movements and adaptation to coastal environments, as well as maritime networks from the Late Pleistocene until the Late Holocene period. Use-wear analysis for this project is conducted by the authors on Late Pleistocene to mid-Holocene assemblages from Northern Sulawesi, especially Leang Sarru on Talaud Islands, Radiocarbon-dated to 35-8ka cal. BP. The assemblages show that the use of non-formal tools extended into areas close or proximate to the Philippines. However, in contrast to the materials from the Philippines, the Sulawesi assemblages include characteristic notched tools. The notched modification is a recurring pattern from the Northern and Central Sulawesi sites (Ono et al., 2009; Fuentes, et al., in review).

3. Current Directions and Perspectives

Microwear studies of lithic assemblages from the Philippines as well as other regions in Island Southeast Asia demonstrated that simple lithic technologies that dominantly were composed of amorphous unretouched flakes and other non-formal tools possess a versatility that enabled their prehistoric users to conduct a large variety of elementary activities, and that the methods of typological and technological studies are insufficient for the lithic analysis for this region and might not reflect actual prehistoric technological and cognitive behaviour. Although lithic technologists proposed a “bamboo hypothesis” to explain the absence of formal tools, no actual evidence for the existence of tools made of bamboo and other woody plants has been found, so far. Nevertheless, direct and indirect evidence for the processing and use of organic materials, particularly bone and shell, can be found in Southeast Asia and the Pacific and their potential for the recognition of human behaviour and technology is obvious. Especially shell has a clear potential for tool production in coastal regions. In East Timor, a fishhook made of Trochus shell was found at Jerimalai Rockshelter in deposits bracketed by radiocarbon dates of 16 and 23ka cal. BP (O’Connor et al., 2011). At Niah Cave in Borneo worked stingray spines were turned into projectile points, dated to between ca. 9-12ka cal. BP. Residue analysis on these intriguing points revealed that they were attached to shafts using tree resin as an adhesive supported by a fibrous binding (Barton et al., 2009).

Figure 3: Flaked and ground shell artefacts from Mindoro. A) *Tridacna* flake tools from Bubog 2; B) *Geloina* flake tools from Bubog 1; C) Edge-ground shell adzes from Bubog 1 and Bilat Cave; D) Shell adze preform / heavy duty tool made of *Tridacna* shell from Bubog 2

Flaked artefacts made of Tridacna shell were found in mid-Holocene deposits of Bubog 2 on Ilin Island (Fig. 3A) while two ground shell adzes were found on Ilin Island at Bubog 1 and just across in Bilat Cave in southwestern Mindoro (Figure 3C). Several direct AMS dates place them into the early to mid-Holocene (Pawlik et al. 2014, 2015). A large *Tridacna* artefact, possibly an unfinished adze pre-form was uncovered at Bubog 2 in secure stratigraphic position and AMS-dated to 9115-8899 cal. BP (Marine13; S-ANU-49209), indicating a local production of those large shell tools already during the early Holocene. The shell artefact displayed battering marks and intense edge wear suggesting a heavy-duty use as a chisel or cleaver (Figure 3D). From the lowest shell midden layer of Bubog 1, a shell tool assemblage was retrieved (Figure 3B). Two direct AMS-dates on flaked *Geloina* shells date the assemblage to between 28113 and 31139 cal. BP (Marine13; S-ANU-49438, 49439). Numerous *Geloina* shells were used as chisels and for scraping and sawing activities. Those shells substituted for chert as raw material for tool production. Chert is absent on the entire island and needed to be acquired from the adjacent Mindoro Island in 7.5km distance. The only lithic tools appearing in the shell midden are unmodified igneous pebbles that served primarily as hammerstones to break open the thick and solid marine shells, and fragments thereof (Figure 4A; Pawlik et al., 2014). The latter, however, carry microwear traces that point to a secondary use for working various other materials. Several pebbles received a waisted modification suggesting a use as netsinkers (Figure 4B). Only from the layers below the shell midden were few chert flakes found together with small obsidian débitage. These lithic artefacts date to before c. 30ka BP and to the Late Pleistocene when Ilin Island was connected with Mindoro. The same layers in Bubog 1 provided the earliest worked bone tools from the Philippines so far. Several fragmented polished bones were found in the mid-Holocene deposits of the shell midden (Figure 5A). Below the shell deposits was an almost complete bone point found that was carefully smoothened on all surfaces to a rather symmetrical, slightly curved shape with circular profile and tapered into a point at either end (Figure 5B). Morphology and manufacturing technique shows an intriguing resemblance to ground bone tools identified as fishing gorges from Batanes in northernmost Philippines, even though they date significantly younger to c. 3500 BP (Piper et al., 2013).

Figure 4

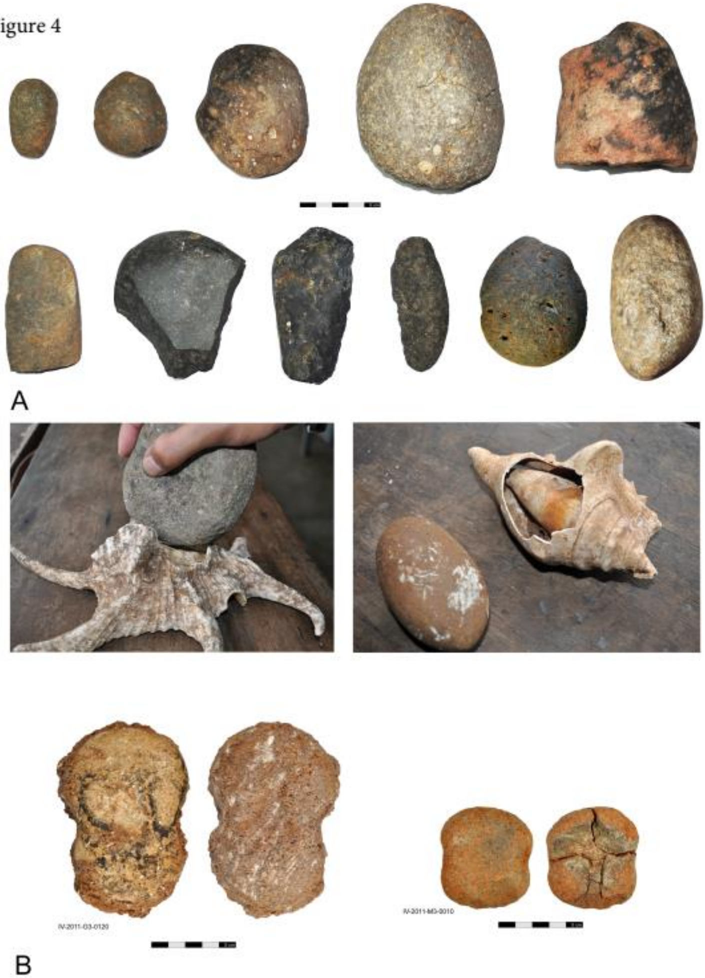

Figure 4: A) Hammerstones and fragments thereof used on large marine shells at Bubog 1; B) Pebbles with waisted modification used as netsinkers.

Figure 5: A) Polished bone point fragments from the mid Holocene at Bubog 1.

The used shell flakes and also the pebble fragments substantiate the claim that simple tools could perform most relevant activities and also demonstrate that primarily functional considerations characterised the prehistoric technology of those early islanders. Only for the production of the polished fishing gorges and edge-ground shell adzes more effort was expended. The recent find of a preform of a *Tridacna* adze at Bubog 2 indicates that those shell adzes have been locally produced, suggesting a very pragmatic and efficient tool manufacturing strategy that would minimise production effort and apply more complex techniques only when necessary (Pawlik et al. 2015).

Evidence for the use of unretouched chert flakes but also stingray spines attached to wooden shafts using resinous adhesives was found in Terminal Pleistocene deposits at Ille Cave in Palawan and Niah Cave in Borneo. The presence of this kind of an elaborate and multicomponent tool technology is certainly not surprising from a European/African perspective. What is worth mentioning though, is that the information was obtained mainly by microscopic analyses. This is not a standard practice for the identification of modern behaviour and neither necessary nor applied to identify blade technology, rock and figurative art, ornaments and most other complex traits. However, it helped to uncover formerly unknown and invisible modern traits in Southeast Asian assemblages. Besides projectile and hafting technology, shell working possibly for ornaments and the use of pigments were identified together with signs of tool curation at Ille Cave (Pawlik, 2012). The use of pigments on shell, bone and turtle plastron has even been dated back for Southeast Asia to as early as c. 41ka cal. BP in Niah Cave (Barton et al., 2009).

Current comparative microwear analysis of assemblages from the Philippines and Sulawesi has demonstrated that the lithic assemblages already studied in the Philippines must be placed in the larger context of a maritime network that probably spanned over the entire Philippine archipelago and included Sulawesi, Borneo, Java, coastal areas of the Southeast Asian Mainland, and was probably reaching as far as Near Melanesia already during the Terminal Pleistocene (Solheim, 1985; Bulbeck 2008; Soares et al. 2008; Pawlik et al., 2015; Neri et al., 2015). In addition, microwear analysis provides actual technical and functional characterisations of lithic artefacts, the identification of working and hunting tools and a determination of activities and site functions (Pawlik, 2009). It has no regional and chronological limitations and shows a potential for the detection of variability in behaviour and cognition, as well as traits of human modernity, like the application of complex technologies, hafting and multi-component tool making, projectile points, curation, fabrication of ornaments, shell fishing, use of pigments and more (Haidle and Pawlik, 2010).

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Technological and behavioural complexity in expedient industries: The importance of use-wear analysis for understanding flake assemblages

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ABSTRACT

Expedient lithic technology has been described as unchanging and without or very limited presence of formal tool types. However, this premise seems to limit the discussion on technological and behavioural complexity when studying amorphous flake industries. To address this issue, we employed multi-stage use-wear analysis to identify features that are not detectable through macroscopic approach. Our analysis of chert tools from Leang Sarru, North Sulawesi indicated the use of both unmodified flakes and retouched tools for plant processing, and we detected evidence for the manufacture of composite tools. Microscopic wear traces on unretouched flakes show that these were attached to shafts for possible use as hafted tools, but not necessarily as projectiles. Our results suggest that simple flake assemblages can be part of complex tool production and present an alternative view on the seemingly unchanging lithic technology from the Late Pleistocene to the Holocene. Furthermore, our current understanding of expedient lithic technology should be reassessed as features that are not observable with standard morphological and technological analyses may be detected through use-wear analysis. Overall, the applied methodology and results of this study are relevant to Pleistocene and Early Holocene archaeological sites and assemblages that exhibit the dilemma of inferring technological and behavioural complexity through the analysis of simple stone tools.

1. Introduction

Early long-distance movements and open water crossing in Island Southeast Asia (ISEA) by modern humans 50,000 years ago is evident in the permanent colonisation of Sahul (Australia and New Guinea) (O'Connor et al., 2011; Clarkson et al., 2017) and maybe even earlier on the Wallacean islands including Flores, Luzon, Mindoro, the Visayas, and Mindanao (Heaney, 1993; Esselstyn et al., 2010; Porr et al., 2012; Pawlik et al., 2014; Sutikna et al., 2017). Sulawesi, the location of Leang Sarru, is the westernmost major island of Wallacea and considered a stepping stone for the peopling of Sahul and Oceania along the northern route (Birdsell, 1977; Aubert et al., 2014; Brumm et al., 2017; Bird et al., 2019). Recent discoveries in Sulawesi, such as the 40,000 to 35,000-year old rock art (Aubert et al., 2014), stone tools as old as 118,000 years ago

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in Talepu (van den Bergh et al., 2016), and evidence of symbolic behaviour from 30,000 to 22,000 years ago (Brumm et al., 2017), demonstrate previously unknown cultural practices in the region, which shows the vital role that this island played in human dispersion. Surveys in the northern section of Sulawesi, including the Talaud Islands, were conducted in the 1970s by Bellwood (1976). One of the sites recorded in this region, Leang Sarru, was first excavated in 1995 by Tanudirjo (2001, 2005), and then in 2004 by Ono et al. (2010, 2015). So far, only technological analysis was conducted on the lithic assemblage from the site (Tanudirjo, 2001, 2005; Ono et al., 2015), and this study is the first multi-stage use-wear analysis on stone tools from North Sulawesi.

Maritime technology showing capability of accessing pelagic fishing grounds and covering distances of open ocean of >90 km has been argued to be available to Pleistocene hunter-gatherers as early as 40,000 years ago (O'Connor et al., 2010, 2011). The presence of a developed open-sea fishing technology for ISEA is supported by evidence such as fishing hooks, net sinkers, and remains of pelagic fish in the archaeological assemblages since the late Upper Pleistocene (O'Connor et al., 2011, 2017; Pawlik et al., 2014; Boulanger et al., 2019; Pawlik and Piper, 2019). Despite the indications for a well-developed maritime technology during the Late Pleistocene, lithic technology of this region appears generally as simple and unsophisticated, seemingly contradicting the assumed high level of cognitive and technological capabilities of the early islanders (Pawlik and Ronquillo, 2003; Patole-Edoumba et al., 2012; Marwick et al., 2016). While during the Late Holocene, past research in ISEA focused predominantly on the hypothesis of migration of technologically advanced 'Austronesian' groups from Taiwan into the Pacific (Bellwood, 2005, 2017). New data indicate the importance of economic and ecological changes in pre-Austronesian and Neolithic societies during the transition from the Terminal Pleistocene to Early to Mid-Holocene (Bulbeck, 2008; Barker and Richards, 2012; Pawlik et al., 2014, 2015; Pawlik and Piper, 2019). These results suggest the importance of this period in understanding the complex interplay of migration, adaptation, and integration of innovations and populations (Soares et al., 2008; Barker and Richards, 2012).

Lithic assemblages associated with these early movements in ISEA do not show a distinctive morphology through time, that at face-value would seem to suggest that lithic traditions stagnated until the introduction of ground stone technologies around 4000 cal. BP (Pawlik, 2001, 2010; Mijares, 2002, 2007; Patole-Edoumba et al., 2012; Borel et al., 2013; Pawlik et al., 2014; Marwick et al., 2016). To overcome this 'typology dilemma', use-wear and residue analysis ('traceology') has been proposed as a method for the classification of stone tools (Haidle and Pawlik, 2009; Pawlik, 2009). Traceology applies basic physical principles of interacting surfaces in relative motion and studies the wear and tear created during such interaction between a tool and the worked object, resulting in formation of traces observable using optical and imaging techniques to identify qualitative features (Semenov, 1964; Tringham et al., 1974; Keeley and Newcomer, 1977; Kamminga, 1979; Keeley, 1980; Odell and Odell-Vereecken, 1980; Odell, 1981; Vaughan, 1985; Unrath et al., 1986; Beyries, 1988; Pawlik, 1992; Anderson et al., 1993; Yamada, 1993; Longo and Skakun, 2008) and to collect quantifiable data (Evans and Donahue, 2008; Ibáñez et al., 2014; Macdonald, 2014; Stemp et al., 2015). Adhering residues on stone tool surfaces provide direct clues to the origin and nature of the worked material and conducted activities (e.g. Anderson, 1980; Christensen et al., 1992; Loy et al., 1992; Kooyman et al., 1992; Pawlik, 1995, 2004; Fullagar et al., 1998; Hardy and Garufi, 1998; Kealhofer et al., 1999; Rots, 2003, 2010; Rots and Williamson, 2004; Torrence and Barton, 2006; Dinnis et al., 2009; Pawlik and Thissen, 2011; Bordes et al., 2017). So far, this method has been long neglected in the analysis of Southeast Asian lithic assemblages, although the few systematic traceological studies, involving experiments, that have been published in the region have demonstrated its importance in addressing key issues in human behaviour and associated technologies (Mijares, 2002, 2007; Davenport, 2003; Lewis et al., 2008; Barton et al., 2009; Pawlik, 2009, 2010; 2012; Haidle and Pawlik, 2010; Xhauflair and Pawlik, 2010; Xhauflair, 2014; Fuentes, 2015; Xhauflair et al., 2016, 2017; Bordes et al., 2017).

To address the issue of expedient lithic traditions, in relation to organic technologies, we employed multi-stage traceological analysis to study lithic samples from Leang Sarru, North Sulawesi. While the assemblage is mostly composed of simple unretouched flakes similar to other sites in ISEA, it also contains a significant number of retouched artefacts. The site was never connected to mainland Sulawesi during the Quaternary Period, making it an ideal setting to address the development of expedient technology in a remote island environment. Our traceological analysis can contribute to the ongoing debate on the typological paucity of lithic assemblages in the region and the reasons for maintaining simple lithic production. Rather than justifying the supposed absence of 'diachronic' changes of tool technology during the Palaeolithic with a hypothetical 'bamboo technology' (Narr, 1966; Pope, 1989), which is even more absent in the archaeological record, we propose that lithic assemblages should be subjected to a functionally-oriented approach (Pawlik, 2012) in order to detect changes in technology and human behaviour during drastic environmental changes over the past c. 35,000 years.

2. Geography and archaeology of Leang Sarru, Talaud Islands

The Talaud chain of islands is located between Mindanao, Philippines and the northern section of Sulawesi, Indonesia. It is composed of the islands of Karakelong, Salibabu, and Kabaruan, along with eight smaller uplifted coral islands called the Nanusa Islands group (Fig. 1). The three major islands are low-lying and of non-volcanic origin, covered with extensive natural forest (Riley, 2002; Ono et al., 2010). Leang Sarru is a rockshelter located along the eastern coast of Salibabu Island within latitude 4°30′ to 21°12′N and longitude 119° to 127°E. The northeast-facing rockshelter is situated in an uplifted coral limestone block at about 15 m above sea level and c. 400 m from the shore (Tanudirjo, 2005). It is c. 5 m by 3 m in area, 2.5 m-high in its curved ceiling at the dripline, and has a dry platform which slopes down away from the wall (Ono et al., 2010, Fig. 2B). It lies at a geographically strategic location between Sulawesi and Mindanao, south of the Philippines, and could have likely acted as a conduit for the movement of people, material culture and ideas between those regions throughout prehistory (Ono et al., 2010, Fig. 1).

Two 1 × 1m test pits (B2 and C2) were opened in 1995 (Tanudirjo, 2001, 2005) while six squares were excavated in 2004 (C3, C4, C5, C6, D2, and D3) (Ono et al., 2010, Fig. 2A, 2B). Ninety centimetres below surface level was excavated in 10-cm spits and four layers were recorded in B2 and C2 (Tanudirjo, 2001, 2005, Fig. 2C). Four units, located inside the rockshelter (C3, C4, D2, and D3), were excavated to a depth of 70 cm before hitting the bedrock. The squares situated beyond the dripline (C5, C6) reached 60 cm from the surface level (Ono et al., 2010, Fig. 2A). Sieving was conducted using 3-mm and 5-mm mesh. Shells, lithic flakes, potsherds, hammerstones, ochre, and a stone anvil were recovered within the four stratigraphical layers (Fig. 2C). However, no animal bones were found on both excavations (Tanudirjo, 2001, 2005; Ono et al., 2010).

Leang Sarru has four main occupation phases, starting from c. 35,000 to 31,000 BP (1st phase, Layer 3) with the recovery of stone tools and shells. From c. 22,000 to 17,000 BP (2nd phase, Layer 2B), a more intensive habitation with the bulk of lithic production was observed. The 3rd phase was dated to c. 10,000 to 8000 BP (Layer 2A). There was no human habitation after 8000 BP until the rockshelter was again occupied between c. 2000 to 1000 BP, during the Metal Age (Tanudirjo, 2001, 2005; Ono et al., 2010; Table 1). Layer 1 (Metal Age) contains potsherds which are similar to jars associated with the Metal Phase (Bellwood, 1976), and for instance found in Leang Buiduane, c. 20 km to the north of Leang Sarru (Ono et al., 2010). The stratigraphical context, dating, and lithic technological analysis of Leang Sarru were discussed in detail by Tanudirjo (2001, 2005) and Ono et al. (2010, 2015). Tanudirjo

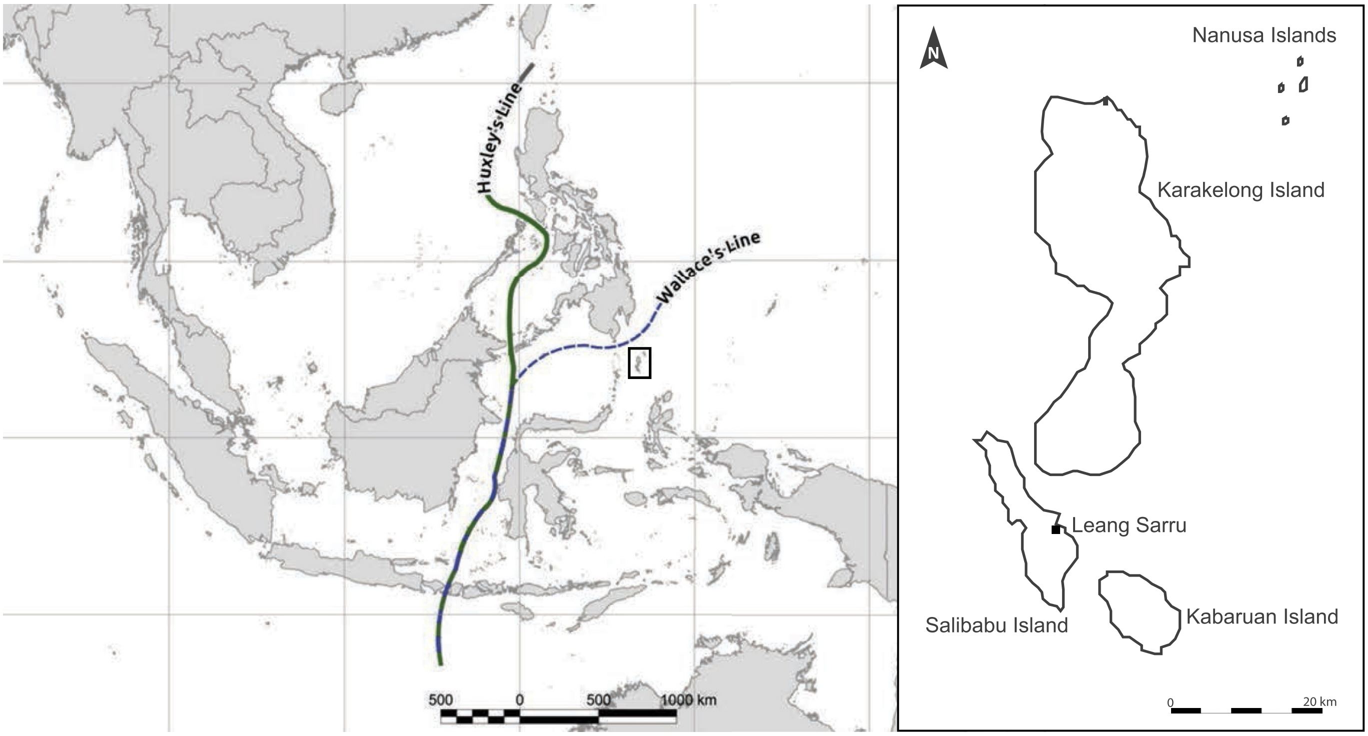


Fig. 1. Location of Leang Sarru in the Talaud Islands, North Sulawesi (modified from Ono et al., 2010).

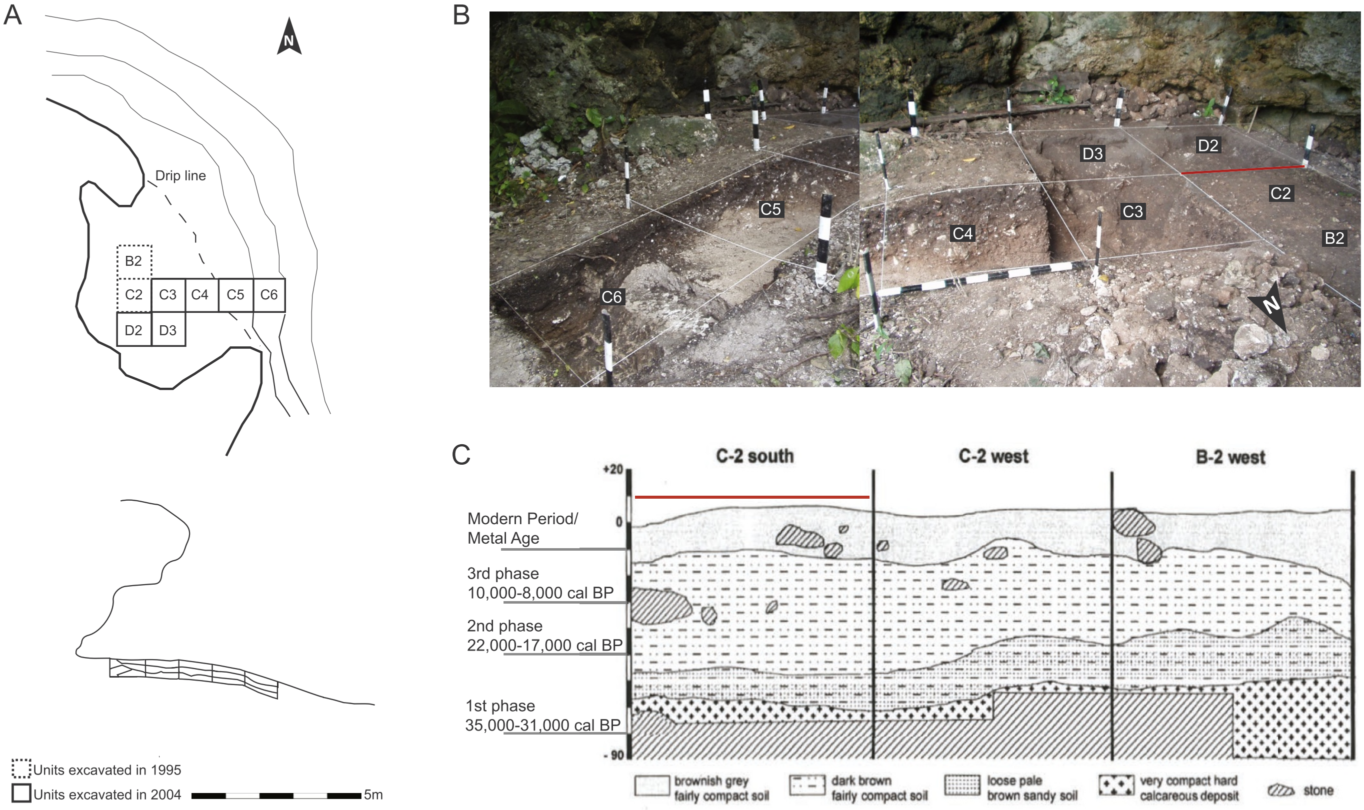


Fig. 2. A. Archaeological units from the 1995 and 2004 excavations (modified from Ono et al., 2010). B. Excavation units within the main platform and beyond the dripline (photos by Rintaro Ono). C. Four stratigraphical layers were excavated revealing four occupation phases (modified from Tanudirjo, 2005).

Table 1
Occupation phases and radiocarbon dates of Leang Sarru (Tanudirjo, 2001, 2005; Ono et al., 2010).

Occupation Phase	Age estimate	Spit	Depth (cm)	Layer	Lab. code	Material	Unit/ Layer	Depth (cm)	14C Age (BP)	Published calibrated age using CalPal2007_HULU (cal BP)[a]	Calibrated age using Marine13 (cal. BP; 2 sigma)	Reference
Modern Period	/	1	0–10	Topsoil	/	/	/	/	/	/	/	Ono et al. (2010)
Metal Age	2-1000 BP	2	10–20	Layer 1	/	/	/	/	/	/	/	Tanudirjo (2005), Ono et al. (2010)
3rd phase	10-8000 BP	3	20–30	Layer 2A	TERRA-070407a05	Turbo sp.	D3/2	−30 cm	7660 ± 40	8033–8144	8218–8000	Ono et al. (2010)
					ANU-10203	Turbo sp.	B2/2	−30 cm	9750 ± 90	10,430–10,683	10,814–10,515	Tanudirjo (2005)
2nd phase	22-17,000 BP	4	30–40	Layer 2B	ANU-10810	Turbo sp.	B2/2	−40 cm	14,820 ± 80	17,309–17,819	17,849–17,320	Tanudirjo (2005)
					ANU-10960	Turbo sp.	C2/2	−50 cm	18,880 ± 140	21,715–22,421	22,618–21,939	Tanudirjo (2005)
1st phase	35-31,000 BP	5–9	40–90	Layer 3,4	ANU-10499	Turbo sp.	B2/3	−50 cm	30,850 ± 340	34,988–35,033	35,001–33,854	Tanudirjo (2005)
					TERRA-070407a04	Turbo sp.	C3/3	−50 cm	28,460 ± 150	32,223–32,832	32,433–31,397	Ono et al. (2010)
					TERRA-070407a03	Turbo sp.	D3/3	−60 cm	28,760 ± 150	32,426–33,079	32,813–31,672	Ono et al. (2010)
					ANU-10498	Turbo sp.	B2/4	−70 cm	29,590 ± 630	32,898–34,087	34,368–31,622	Tanudirjo (2005)
					ANU-10204	Turbo sp.	B2/4	−80 cm	29,760 ± 650	33,031–34,201	34,592–31,750	Tanudirjo (2005)

ANU = The Australian National University Radiocarbon Dating Laboratory.
TERRA = Tandem Accelerator for Environmental Research and Radiocarbon Analysis.
Note: All uncalibrated radiocarbon dates from Leang Sarru reported herein have been recalibrated with Calib 7.0.4 (Stuiver and Reimer, 1993) using Marine13 for shell (Reimer et al., 2013), and are given as a 95.4% or higher probability range. See Ono et al. (2010) for rejected dates.

[a] Calibrated by Ono et al. (2010) using CalPal2007_HULU.

(2005) categorised the stone artefacts from units B2 and C2 into cores, lithic waste, blade-like flakes, and utilised flakes - pieces with retouches or macroscopically visible wear traces. Utilised flakes, blade-like artefacts, and a hammerstone were recovered in unit B2 within Layer 3, dated to 35,001–33,854 cal. BP (ANU-10499, Tanudirjo, 2005), while in C2, those artefacts began appearing in Layer 2 (ANU-10960, 22,618–21,939 cal. BP; Tanudirjo, 2005). Ono et al. (2015) and Tanudirjo (2001) proposed the presence of flakes that resemble gull wings (cross section of the striking platform), which were produced through successive flaking with a single direction on the same section of the striking platform.

3. Materials and methods

A total of 14,525 lithic artefacts were recovered - 5060 in 1995 (Tanudirjo, 2005) and 9465 in 2005 (Ono et al., 2010). Although unretouched flakes are dominant, the assemblage contains retouched artefacts, mainly notched pieces (Ono et al., 2010). R. Fuentes and A. Pawlik selected 183 artefacts, with 361 *potentially used areas* (PUA) (Vaughan, 1985; van Gijn, 1989; Table 2; SI Tables 2 and 4; SI 5), to undergo multi-level use-wear analysis (van Gijn, 1989). We defined PUA based on the presence of an edge which can be assigned as a unit within the stone tool, and was deemed to have been used to perform specific tasks (Vaughan, 1985; van Gijn, 1989; SI 5). The samples were recovered from Spits 1 to 6 (0–60 cm from surface level), covering Layers 1 to 3 and four occupation phases. These include 15 artefacts from the 1st phase (PUA = 24), 37 from the 2nd phase (PUA = 71), and 82 from the 3rd phase (PUA = 168). In addition, we analysed 42 stone tools from the Metal Age (PUA = 82) and seven from the Modern Period (PUA = 16), tools with potentially used edges (Table 2; SI Tables 1 and 3) to identify the diachronic changes in technology. We based the selection on the following parameters: 1) condition of raw material and suitability for use-wear analysis, 2) presence of working edge, 3) visible microscarring or reflective surfaces (polishes) inspected with the aid of 2× and 10× hand lenses, and 4) presence of PUA. All artefacts are currently stored at

Table 2
Summary of tool and PUA edge types per occupation phase.

Category		Modern Period		Metal Age		3rd Phase		2nd Phase		1st Phase		Total	
		Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
Tool type	Unretouched	5	3%	30	16%	63	34%	22	12%	11	6%	131	72%
	Notched	2	1%	11	6%	17	9%	15	8%	3	2%	48	26%
	Micronotched	0	0%	1	1%	2	1%	0	0%	0	0%	3	2%
	Shatter	0	0%	0	0%	0	0%	0	0%	1	1%	1	1%
	Total	**7**	**4%**	**42**	**23%**	**82**	**45%**	**37**	**20%**	**15**	**8%**	**183**	**100%**
PUA edge type	Concave	6	2%	32	9%	61	17%	24	7%	6	2%	129	36%
	Convex	3	1%	14	4%	40	11%	16	4%	9	2%	82	23%
	Straight	1	0%	9	2%	21	6%	11	3%	1	0%	43	12%
	Irregular	6	2%	27	7%	46	13%	20	6%	8	2%	107	30%
	Total	**16**	**4%**	**82**	**23%**	**168**	**47%**	**71**	**20%**	**24**	**7%**	**361**	**100%**

Table 3
Mean and median values of morphological measurements per occupation phase.

Attributes	Modern Period		Metal Age		3rd Phase		2nd Phase		1st Phase		Total	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Weight (gm), N = 183	7.81	5.34	6.80	6.07	6.42	4.34	9.53	7.62	9.52	6.58	7.44	5.53
Max length (mm)	32.50	33.60	29.73	29.35	30.63	28.70	33.83	32.80	32.99	36.20	31.33	30.80
Max width (mm)	30.71	29.00	27.75	26.85	24.59	22.75	29.44	28.50	28.23	29.90	26.83	26.60
Max thickness (mm)	10.39	9.60	9.53	9.05	9.77	8.75	11.25	10.80	9.65	9.20	10.03	9.30
Striking platform thickness (mm), N = 149	9.27	6.80	5.87	5.10	6.04	5.10	7.76	7.25	6.84	5.85	6.59	5.80
Striking platform width (mm)	12.77	11.30	14.23	13.45	12.14	11.65	17.51	15.75	14.43	13.90	13.99	13.00
PUA length (mm), N = 361	25.24	27.75	25.96	25.10	24.86	23.70	26.77	26.60	27.14	25.20	25.65	24.70
PUA edge angle (deg)	48	49	51	52	51	53	49	50	56	55	51	52

the Balai Arkeologi (BALAR) in Manado, North Sulawesi where they are kept in labelled zip lock bags. These had been already cleaned and adhering sediments removed under running water before storage. Prior to analysis, stains from handling and storage were removed through a gentle cleaning procedure using an ultrasonic tank filled with a mild solution of dishwashing liquid and distilled water for c. 3 min, and consequently rinsed with distilled water and 70% alcohol, then dried on paper towels. This procedure cleans artefacts for microscopic analysis gently and efficiently without leaving stains on the surface or causing damage to residues (Unrath et al., 1986).

We conducted morphological analysis on the samples to present the attributes of the selected tools and to investigate changes in the qualitative features and metrical attributes. The detailed morphological analyses were already conducted by Tanudirjo (2001, 2005) and Ono et al.

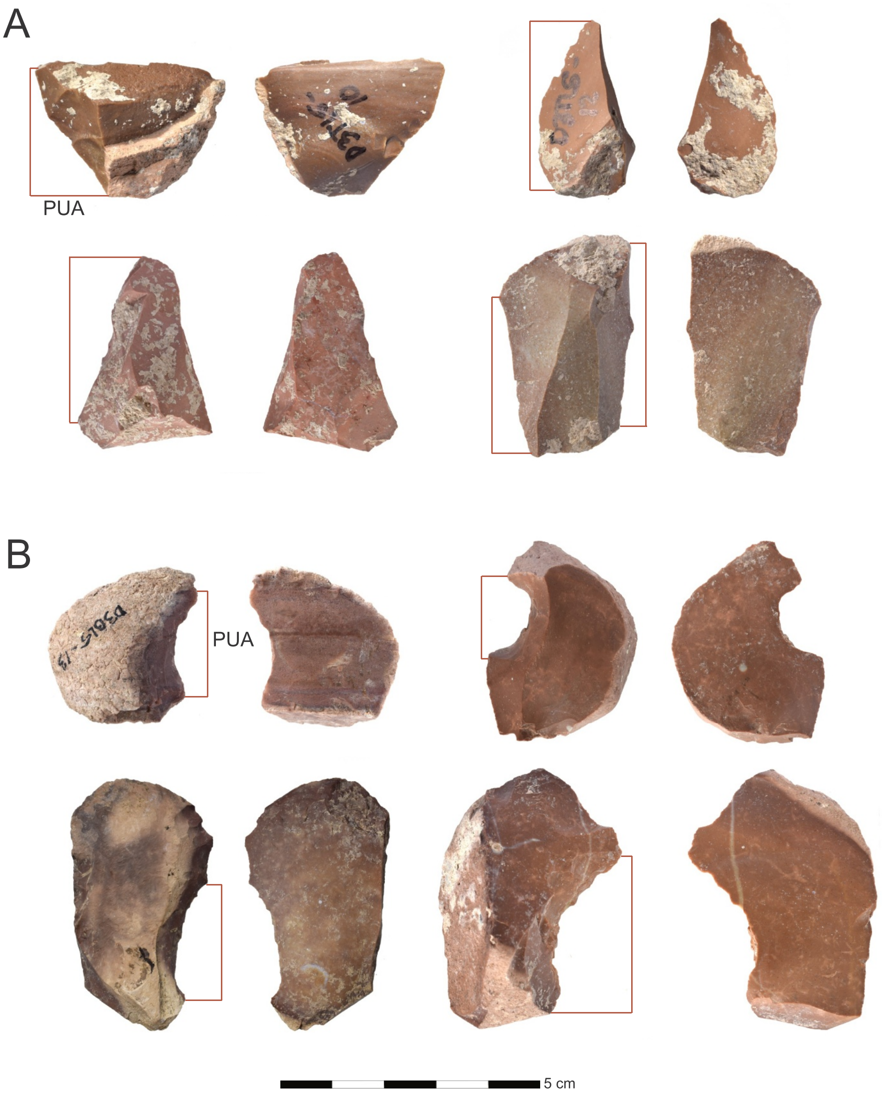


Fig. 3. A. Unretouched flakes from the 1st phase B. Notched tools from the 2nd phase. Locations of potentially used areas are marked with red lines. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

(2015). Analysis had to be conducted in the collection holding facility at BALAR Manado, hence a portable microscope set-up was required. Low-power analysis was carried out with a Euromex NexiusZoom stereo-microscope (6.7–45×) and a Promicron 48-LED ring light illumination unit with incremental light control. For high power analysis, we used Olympus BHMJ (110×, 220×, 440×) and BXFM (100×, 200×, 500×) reflected light microscopes modified for LED spotlight illumination and operating with differential interference contrast (DIC)/Nomarski interference contrast (NIC) and long-working-distance (LWD) objectives. The artefacts were mounted with plasticine on a free-moving cup stage. Photomicrographic documentation was performed using a Nikon D5300 attached to the microscope via an AmScope and Promicron phototube and adapter for Euromex NexiusZoom and Olympus BXFM. Respectively, a Canon Powershot G9 via a Promicron phototube and Olympus MTV-3 C-mount adapter for the Olympus BHMJ. Both cameras were connected to a personal computer and remotely controlled with dedicated image capture software. We used recording forms to document descriptions, locations, and magnifications of use-wear traces. Artefacts with potentially use-related residues were exported for further analysis. Scanning electron microscopy was conducted at the National Institute of Geological Sciences of the University of the Philippines (Hitachi S-3400N Variable Pressure Scanning Electron Microscope with Deben Peltier Coolstage) and at the Microfossils Laboratory in the Department of Geosciences of the Eberhard Karls Universität Tübingen (PhenomWorld Scanning Electron Microscope and Energy Dispersive X-ray).

4. Results

4.1. *Morphological attributes of samples for use-wear analysis*

We analysed 182 flakes and one shatter, all made from chert (Table 2; Fig. 3). These are composed of 131 unretouched flakes (72%), 48 notched-type (26%), three with micronotch (2%), and one shatter (1%) (Table 2). Most are complete flakes from all occupation phases – 11/15 from the 1st phase, 85/119 from the 2nd and 3rd phases (Layers 2A and 2B), and 37/49 from the Metal Age and Modern Period (SI Table 3). The notched tools were present beginning the 1st phase but only minimal (n = 3), and were mostly identified from the 2nd phase (n = 15), 3rd phase (n = 17), and Metal Age (n = 11). Majority of the samples, from all the occupation phases, were produced through Hertzian initiation, pronounced bulbs of percussion, and feather termination with no significant change in the production technique (SI Table 3). Plain-type striking platforms were dominant for all occupation phases. During the 3rd phase, prepared striking platforms first appeared and were identified on 13 of the 64 flakes with proximal sections (Table 2; SI Table 3). The selected stone tools have a median weight of 5.53 gms and maximum dimensions of 30.8 mm (length) by 26.6 mm (width) by 9.3 mm (thickness). The dimensions of our samples, including their striking platforms (median thickness = 5.8 mm, width = 13.0 mm), did not vary across all the occupation phases (Table 3).

Three hundred sixty one PUAs were assigned and categorised into the following working edge types - convex (82, 23%), concave (129, 36%), straight (43, 12%), and irregular (107, 30%) (Table 2). Twenty four PUAs were identified during the 1st phase, 71 from the 2nd phase, 168 from the 3rd phase, 82 from the Metal Age, and 16 from the Modern Period. The four main edge types (concave, convex, straight, and irregular) were produced from the 1st phase until the Metal Age and there is no clear trend for the samples, except for the minimal presence of straight edges. Overall, the samples do not show change across the occupation phases – PUA median length of 24.8 mm and 52° edge angle (Table 3). No flake modification or types were identified except for notched tools, which were produced in all phases (Table 2).

4.2. *Use-wear analysis*

4.2.1. *Traces on potentially used areas*

Two hundred thirty three of 361 PUAs have proximal scar initiations (65%), which were categorised into shallow, steep, break-shallow, and crescent break (after Vaughan, 1985). For distal scar terminations, these were classified into feather, hinge, step, and crescent, and are present on 249 of 361 PUAs (69%) (Vaughan, 1985, Table 4; SI Tables 2 and 4). The formation of traces exclusively on one face of the PUA, and their perpendicular orientation is in concordance with transversal activities such as scraping or heckling. Also, rounding frequently occurred, another wear pattern that is associated with processing of softer materials (Keeley and Newcomer, 1977; Plisson, 1985; Vaughan, 1985; Unrath et al., 1986; van Gijn, 1989; Pawlik, 1995: 96), is present on 117 of 361 PUAs (Table 4). These were categorised into light, mid, to intensively-developed rounding types. We do not exclude the processing of hard material such as bone, however the absence of larger mammals in the faunal assemblage of Leang Sarru (Ono et al., 2010) makes such a factor quite unlikely. Polishes, present on 171 of 361 PUAs (47%), and were categorised as generic weak, smooth-pitted and well-developed (Vaughan, 1985, Table 4). Bright spots (Levi-Sala, 1996) were also identified on the samples (21/361 PUA, 6%). Striations were occasionally present in sections with polishes (52/361 PUA, 14%; Table 4), and appear mainly in transversal (37/361 PUA, 10%) and diagonal orientation (13/361 PUA, 4%; SI Table 4), indicating scraping actions. The formation of parallel (7/361 PUA, 2%) and multidirectional striations (2/361 PUA, 1%) was minimal (SI Table 4).

For types of actions, we identified 7/361 PUAs (2%) that were used in longitudinal orientation, from the 2nd and 3rd phases. One hundred sixty seven PUAs (46%) were employed in transversal motion while 13 (4%) has traces showing diagonal action – both directions inferred as scraping action. The PUAs with traces of both longitudinal and transversal actions were identified as multifunctional while those that were possibly used as part of a hafted tool were labelled as composite. Tools with faint traces or those which also show knapping or fresh breakage, and deemed to be taphonomic were grouped under undeterminable (43 PUA, 12%), while unused PUAs account for 135 (37%) in total (Table 5). Overall, majority of the tools appear to have been used in transversal orientation based on the locations of the traces that were identified, and

Table 4
Summary of presence of use-wear traces per occupation phase.

Use-wear category	Modern Period		Metal Age		3rd Phase		2nd Phase		1st Phase		Total Presence		Total Absence	
	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
Distal scarring	8	50%	49	60%	113	67%	49	69%	14	58%	233	65%	128	35%
Proximal scarring	9	56%	51	62%	119	71%	54	76%	16	67%	249	69%	112	31%
Rounding	2	13%	25	30%	57	34%	26	37%	7	29%	117	32%	244	68%
Polish	5	31%	33	40%	77	46%	42	59%	14	58%	171	47%	190	53%
Striations	1	6%	9	11%	27	16%	13	18%	2	8%	52	14%	309	86%
Retouch	7	44%	31	38%	53	32%	31	44%	6	25%	128	35%	233	65%
Possible residues	6	38%	25	30%	34	20%	28	39%	2	8%	95	26%	266	74%

Table 5
Inferred PUA actions and contact materials per occupation phase.

Inference per PUA		Modern Period		Metal Age		3rd Phase		2nd Phase		1st Phase		Total	
		Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
Action	Transversal	2	13%	30	37%	81	48%	33	46%	8	33%	154	43%
	Longitudinal	0	0%	0	0%	5	3%	2	3%	0	0%	7	2%
	Diagonal	1	6%	4	5%	4	2%	3	4%	1	4%	13	4%
	Composite	0	0%	0	0%	6	4%	3	4%	0	0%	9	2%
	Undeterminable	3	19%	14	17%	17	10%	7	10%	2	8%	43	12%
	Unused	10	63%	34	41%	55	33%	23	32%	13	54%	135	37%
	Total	**16**	**100%**	**82**	**100%**	**168**	**100%**	**71**	**100%**	**24**	**100%**	**361**	**100%**
Contact material	Soft	3	19%	19	23%	40	24%	16	23%	2	8%	80	22%
	Soft-hard	0	0%	4	5%	2	1%	1	1%	1	4%	8	2%
	Hard	0	0%	1	1%	14	8%	7	10%	1	4%	23	6%
	Phytolith-rich plant	0	0%	8	10%	32	19%	11	15%	3	13%	54	15%
	Undeterminable	3	19%	16	20%	25	15%	13	18%	4	17%	61	17%
	Unused	10	63%	34	41%	55	33%	23	32%	13	54%	135	37%
	Total	**16**	**100%**	**82**	**100%**	**168**	**100%**	**71**	**100%**	**24**	**100%**	**361**	**100%**

on directionality of polishes and striations.

For contact materials, a total of 80 PUAs were used on soft materials while eight have traces associated with the soft-hard category. Well-developed polishes ('sickle gloss') caused by processing phytolith rich-plants were present on 54/361 PUAs (15%), and were mostly identified on samples from the 3rd phase (32/54 PUA). Intensive scarring associated with hard materials were inferred on 23 PUAs (6%) (Table 5). These show contact with hard woody plants and possibly even bones, although these are absent in the archaeological record (Ono et al., 2010). Traces associated with plant processing were identified as early as the 1st phase, although very minimal (3 PUA) (Table 5). Intensified activities during the 2nd and 3rd phases indicate continuity of processing of soft materials and phytolith-rich plants (Table 5; SI Tables 2 and 4). In the next section, we interpreted the function of each tool (N = 183) based on the combination of types of actions and contact materials for each PUA.

4.2.2. *Interpretations of tool function*

During the 1st phase (N = 15), five tools were used for scraping soft material (n = 1), soft-hard, (n = 1), phytolith-rich plants (n = 2), while one has undeterminable contact material. One artefact was used as notched scraper on soft material while no cutting tools were identified during this period. The few samples suitable for use-wear analysis reflects limited activities in the site during this period. Out of the 15 artefacts, two were interpreted as undeterminable and seven as unused. During the 2nd phase (N = 37), 13 unretouched flakes were used in scraping action on a variety of materials (soft = 3, hard = 1, soft-hard = 1, phytolith-rich plant = 7, undeterminable = 1) and six notched tools were used in scraping action (soft = 3, phytolith-rich plant = 1, undeterminable = 2; Table 7). Two artefacts were categorised as multifunctional (soft-hard = 1, and phytolith-rich plant = 1; Table 7) and one as composite tool (soft = 1, hard = 1). For the 3rd phase (N = 82), the same trend was observed - processing of soft materials (n = 14) and phytolith-rich plants (n = 20) through scraping especially using unretouched flakes. Scraping with notched tools was also detected (soft = 7, hard = 2). We identified lithics used in grooving (n = 2), cutting (n = 3), and part of composite implements (n = 3), but still minimal compared to scraping tools. Seven tools were undeterminable and 16 were unused. Twenty-three tools were inferred to have been used in processing phytolith-rich plant (Table 7). After the 3rd phase and during the Metal Age, the same trend was observed – most activities were associated with scraping of soft materials and plant processing.

Across all occupation phases, majority of the tools were used in scraping (transversal/diagonal PUA actions) soft materials (43 tools, 23%; 79 PUA, 22%) and phytolith-rich plants (37 tools, 20%; 48 PUA, 13%; Table 6). On the other hand, cutting action (3 tools, 2%; 7 PUA, 2%) and processing of hard materials (12 tools, 7%; 23 PUA, 6%) were minimal (Table 6). Processing of phytolith-rich plants most likely began during the 1st phase (n = 2) but substantial evidence was identified during the 2nd and 3rd phases, with 33 tools showing contact with this

Table 6
PUA actions and tool interpretations per type of contact material.

Action		Contact material													
		Soft	%	Hard	%	Soft-hard	%	Phytolith-rich plant	%	Undeterminable	%	Unused	%	Total	%
PUA	Longitudinal	1	0%	4	2%	0	0%	2	1%	0	0%	0	0%	**7**	**2%**
	Transversal	77	21%	14	8%	8	4%	40	11%	15	4%	0	0%	**154**	**43%**
	Diagonal	2	1%	3	2%	0	0%	8	2%	0	0%	0	0%	**13**	**4%**
	Part of hafted tool	0	0%	2	1%	0	0%	4	1%	3	1%	0	0%	**9**	**2%**
	Undeterminable	0	0%	0	0%	0	0%	0	0%	0	0%	43	12%	**43**	**12%**
	Unused	0	0%	0	0%	0	0%	0	0%	0	0%	135	37%	**135**	**37%**
	Total	**80**	**22%**	**23**	**6%**	**8**	**2%**	**54**	**15%**	**18**	**5%**	**178**	**49%**	**361**	**100%**
Tool	Cutting	1	1%	1	1%	0	0%	1	1%	0	0%	0	0%	**3**	**2%**
	Scraping	27	15%	7	4%	7	4%	35	19%	3	2%	0	0%	**79**	**43%**
	Notched scraper	16	9%	2	1%	2	1%	2	1%	2	1%	0	0%	**24**	**13%**
	Grooving	0	0%	1	1%	0	0%	1	1%	0	0%	0	0%	**2**	**1%**
	Composite tool	1	1%	1	1%	0	0%	2	1%	1	1%	0	0%	**5**	**3%**
	Multifunctional	0	0%	0	0%	1	1%	1	1%	0	0%	0	0%	**2**	**1%**
	Undeterminable	0	0%	0	0%	0	0%	0	0%	23	13%	0	0%	**23**	**13%**
	Unused	0	0%	0	0%	0	0%	0	0%	0	0%	45	25%	**45**	**25%**
	Total	**45**	**25%**	**12**	**7%**	**10**	**5%**	**42**	**23%**	**29**	**16%**	**45**	**25%**	**183**	**100%**

Table 7
Interpretations of tool use per occupation phase.

Activity	Contact material	Modern Period		Metal Age		3rd Phase		2nd Phase		1st Phase		Total	
		Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
Cutting	Soft	0	0%	0	0%	1	1%	0	0%	0	0%	**1**	**1%**
	Hard	0	0%	0	0%	1	1%	0	0%	0	0%	**1**	**1%**
	Phytolith-rich plant	0	0%	0	0%	1	1%	0	0%	0	0%	**1**	**1%**
Scraping	Soft	2	1%	8	4%	14	8%	3	2%	0	0%	**27**	**15%**
	Hard	0	0%	0	0%	5	3%	1	1%	1	1%	**7**	**4%**
	Soft-hard	0	0%	3	2%	2	1%	1	1%	1	1%	**7**	**4%**
	Phytolith-rich plant	0	0%	6	3%	20	11%	7	4%	2	1%	**35**	**19%**
	Undeterminable	0	0%	0	0%	1	1%	1	1%	1	1%	**3**	**2%**
Notched scraper	Soft	1	1%	4	2%	7	4%	3	2%	1	1%	**16**	**9%**
	Hard	0	0%	0	0%	2	1%	0	0%	0	0%	**2**	**1%**
	Soft-hard	0	0%	2	1%	0	0%	0	0%	0	0%	**2**	**1%**
	Phytolith-rich plant	0	0%	1	1%	0	0%	1	1%	0	0%	**2**	**1%**
	Undeterminable	0	0%	0	0%	0	0%	2	1%	0	0%	**2**	**1%**
Grooving	Hard	0	0%	0	0%	1	1%	0	0%	0	0%	**1**	**1%**
	Phytolith-rich plant	0	0%	0	0%	1	1%	0	0%	0	0%	**1**	**1%**
Composite tool	Soft	0	0%	0	0%	0	0%	1	1%	0	0%	**1**	**1%**
	Hard	0	0%	0	0%	0	0%	1	1%	0	0%	**1**	**1%**
	Phytolith-rich plant	0	0%	0	0%	2	1%	0	0%	0	0%	**2**	**1%**
	Undeterminable	0	0%	0	0%	1	1%	0	0%	0	0%	**1**	**1%**
Multifunctional	Soft-hard	0	0%	0	0%	0	0%	1	1%	0	0%	**1**	**1%**
	Phytolith-rich plant	0	0%	0	0%	0	0%	1	1%	0	0%	**1**	**1%**
No function	Undeterminable	1	1%	9	5%	7	4%	4	2%	2	1%	**23**	**13%**
	Unused	3	2%	9	5%	16	9%	10	5%	7	4%	**45**	**25%**
Total		**7**	**4%**	**42**	**23%**	**82**	**45%**	**37**	**20%**	**15**	**8%**	**183**	**100%**

material type (Tables 6 and 7; SI Table 2). In the following sections, we provide examples of distinct technological activities that include plant processing using unretouched flakes and notched tools, use of grooving and planing tools, and production of composite implements.

4.3. Plant polish on unretouched flakes

Evidence of plant processing was recorded on flaked tools from the 2nd phase and even as early as the 1st phase. For example, artefact no. D2_TL_S5_0003 and D2_TL_S5_0004 have intensive micropolishes, with diagonal orientation, formed approximately 10 μm away from the immediate edge (Fig. 4A, 4B). During the 2nd phase, activities associated with plant working appeared to have intensified, with the processing of phytolith-rich grassy plants as the dominant activity. The plant polishes reached an intensity in development comparable to sickle gloss, for instance on tool no. D3_TL_S4_0009 (Fig. 4C) and D3_BL_S4_0006 (Fig. 4D). Identical patterns of polish formation were also identified within the 3rd phase (D3_BD_S3_0003, Fig. 4E; D3_TL_S3_0009, Fig. 4F) and the Metal Age (D3_TG_S2_0001, Fig. 4G; D3_BL_S2_0007, Fig. 4H), with flat polishes and bevel formation. In most cases, polishes and striations were oriented diagonally and perpendicular to the tool edges indicating transversal activities, different from

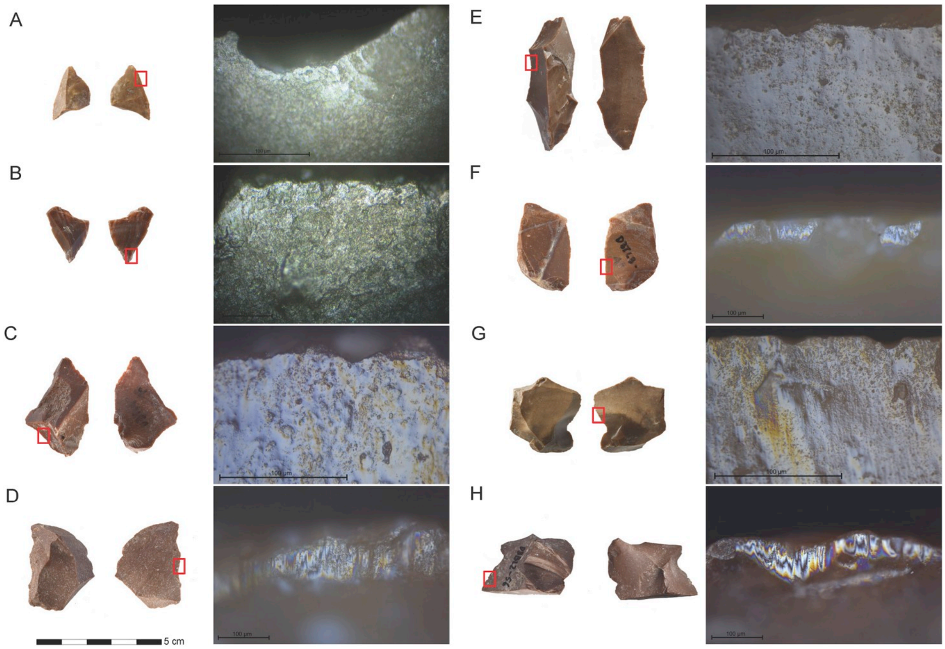


Fig. 4. Polishes and bevel formed on unretouched flakes from the 1st phase (A,B), 2nd phase (C,D), 3rd phase (E,F), and Metal Age (G,H).

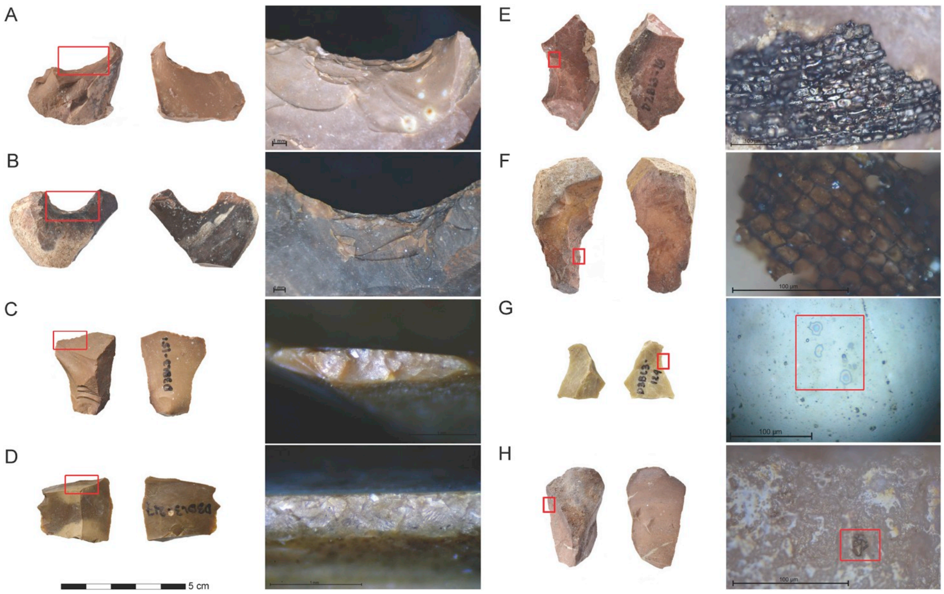


Fig. 5. A,B. Notched tools with scarring from retouch. C,D. Traces of chamfering resulting in flat working edges ideal for grooving and planing activities. E,F. Notched tools with plant remains on working edges. G. Phytoliths preserved on well-developed polish. H. Plant tissues on polished sections.

cutting or reaping of cereal plants typical for Neolithic sickle implements. Instead, the observed traces compare favourably to experimental traces attributed to transverse actions in the processing of tropical plants such as whittling, scraping, and heckling (Xhauflair, 2014; Xhauflair et al., 2016). These polishes are fully-linked flat and undulating surfaces with micropitting are similar with those documented in previous studies and based on experiments and artefact analyses on tools from ISEA (Davenport, 2003; Xhauflair and Pawlik, 2010; Xhauflair, 2014; Xhauflair et al., 2016).

4.4. *Retouched tools and plant remains*

Notched artefacts were initially recorded in the Leang Sarru assemblage by Tanudirjo (2001), who considered them as similar to the steep-angled obsidian scrapers with notches found in the Passo shell midden site in North Sulawesi and lateral scrapers from East Timor (Bellwood, 1976). Glover (1986) proposed that these artefacts were used in creating small cylindrical objects that include bows, spears, blow guns, and digging sticks. He also noted that the retouch on the medial part of one or both sides of the flakes. We inferred that blanks were modified through unifacial retouch from the ventral face and within the thickest part of the flakes, at the proximal section and towards the bulb of percussion, to create notched working edge. Multiple secondary row scarring, characterised by step and hinge terminations, were formed in the process of retouching and resulted in steeper edge angles ideal for performing transversal actions (D3_BL_S4_0001, Fig. 5A; D2_BL_S3_0003, Fig. 5B). It seems that the notches were used for plant processing through repetitive scraping motions. Very similar formation and distribution of micropolishes were observed in experiments aimed at extracting fibres from reeds (Pawlik, 1995: 91–93). The limited formation of polishes and striations on the immediate edge shows the continuous abrasion and reduction of the edge while being used, and/or resharpening. In several instances, the notches were possibly used to support attachment of the lithic implements to a shaft with a binding.

The notched tools were designed as scrapers, with steep edge angles, and were inferred to have been used mainly for plant processing. We foundevidence of plant remains on fifty one artefacts, 15 from the Pleistocene and 36 from the Holocene layer, with cases showing preservation right on the negatives of the retouched sections (D2_BL_S3_0010, Fig. 5E; D3_TL_S4_0001, Fig. 5F). Although, the residues were mostly preserved on the notched tools, these were also present on unretouched flakes. In one case, phytoliths were embedded within the polish (D3_BL_S3_0019, Fig. 5G). Plant tissues were also deposited along the edge outline (D2_BL_S3_0002, Fig. 5H). The detailed identification of plant remains will be presented in a separate paper (Fuentes et al., in review).

4.5. *Grooving and planing tools*

Five artefacts have chamfered edges (3rd phase = 4, Metal Age = 1; Table 4), formed through a row of fine feather-terminated scars. The used edges appear ‘flattened’ from a vertical point of view (D3_BL_S3_0004, Fig. 5C) and seem to be well-suited for transversal actions such as scraping, whittling, and grooving. The modification is characterised by regular shallow-initiated and feather-terminated negatives located on either the distal or proximal section of the tools (D3_BL_S3_0010, Fig. 5D). These micro-retouches are mainly found on trapezoidal and triangular flakes. Although wear traces indicating use on softer material are more common (46 tools, 25%), traces from soft-hard (11 tools, 6%) and mainly hard organic materials (12 tools, 7%; Table 6) indicate processing of woody plants, yet we cannot discount osseous materials even though no animal bones were recovered at Leang Sarru (Ono et al., 2010). Aside from utilitarian objects made of wood, this can also include the manufacturing of shafts for composite tools since potential hafting traces and residues were detected on several flake tools in the assemblage.

4.6. *Composite tools*

Tool technology is considered as composite when it has several parts made of different materials, most commonly a lithic or bone implement attached to a shaft made usually of wood but also bamboo, antler, or bone. This tool is then fixed with a binding, glue, or a combination of both (Ambrose, 2010). Hereby, a composite tool is not necessarily used exclusively as a projectile but could have also been deployed for utilitarian purposes. Evidence of use of this tool type, with symmetrical form, scarring at the hafting boundary, scalar scars, hafting polishes, and residues that are distributed in presumed areas where a form of binding

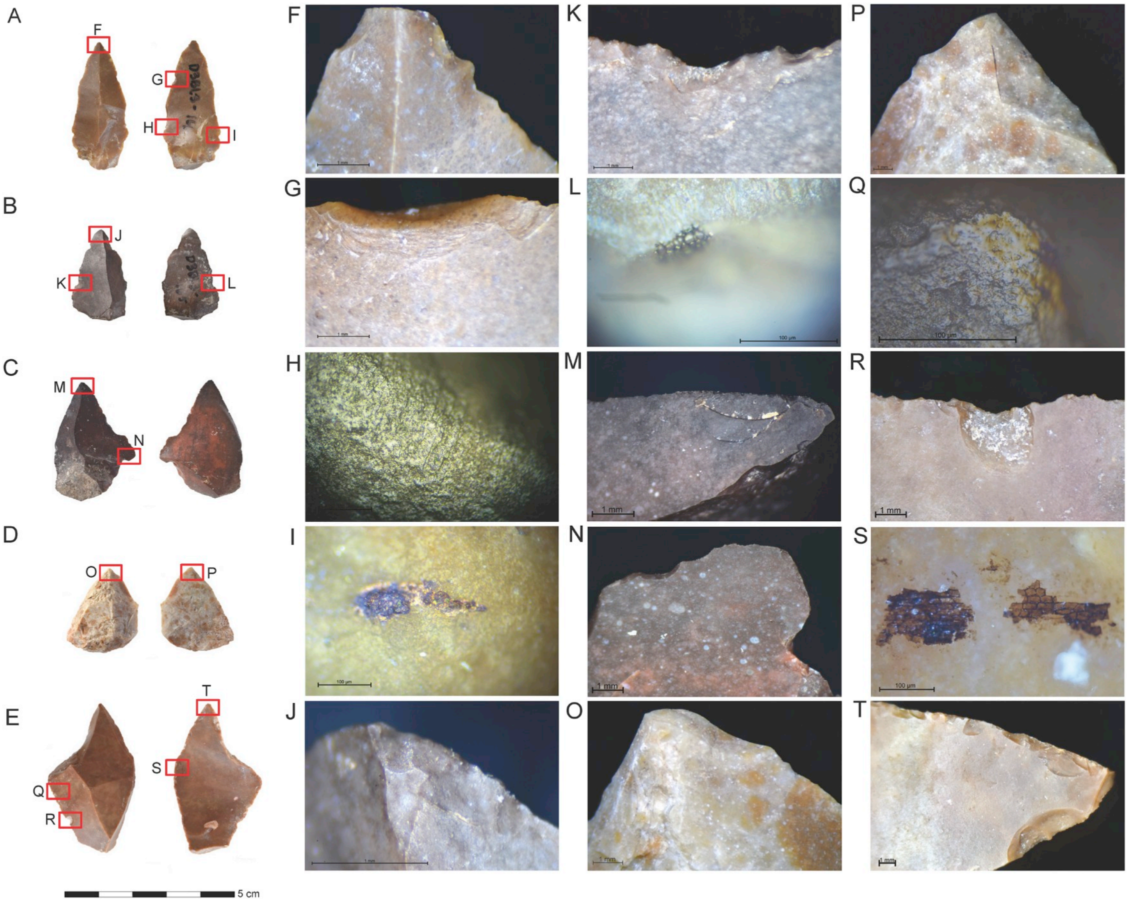
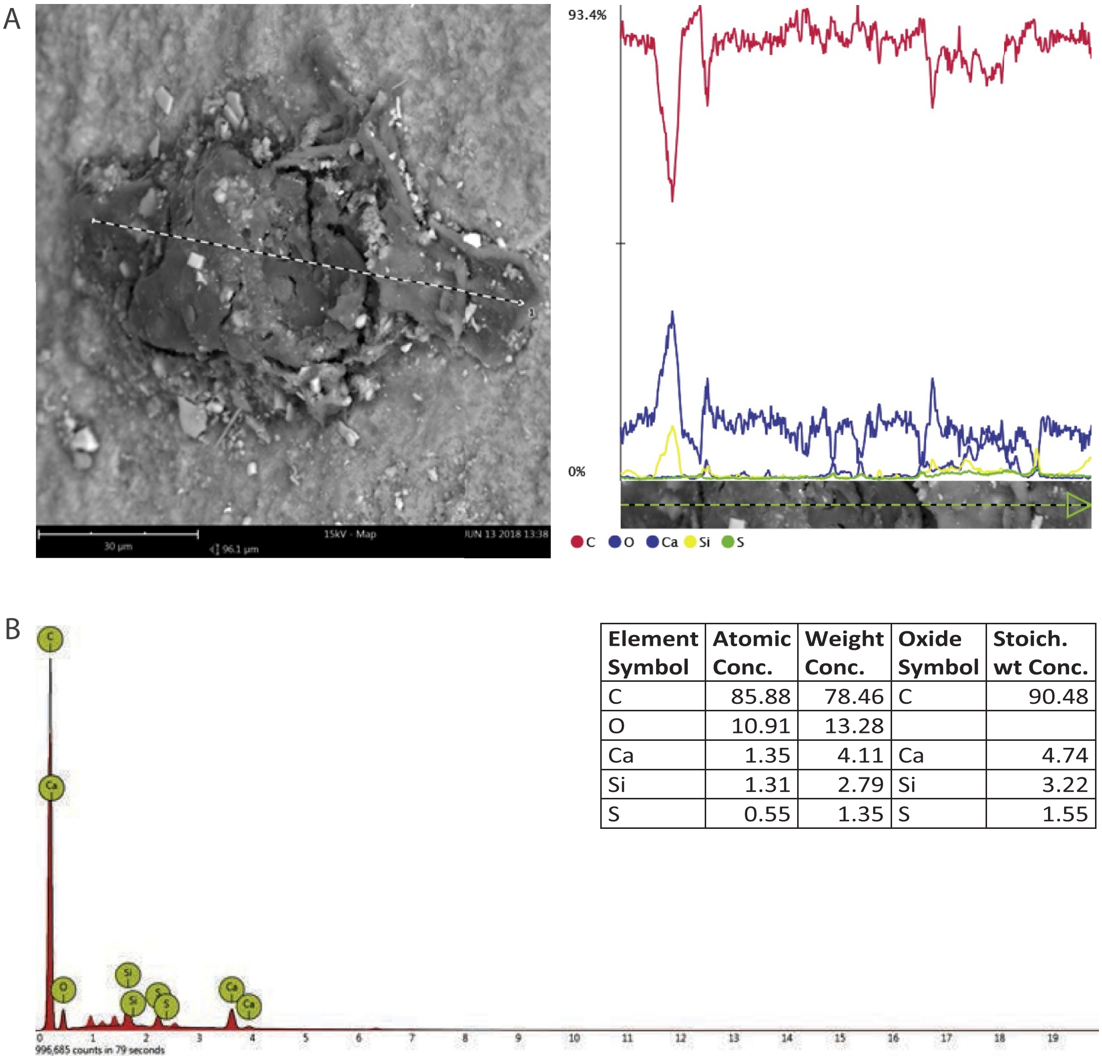


Fig. 6. Artefacts interpreted as part of composite tools from the 3rd phase (A,B,C) and 2nd phase (D,E). F-I. Traces on D3_BL_S3_0038 (6.A). F. Impact scars at the tip. G. Sliced into scalar scar (curved initiation) located on the left and right lateral sections. H. Polishes formed along scars. I. Hafting residues. J-L. Traces on D3_BL_S3_0037 (6.B). J. Impact traces. K. Scars due to hafting. L. Plant remains within one of the scars. M,N. Traces on D2_BL_S3_0001 (6.C). M. Scars at the tip of the tool. N. Scars at the hafting boundary. O,P. Impact scars on both dorsal and ventral faces of D2_BL_S4_0002. Q-T. Traces on D3_TL_S4_0005. Q. Hafting polish. R. Scars at the hafting boundary. S. Plant remains associated with hafted section of the tool. T. Scars at the tip of the tool.

was used, was detected on five samples (3%) (Table 7; SI 6). Potentially hafted implements included mostly blade-like flakes, such as D3_BL_S3_0038 (Fig. 6A), D3_BL_S3_0037 (Fig. 6B), and D2_BL_S3_0001 (Fig. 6C), recovered from the 3rd phase; and D2_BL_S4_0002 (Fig. 6D) from the 2nd phase. One retouched tool, D3_TL_S4_0005 (Fig. 6E), from the 2nd phase, was also interpreted as part of a composite implement. D3_BL_S3_0038, D3_BL_S3_0037, and D2_BL_S3_0001 are characterised by lateral sections divided by arises, indicating knapping preparation to form the triangular and blade-like feature (Fig. 6A, 6B, 6C). Impact scars are present at the 'tip' of the artefacts (Fig. 6F, 6J, 6.M, 6.O, 6.P, 6.T). We also identified sliced into scalar scars (Fig. 6G) and scars at the hafting boundary (Fig. 6K, 6.N, 6.R), aligned on the left and right lateral sections, traces that form due to contact with bindings (Rots, 2008, 2013; Rots et al., 2006; Sano, 2009; SI 6). This is further substantiated by the formation of polishes associated with hafting (Fig. 6H, 6.Q).

Although the plant residues on the assemblage appear to be directly associated with plant processing, we also detected it as possibly part of production of composite tools. For example, D3_BL_S3_0037 (Fig. 6B) and D3_TL_S4_0005 (Fig. 6E) have sections with plant residues (Fig. 6.L, 6.S). One possibility for binding composite tools is the use of fibres, but this has not been documented for stone tools in the region yet. We only found possible fibre and plant cells on a single notched tool from the Metal Age, and will be presented as part of a study on identification of plant remains from the site (Fuentes et al., in review). The resinous material (Fig. 6I) on D3_BL_S3_0038 (Fig. 6A) probably stems from the use of mastics to support binding. Our sample shows highly organic residues with cracks, a typical feature of mastics after setting (Fig. 7A). EDX analysis shows that it is organic-based (Fig. 7B). Similar adhesives used for composite technology have been identified through microwear and residue analysis, and were found for instance on projectile points made of bone and stingray spine from the west mouth of Niah Cave in Borneo, dated to 11,700–10,690 cal. BP (Barton et al., 2009), and on multicomponent stone tools from the Terminal Pleistocene layers at Ille Cave in Palawan (Pawlik, 2012).



Element Symbol	Atomic Conc.	Weight Conc.	Oxide Symbol	Stoich. wt Conc.
C	85.88	78.46	C	90.48
O	10.91	13.28		
Ca	1.35	4.11	Ca	4.74
Si	1.31	2.79	Si	3.22
S	0.55	1.35	S	1.55

Fig. 7. A. SEM image of residues with drying cracks and EDX sample area. B. Results of elemental analysis.

5. Discussion and conclusion

Through multi-stage use-wear analysis, we identified human activities at Leang Sarru dating back from c. 35,000 years ago. During the Last Glacial Maximum and Early Holocene, lithic production and activities intensified (Tanudirjo, 2001, 2005; Ono et al., 2010, 2015), and it was also during this time that more ‘complex’ activities began to be conducted at the rockshelter. Similar to other sites in ISEA, the stone tool assemblage from Leang Sarru is mainly composed of unretouched flakes, however, through simple modification, notched tools were also produced. We identified activities that were aimed at plant processing as indicated by the presence of polishes formed by direct and prolonged contact with phytolith-rich plants. This interpretation is supported by the adherence of plant remains on both unretouched and retouched tools. No animal bones were recovered during the excavations at Leang Sarru in 1995 and 2004, suggesting that the main raw material source for subsistence and production of other forms of technology were plant-based (Tanudirjo, 2001, 2005; Ono et al., 2010). Grooving or planing tools, characterised by blunt edges formed through secondary scarring were inferred to have been part of this plant processing toolkit. This supports our idea that simple unretouched tools as the main qualifier for an expedient technology should be re-assessed through use-wear analysis. Aside from the activities focusing on plant working, evidence for the production of composite tools was also identified though microscopy.

Our research shows that some or all elements of a hafted tool can be identified within a supposedly unchanging technology in ISEA. At present, there are no published reference collections for hafted unretouched lithic flakes from ISEA. Also, we basically avoid tackling this issue because of the ‘form’ of lithic flakes which does not conform to the morphological standards of what a ‘point’ or a ‘hafted’ tool should be. Furthermore, it is compounded by the issue of plant-based technologies that supposedly either replaced or complemented the lithic assemblages in the region and one of the reasons why lithic technology stagnated. Hafting technology in ISEA is equated with bone points because of the modification, form, traces, and residues on these artefacts (Barton et al., 2009), while for hafted lithic flakes, we still lack a published substantial experimental database while the archaeological record is limited to single observations (Pawlik, 2012).

Palaeolithic assemblages in ISEA are characterised by a general absence of secondary modification and formal lithic tools. The issue of a paucity of recurring tool types is the cause for the so-called ‘typology dilemma’ (Haidle and Pawlik, 2009), preventing meaningful typological and technological classifications in the lithic record of the region. To overcome this dilemma, Pawlik (2009) proposed functional analysis using microscopic use-wear and residue analysis as a method for the classification of stone tools. Use-wear analysis of artefacts from the lowest layers of Ille Cave, Palawan demonstrated that seemingly simple flakes served a variety of activities and also functioned as hafted armatures (Lewis et al., 2008; Pawlik, 2012). This potential multi-component aspect must be considered in determining and classifying lithic technologies in ISEA (Pawlik, 2010, 2012).

The variety of activities carried out with unmodified flakes paints a picture somewhat different from a solely expedient technology (Binford, 1979) and the hypothesis of a primarily organic technology for ISEA. The identification of a variety of materials that were processed using stone tools established that 1) it is possible to carry out numerous different activities with simple lithic flakes, and 2) if the processed materials remained the same over time, there might have been no significant reason for a change or modification of tool forms. The recent microwear studies of several Southeast Asian lithic assemblages demonstrated that typological and technological studies alone are insufficient to address the issue of tool function and activity as the most relevant features of a stone tool. Microwear analysis on the other hand offers actual technical and functional characterisations of lithic artefacts, the identification of working and hunting tools and a determination of activities and site functions (Pawlik, 2009). It has no regional and chronological limitations and shows a potential for the detection of variability in behaviour and cognition, as well as traits of human modernity, like the application of complex technologies, hafting and multi-component tool making, projectile points, curation, fabrication of ornaments, shell fishing, use of pigments and more (Haidle and Pawlik, 2010).

Use-wear analysis has shown the capacity to address the lithic assemblages of ISEA more comprehensively than solely morphological and technological analyses. Traceological analysis of such amorphous flake assemblages associated with ‘expedient technology’ (Mijares, 2002) and ‘smash and grab’ production (Coutts, 1983) have demonstrated their potential to address issues caused by the absence of modified lithic artefacts and recurring tool types. For instance, analysis conducted on assemblages from several caves in northern Luzon, Philippines such as Eme, Callao and Dalan Serkot (Mijares, 2005, 2007) and Vito Cave (Fuentes, 2015), have shown that despite the presence of an ‘unchanging technology’ and the use of unmodified lithic flakes, a variety of materials such as bone, wood, bamboo, and other plants as well as meat and other soft tissues were worked and processed.

Furthermore, the seemingly simple lithic traditions in ISEA were not exclusively composed of unretouched flakes, but retouched tools may have played an important role in the production of other technologies vital to the movements into the remote islands of Southeast Asia. Through multi-stage use-wear analysis, seemingly expedient lithic technology revealed a complexity that warrants further scrutiny in future studies to detect changes in technology. We might have missed some aspects of technology, especially those that are not visible with the naked eye or hand lenses. Identifying cultural traits through techno-typological approach has proven to be an inappropriate method in discerning minor changes in the lifeways of prehistoric people, especially in ISEA. Overall, this reflects the complexity of expedient stone tool traditions that merits more research not just in Wallacea but also in regions that produced ‘simple’ and ‘unchanging’ lithic flakes.

Note

All uncalibrated radiocarbon dates from Leang Sarru reported herein have been recalibrated with Calib 7.0.4 (Stuiver and Reimer, 1993) using Marine13 for shell (Reimer et al., 2013), and are given as a 95.4% or higher probability range. Calibrated dates are given in cal BP.

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Appendix A. Supplementary data

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B. Submitted manuscripts

1. **Fuentes, R.**, Ono, R., Carlos, J., Kerfant, C., Sriwigati, Miranda, T., Aziz, N. Sofian, H. O., and Pawlik, A.F. **Under review**. *Stuck within notches: direct evidence of plant processing 22,000 years ago in North Sulawesi*. Proceedings of UISPP Sessions XII-1 and XII-2 on Functional Studies. Journal of Archaeological Science: Reports.

Stuck within notches: direct evidence of plant processing during the Last Glacial Maximum to Holocene in North Sulawesi

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Abstract

The existence of an organic or plant-based technology during the Late Pleistocene and Early Holocene is an ongoing debate in Island Southeast Asia (ISEA). Evidence of plant-based organic technologies in the current archaeological record of ISEA is very limited. Nevertheless, excavations of prehistoric sites across the region have provided clues that plants played a key role in the subsistence and technology of the early islanders. Our previous use-wear study on the assemblage from Leang Sarru, a rockshelter with an occupation history of c. 35,000 years, indicate that plant remains were preserved on artefacts from 22,000 years ago. In this paper, we identified these plant remains that include parenchyma, fibres, stomata, starch, phytolith, and raphides. However, in the case of Leang Sarru, we observed that not only were those residues deposited on unretouched lithic flakes typical for prehistoric sites in ISEA but were especially preserved on flakes with a notched retouch – a case which has never been documented in the region yet. We conducted experiments using replicas of notched tools to test our hypothesis that they were particularly designed and used for scraping and smoothing plant materials. Our results show that a variety of plants can be processed using these retouched tools. The simple modification was observed to be efficient in scraping experiments, and plant residues were stuck within the notches – possibly a factor in their preservation. Overall, the current debate on the presence or absence of plant working revolves around expedient technology and the absence of formal tools. Other aspects of cultural and technological adaptations, such as tool retouching, might have been overlooked in favour of a justification that plant-based technologies were preferred.

Keywords
Island Southeast Asia, use-wear analysis, prehistoric plant processing, notched tools, expedient lithic technology

Note: All uncalibrated radiocarbon dates from Leang Sarru reported herein have been recalibrated with Calib 7.0.4 (Stuiver and Reimer, 1993) using Marine13 for shell (Reimer et al., 2013), and are given as a 95.4% or higher probability range. Calibrated dates are given in cal BP.

1. Introduction

Lithic use-wear research in Island Southeast Asia (ISEA), especially in Wallacea, indicates plant processing in karstic sites from the Late Pleistocene (Pope, 1989; Pookajorn, 1996; Barker et al., 2007; Mijares, 2007; Lewis et al., 2008; Xhauflair and Pawlik, 2010; Pawlik, 2012; Borel et al., 2013; Reynolds et al., 2013). Polishes associated with silica-rich plants are often observed on stone tools recovered from cave sites within ISEA that are associated with anatomically modern humans (Barker et al., 2007; Lewis et al., 2008; Xhauflair and Pawlik, 2010; Borel et al., 2013). Experimental studies on prehistoric stone tool production and use, in relation to plant-working, have been conducted in the region mainly to address 'typology dilemma' and presence of organic-based technologies as replacement or complement to amorphous flakes from the Late Pleistocene to the Holocene (Davenport, 2003; Mijares, 2007; Xhauflair and Pawlik, 2010; Borel et al., 2013; Fuentes, 2015; Xhauflair et al., 2016; Xhauflair et al., 2017b). In the absence of formal tool types, plant-based technology has been proposed to have complemented the use of unretouched stone tools (Narr, 1966; Solheim, 1970; Pope, 1989; Xhauflair et al., 2016). An attempt to create an extensive database on use-wear traces through ethnographic and experimental study was conducted in the 1980's by Johan Kamminga in Luzon, Philippines (see Davenport, 2003). More recently, systematic experimental and ethnographic research conducted in Palawan Island, Philippines resulted in a detailed reference database and also addressed the issue on the rather lacking information on species other than bamboo (Xhauflair, 2014; Xhauflair et al., 2016, 2017b). However, actual evidence of plant remains attached to stone tools, such as cells, tissues, starch, and fibres, are still rare due to the nature of karstic sites and the generally poor preservation of organic materials in tropical conditions. Although it is generally accepted that flaked tools, without any form of modification, were used in plant processing (Fox, 1970; Coutts and Wesson, 1980; Mijares, 2007; Pawlik, 2009), the relationship of plant working and lithic tools designed to process and extract materials has never been explored yet in the region and we attempt to address this issue through use-wear analysis.

Recent microscopic analysis of artefacts from Leang Sarru reveal intensive plant working, mainly with the presence of 'sickle' polish (Fuentes et al., *in press*). Possible residues were identified on the tool surfaces even after mild cleaning. Other than employing unretouched flakes for plant processing, there is evidence of flake modification. Therefore, we hypothesise tool specialisation at Leang Sarru beginning since c. 22,000 years ago, if not earlier, for the purpose of extracting plant materials. Intentional retouching was practiced to produce tools that were more 'efficient' for scraping activities compared with unretouched flakes. Furthermore, retouched sections with several layers of step scars might have played a key role in the preservation of plant remains - these acted as catchments for residues that even after thousands of years were still intact. To test this hypothesis, we conducted experiments at the Talaud Group of Islands, North Sulawesi. The plant remains were documented *in situ* on the tool surface, and were later compared with the residues recorded on the artefacts.

2. Plant remains on tools from ISEA

Plant materials are generally not preserved after exposure to tropical environment (Kumar et al., 1994), and only in very few cases, these were recovered on stone tools from Late Pleistocene karstic and open sites. Bubog 1, Mindoro, Philippines has produced a charred nutshell of *Canarium hirsutum* Willd., directly dated to 10,760-11,100 cal. BP and the remains of yam-like fragments were recovered in 6,000-7,500-year old deposits of its shell midden (Pawlik et al., 2014). *Canarium* spp. nuts were also identified from sediments of Niah Cave at 10,000 years ago (Paz, 2005). Barker et. al (2007) presented the overall occupation sequence of Niah Cave, Borneo with results showing plant remains on the stone tool surface including starch granules and bast fibres from palm, and phytoliths of rattan or bamboo from deposits dated to between c. 46,000-19,000 BP and during the Early Holocene (Barker et al., 2007). *Alocasia* sp. and *Crytosperma* sp. residues were recovered from tool surfaces as old as 28,000 BP in Kilu Cave, Solomon Islands (Loy et al., 1992) and c. 14,000 BP in New Ireland (Barton and White, 1993). Plant remains in relation to prehistoric consumption and domestication of tubers were reported from Papua New Guinea. For instance, evidence of processing of *Pandanus* and *Dioscorea* spp. was identified as early as 49,000-36,000 years ago at Kosipe Mission, Ivane Valley, Papua New Guinea (Summerhayes et al., 2010). Plant residues were reported on Late Pleistocene to Early Holocene lithic artefacts from PNG (Fullagar, 1993;

Barton et al., 1998; Denham et al., 2003; Fullagar et al., 2006; Denham, 2010; Summerhayes et al., 2010). Domestication of yam *(Dioscorea* sp.) and taro (*Colocasia esculenta* Schott.*)* has been proposed to commence by 10,200 cal. BP in Kuk Swamp, PNG (Fullagar et al., 2006). Although these studies addressed several issues in prehistoric domestication and consumption of plants yet direct evidence of 'bamboo technology' remained absent in the archaeological record.

3. Archaeology of Leang Sarru

Leang Sarru is a rockshelter located along the eastern coast of Salibabu Island – part of the Talaud Group of Islands, which is located between Mindanao (Philippines) and North Sulawesi (Indonesia) (Figure 1). Talaud is composed of the islands of Salibabu, Karakelong, and Kabaruan, along with eight smaller uplifted coral islands called the Nanusa Islands Group (Riley, 2002; Ono et al., 2010). The northeast-facing Leang Sarru rockshelter appears in an uplifted coral limestone block at about 15m above sea level and c. 400m distance from the shore (Tanudirjo, 2005). It is 5m (length) x 3m (width), with a 2.5m-high curved ceiling at the dripline, and a platform that slopes down away from the wall. Two 1x1m test pits (B2, C2) were opened in 1995, exposing four layers within the 1-meter stratigraphy (Tanudirjo, 2001, 2005). The site was re-excavated in 2004 and six 1x1m squares were opened (D2, D3, C3, C4, C5, and C6) (Ono et al., 2010). Shells, lithic artefacts, potsherds, hammer stones, ochre, and a stone anvil were recovered. Four major occupation phases were identified through radiocarbon dates on opercula of *Turbo marmoratus*, with the 1st phase dated to c. 35-31,000 BP (Tanudirjo 2001, 2005; Ono et al., 2010; Table 1). The rockshelter was intensively used during the 2nd (c. 22-17,000 BP) and 3rd phases (c. 10-8,000 BP) (Tanudirjo, 2005; Ono et al., 2010). The site was reoccupied during the so-called Metal Age (Tanudirjo, 2005; Ono et al., 2010). The faunal remains (NISP=3371) include mostly marine shells, land molluscs, crustaceans, and sea urchins (Ono et al., 2010). No larger or mid-sized mammal bones were recovered from the site. Currently, the endemic species present in the Talaud Group of Islands only include bats (14 species), rats (5 species), 4 species of flying fox (*Pteropus* spp.), and cuscus (*Ailurops ursinus* and *Strigocuscus celebensis*), while chicken, dog, cattle (*Bos javanicus*), and pig (*Sus celebensis*) were more recently introduced (Riley, 2002; Ono et al., 2010). A total of 14,525 lithic artefacts were recovered from the site, which were classified into blade-like flakes, stone waste, utilised flakes, and cores (see Tanudirjo, 2001 and Ono et al., 2015) for detailed lithic morphological analyses). Use-wear analysis was only conducted recently by the authors (RF and AP) at Balai Arkeologi Manado and this paper complements previous research on the Leang Sarru lithic assemblage (Tanudirjo, 2001, 2005; Ono et al., 2015; Fuentes et al., *in press*).

[insert here Table 1. Archaeological context and radiocarbon dates.]

[insert here Figure 1. Location of Leang Sarru, North Sulawesi.]

4. Materials and methods

In our previous analysis of tools from Leang Sarru, we identified 51 artefacts with traces of plant working and associated residues - Trench D2 (n=13) and Trench D3 (n=38) (Fuentes et al., *in press*; see SI 1, 2, 3, 6, 7, 8). The samples were recovered from Layers 1 to 3 which were designated to four main occupation phases (Tanudirjo, 2001, 2005; Ono et al., 2010; Table 1). The samples include 20 notched tools, 22 unretouched flakes, and nine unretouched flakes with concave edges similar in morphology with notched edges. The notched tools have 41 working edges, with 23 displaying features of concave notches (Figure 2; see SI 7)).

Photographs of dorsal and ventral faces of all artefacts were taken before cleaning. To remove potential contaminants, the artefacts underwent ultrasonication in a solution of distilled water and liquid detergent soap for 3 minutes, individually placed in resealable bags. Then, the samples were rinsed with distilled water and air dried on paper towels. Next, these were soaked in 70% alcohol for 3 minutes and air dried again. Finally, each artefact was wrapped in paper towel and stored in individual resealable bag. The locations of residues were marked on the recording forms, with photos of dorsal and ventral faces and were later digitised. The experimental tools were not washed prior to recording of residues. Artefact analyses was conducted using a Euromex NexiusZoom incident light stereo-microscope (6.7-45x optical magnification), an Olympus BHMJ reflected light microscope with differential interference contrast (DIC) and long working distance (LWD) objectives (110x, 220x, and 440x), and an Olympus BXFM reflected light microscope with DIC and LWD (100x, 200x, and 500x). Photomicrographs were taken with a Canon Powershot G9 digital camera (for Olympus BHMJ), and Nikon D5300 digital single lens reflex camera (for Euromex NexiusZoom and Olympus BXFM). The residues from the experimental notched tools were documented using an Olympus BX53M_UC90 (DIC/ POL set to zero), with cross-polarised light microscopy. Scanning electron microscopy was conducted at the National Institute of Geological Sciences in the University of the Philippines (Hitachi S-3400N Variable Pressure Scanning Electron Microscope with Deben Peltier Coolstage) and at the Microfossils Laboratory at the Department of Geosciences of the Senckenberg Centre for Human Evolution and Palaeoenvironment (SHEP) Tübingen (PhenomWorld Scanning Electron Microscope coupled with energy dispersive X-ray microprobe). Photomicrographs of plant remains and residues were sent to specialists (JC, CK, and TM).

We conducted experiments at Talaud Islands using retouched chert tools on plants (see Table 5). We employed transversal scraping activities associated with consumption (e.g. scraping of tuber outer skin) and production of other forms of technology (e.g. thinning of strips, fibre extraction, cleaning of outer skin, and smoothening of sticks). The experiments lasted for 30 minutes with continuous motion, excluding breaks, using one working edge per tool. We employed transversal motion, e.g. scraping, planing and heckling using steep edge angle that varies from 45-90 degrees. The notched ventral face, served as flank while dorsal where the negatives occurred was the rake face and in contact with the plant shavings, with working angles ranging from 30-90 degrees. The tools were individually packed in two resealable bags each, immediately after the experiments and kept prior to microscopic documentation. Plant residues were not extracted from the tool surface but rather recorded *in situ*.

5. Results

5.1. Types of archaeological plant remains

The residues were assigned into three main groups (Table 3). The 1st group represents cells and tissues - parenchyma, epidermis, hypodermis, stomata and long cells, fibre and epidermal-hypodermal cells. The 2nd group includes starch, raphides, and phytoliths while indistinct cells, resinous (decaying residues that appear organic), and indistinct blackish materials comprised the 3rd group. Parenchyma cells were identified on 29 artefacts and in four cases can be further categorised as vascular parenchyma. Epidermis and hypodermis cells of monocot (n=2) and palm (n=2) were also present. Stomata and long cells were preserved on four artefacts. Cells that appear similar to that of monocot leaf were identified on four samples, while fibres with epidermal and hypodermal cells (n=4) were also present. Disintegrated plant remains that show cell-like features were categorised as indistinct cells (n=7). Although limited, starch (n=1), phytoliths (n=2), and raphides (n=1) were present on the assemblage. Indistinct black material (n=2) and resinous (n=3) were assigned into one group. We also recorded fungal growth on five artefacts (Tables 2, 3, 4; see SI 4).

5.1.2. Plant cells and fibres

Most of the samples were identified as parenchyma, which are characterised by elongated or rounded shapes and undifferentiated tissues that play a vital role in plant growth. They can obtain a specific function while gaining differentiated structure. As storage, parenchyma cells are filled with nutrients such as starch grains. The cortical parenchyma located in a stem supports the plant growth while surrounding the vascular system. When the growth of organs is achieved, parenchyma cells thicken their walls (Speranza and Calzoni, 2005: 85-87). These were identified on the notched edge, non-utilised segments, and cortical section but mainly deposited on the notched working edges and retouch negatives within the proximal section (e.g. D3_TL_S4_0001, Figure 2A; D2_BL_S3_0002, Figure 2B; D3_BD_S3_0004, Figure 2C; D3_TL_S4_0001, Figure 2M; D2_BL_S3_0010, Figure 2N; D3_BD_S3_0004, Figure 2O; D3_TG_S2_0013, Figure 2P). These were also present within the medial section, where use-wear traces such as scalar scars and micropolishes were formed, possibly with the use of bindings made from plants (Fuentes et al., *in press*).

Four stone tools display monocot epidermis or hypodermis - with two further classified as palm. It was both preserved on the notch and adjacent non-working segments. Epidermal tissue covers all aerial plant part and protect it from various external aggression and desiccation issues. It is composed of various continuous cells of different function and shape such as stomata, short cells, hairs among others that could be diagnostic to the genus level (Speranza and Calzoni, 2005). Tissues and cells from monocot leaf were present on four stone tools (e.g. D2_TL_S4_0011, Figure 2D). These cells display parallel venation with stomata oriented in linear file (Dickison, 2000). Stomata (n=4), characterised by elongated pores were deposited on working sections, medial-distal and medial-proximal segments – both non-working areas (e.g. D3_TL_S2_0001, Figure 2E). Four artefacts have fibres and epidermal/ hypodermal cells, which were all deposited adjacent to the notched sections. One tool has fibres, cells, and stomata that are identical with *Musa* sp. (D3_TL_S2_0001, Figures 2E, 2F, 2R).

5.1.3. Starch, raphides, and phytoliths

Starch was located as clusters within the notched section (D3_TL_S3_0001, Figures 2.G, 2.Q). The starch clusters were deposited on both left and right lateral sides dorsal face of the notched sections. An elongated tubular phytolith with fibre size of 20-30 µm, and with pointed morphology at the end of the fibre cells matches *Musa* sp. (D2_TG_S1_0001, Figure 2.H; Catling and Grayson, 1998; Valmayor et al., 2000). It was deposited along the edge outline and appears as providing strong evidence that the tool was used in processing *Musa* sp. Phytoliths with volcaniform shape (cf *Musa* sp.) were also preserved on an unretouched flake (D3_BL_S3_0019, Figure 2I; Vrydaghs et al., 2003), and embedded within micropolishes formed on transversal orientation. Phytoliths are bodies of silica present in all plants, as they precipitated in and in between plant cells they could be diagnostic to the family or the genus level (Dickison, 2000). The starch and phytoliths associated with *Musa* on tools used for scraping indicates fibre extraction from the pseudostem for the production of ropes and bindings (Frison and Sharrock, 1999). Raphides were deposited within scars on the notched section (D3_TL_S4_0002, Figure 2J). These are crystals of calcium oxalate that resemble elongated needles and are usually contained within larger cells called raphide sacs (Dickison, 2000).

5.1.4. Indistinct cells and resinous residues

Four samples showed indistinct cells (e.g. D3_TL_S3_0005, Figure 2K) while three possessed adhering resinous residues (e.g. D3_BL_S4_0008, Figure 2L). Residues that appear as 'processed', such as tar, and used for binding were not included in this research since these were already characterised in our previous study (Fuentes et al., *in press*).

[insert here Table 2. Stone tools with plant remains.]

[insert here Table 3. Stratigraphical distribution of plant remains.]

[insert here Table 4. Locations of plant remains on tool surface per occupation phase and per type.]

[insert here Figure 2. Types of archaeological plant remains. A-C. Parenchyma cells. D. Monocot epidermis/ hypodermis. E. Stomata. F. Fibre. G. Starch. H-I. Phytolith. J. Raphides. K. Indistinct cells. L. Resinous residues. M-P. SEM images of parenchyma. Q. SEM image of starch. R. SEM image of fibres.]

5.2. Locations and distribution of plant remains

Residues were present on 38 out of 51 artefacts on the working areas of both notched (Table 4; Figures 3A, 3B, 3C; Figures 4A, 5A, 6A) and unretouched flakes (Figures 3D, 3E, 3F; Figures 4B, 5B, 6B). These were deposited on the working sections (Figures 3A, 3D). Adjacent areas also display residues, including medial-distal (Figure 3F), medial-proximal (Figures 3C, 3E), and medial beside the notched section (Figure 3B). Three tools have residues on both medial-proximal or medial-distal sections and on the working edge. Ten samples have plant remains within non-contact areas - medial (n=1), medial-proximal (n=5), and medial-distal (n=4) sections. Fifteen of the 20 notched tools display residues along the working edge while three have residues preserved within the interior of the tool surface (medial or medial-proximal). Two artefacts have residues on both notched section and non-working parts of the tool. The notched tools have intensive step- and hinge-terminated scars along the edge and progresses as feather-terminated scars away from the edge outline. Plant remains were deposited on these negatives. Twenty one of the 31 unretouched flakes have residues along the working edge or adjacent areas (Table 4; see SI 4).

[insert here Figure 3. Locations of residues on notched tools. A. Working edge. B. Medial-distal. C Non-working proximal base. D-F. Locations of plant remains on unretouched tools. D. Working edge. E. Non-working edge. F. Medial section of concave edge.]

Two artefacts display possible plant remains during the 1st occupation phase (Figures 4A.1, 4B.1; Table 3; see SI 4). One tool (D3_BL_S5_0002, Figure 4A.1) has traces that appear as cells however upon comparison with our experimental results, these resemble dried sap from processing epidermis of tubers (Figure 9A). The other artefact has decaying residues that appears as organic (D3_TL_S5_0003, Figure 4B.1). However, no clear indication of plant processing, especially the presence of intact cells, was detected. During the 2nd phase, we identified parenchyma, stomata and long cells, fibre and epidermal-hypodermal cells, monocot leaf cells, and indistinct cells, providing direct evidence of plant working during the LGM using both retouched (Figure 4A) and unretouched flakes (Figure 4B). It is apparent that intensive processing of plant materials was conducted during this phase, and both, unretouched and retouched flakes were used. Six unretouched flakes and seven notched tools display plant remains during this period. One of the notched tools (D3_TL_S4_0005, Figure 4A.5) has been previously identified as possibly hafted tool (Fuentes et al., *in press*). Four artefacts have residues located right on the notched sections, with raphides (D3_TL_S4_0002, Figure 4A.8), parenchyma (D3_TL_S4_0001, Figure 4A.6; D3_TL_S4_0004, Figure 4A.4), and indistinct plant cells (D3_BL_S4_0007, Figure 4A.3).

Vascular parenchyma, epidermis/ hypodermis (monocot, palm), phytolith, and starch were recovered from the 3rd phase. Seven notched tools (Figure 5A) and 11 unretouched flakes (Figure 5B) display plant remains. During this period, starch was preserved within notched sections (D3_TL_S3_0001, Figure 5A.2). Raphides were also identified (D2_TG_S1_0001, Figure 5B.1). Plant remains were preserved on stone tools until the Metal Age and Modern Period (Figures 6A, 6B). From Metal Age context, fibres were identified on a notched tool (D3_TL_S2_0001, Figure 6A.3). These were preserved with plant cells on the medial section and adjacent to the notch. Comparison with experimental tool show identical residues with processing of *Musa textilis* (Figures 9B.1, 9B.2).

[insert here Figure 4. Plant remains on notched and unretouched tools during the 1st (4A.1, 4B.1) and 2nd phases (4A.2-8, 4B.2-7). A. Notched tools B. Unretouched flakes.]

[insert here Figure 5. Samples from the 3rd phase. A. Notched tools (5A.1-7). B. Unretouched flakes (5A.1-11).]

[insert here Figure 6. Samples from the Metal Age. A. Notched tools (6A.1-5). B. Unretouched flakes, (6B.1-12) and Modern Period (unretouched flake, 6B.13).]

5.3. Experimental framework: notched tool production and plant working

Knapping was conducted at BALAR Manado using raw materials that were previously collected from the Talaud Islands. Large flakes were selected and marked on the proximal base. The notched sections were retouched using a hammerstone c. 5cm in diameter. The marked area was targeted and continuously knapped in order create a concave notched working edge (Figure 7A). Then, we conducted experiments using these tools at the periphery of Leang Sarru in Salibabu Island on eleven plant species (Table 5; see SI 5) - *Dioscorea* sp. (Figure 7B), *Schizostachyum* sp. (Figures 7C, 7D), *Colocasia esculenta* (Figure 7E), *Musa x paradisiaca* L. (Figure 7F), *Bambusa* sp. Schreb (Figure 7G), *Pandanus* sp. (Figure 7H), *Colocasia esculenta* (Figures 7E, 7J), *Musa textilis* Née (Figure 7K), *Alocasia macrorrhiza* (Figure 7L), *Calamus* sp. (Figure 7M), and *Flagellaria indica* L. (Figure 7N).

Step and hinge terminated negatives and secondary edge row scarring led to the formation of edges with 'steps'. This edge geometry made scraping more efficient as compared to the 'single' blade of unretouched flakes, probably one of the reasons why the residues were deposited on the working edge negatives. We identified plant traces along the main contact areas of the working edge and within the notches. The locations of the residue do not follow a general pattern except for the concentration within the negatives of notched tools. The notched tools were utilised as specialised tools for smoothing (e.g. shaft making).

Plant remains were deposited on all the experimental tools and were present on both the working contact and handling sections. Examples of plant remains from NT1 to NT13 show that majority has preserved residues on the tool surface, especially without cleaning (Figure 8). Plant cells were present on all the experimental tools except for the one used on *Pandanus* sp., probably because of the dry state of the contact material during the experiment and because the outer part of the root was already removed. Stomata and long cells were preserved on *Musa x paradisiaca* (NT5, Figures 8E.1-4) and *Dioscorea* sp. (NT1, Figures 8A.1-4). Fibres were deposited on tools used on *Bambusa* sp. Schreb. (NT6, Figures 8F.1-4), *Schizostachyum* sp., *Musa x paradisiaca* L., *Calamus* sp., and *Colocasia esculenta*. Lumps of fibres with plant cells were deposited along the main concave edge of the experimental tools and spreads inwards and deposited even on the opposite handling segment of the tools. Raphides, deposited with fibres, were identified on the tool used on *Bambusa* sp. Schreb. Phytoliths were preserved after processing *Pandanus* sp. Starch is present on experiments involving *Dioscorea* sp. and *Colocasia esculenta*. It was also documented on experiments involving *Pandanus* sp., *Calamus* sp., and *Bambusa* sp. Schreb, and *Flagellaria indica* L. Nine experimental tools have fungal growth, after the plant remains were documented approximately three months after the experiments (Table 4; Figure 8).

Plant remains were present on the edge outlines of the experimental tools. Processing of plant epidermis resulted in the deposition plant tissues within the notched sections. With continued use, these were still preserved on the negatives and were not scraped by materials from succeeding contact. The plant remains were mostly deposited along the edge outline within the negatives on the notches. The same pattern was observed for all the tools after use and, without washing or any form of cleaning, the residues were stuck on the notched sections after each experiment. The use of steep-edge concave tools resulted in relatively efficient plant processing. Working angles and position can easily be changed through tilting due to the concave edges. For example scraping the epidermis of tubers needed acute working angle for the 'softer' part of the skin while cleaning sections towards the proximal part of the tuber needed more acute working edge in combination with diagonal motion in order to remove the roots. All these actions were done using the notched tool without the need for sharper edges and acute edge angles, common on unretouched flaked tools. Notched tools can be used in a combination of scraping and cutting and with an advantage of having sturdier edge, compared to unretouched flakes, due to their steep angles. Similar activities could have also been conducted using the notched artefacts, thus, we compared the residues found on the notched tools and on the artefacts.

[insert here Table 5. Presence or absence of plant remains on experimental tools.]

[insert here Figure 7. A. Knapping experiments to create notched tools. B-M. Experiments using notched tools. Dioscorea sp. (B), Schizostachyum sp. (C,D), Colocasia esculenta (E), Musa x paradisiaca L. (F), Bambusa sp. Schreb (G), Pandanus sp. (H), Colocasia esculenta (E, J), Musa textilis Née (K), Alocasia macrorrhiza (L), Calamus sp. (M), Flagellaria indica L. (N).]

[insert here Figure 8. A-M. Plant remains on experimental tools. Dioscorea sp. (A), Schizostachyum sp. (B,C), Colocasia esculenta (D), Musa x paradisiaca L. (E), Bambusa sp. Schreb (F), Pandanus sp. (G), Colocasia esculenta (H, I), Musa textilis Née (J), Alocasia macrorrhiza (K), Calamus sp. (L), Flagellaria indica L. (M).]

Direct comparison of the experimental reveals patterns on the types of residues that can be preserved per type and state of each plant species. These are based on the similarities with morphology, colour, and state when the residues were preserved. Their locations were also noted, however, as mentioned in our previous study, the locations of residues on the tool surface are not strong indicators of use and/or contamination (Fuentes et al., *in press*). We directly compared the types and locations of the plant remains on the experimental tools and artefacts, and the following features appeared hereby as significant:

A. Reddish and brownish cell-like structures were observed within the circular patterns of dried sap for the experiments involving yam and taro. The circular patterns appear as dried bubbles from the sap of the processed material. The patterns indicate processing of fresh tuber and without post-use cleaning leaving the dried sap with bubble patterns (D3_BL_S5_0002; NT4 *Colocasia esculenta*; Figure 9A).

B. Fibres and parenchyma cells were identified in fibre extraction experiment using *Musa textilis* pseudostem. These residue type remained intact even after continued use and preserve together with the tissues and are consistently resulting from fibre. Identical features were observed on an artefact from the Metal Age (D3_TL_S2_0001; NT10 *Musa textilis* Née; Figure 9B).

C. Starch granules were present on the tools used on *Colocasia esculenta*, *Dioscorea* sp., *Alocasia macrorrhiza, Musa x paradisiaca* L., and *Calamus* sp. We identified starch granules still preserved on the notched section (D3_TL_S3_0001; Figure 9C) and is comparable with the ones from *Alocasia macrorrhiza* (NT11; Figure 9C). Following initial identification, these starch grains have the potential to undergo further classification through comparison with existing databases (Barton et al., 1998; Kealhofer et al., 1999; Torrence and Barton, 2016).

D. Raphides were present on artefact located on the notched section while the experimental tool used on bamboo has raphides preserved on the tool surface (D3_TL_S4_0002; NT6 *Bambusa* sp.; Figure 9D).

E. Stomata was identified on experimental tools used on scraping outer plant skin (D3_TL_S2_0001, Figure 9E.1-3; NT4 *Colocasia esculenta,* Figure 9F.1; NT11 *Alocasia macrorrhiza;* Figures 9F.2). Comparison with plant remains of *Calamus* (Figure 9F.3) and *Musa* (Figure 9F.4) shows resemblance with archaeological samples.

[insert here Figure 9. Comparison of archaeological and experimental plant remains. A. Dried sap. B. Fibre. C. Starch. D. Raphides. E, F. Stomata.]

6. Discussion

The *chaîne opératoire* of plant working could be further explained by studying the relationship between plant remains and stone tool type (e.g. unretouched or notched) and locations of the residue on the tool surface. On our experiments, the plant residues were mainly preserved on the retouches of the notched tools. These were concentrated along the edge outline due to the steep working and edge angles. The notched tools have greater variety of angle to work with simply by tilting and changing the working orientation, and a certain similarity of the notched edges and their handling with sickles was observed during the experiments. The retouched working sections are steep-angled and robust enough to resist and plane both fresh and dried materials - suitable for repetitive scraping or smoothing action. Furthermore, the types of residues deposited on the tool surface is influenced by the stage in which the plant was processed (e.g., procurement, smoothing). Processing of the outer part of the plant (epidermis/hypodermis) left intact plant tissues on the tools. Therefore, identifying plant anatomy would allow us to infer in which stage of the processing sequence the tool was used. For instance, the epidermis should be removed first before scraping other plant parts.

Identifying the stages of plant processing (e.g. cutting, harvesting, scraping, cleaning) is a vital aspect of understanding prehistoric plant working in ISEA. Certain techniques in extracting plant materials require specific working edge type and working edge angle to be able to complete the task – steep concave notched edges in the case of Leang Sarru. The comparison of residue types and locations between unretouched and notched tools reflect the ‘specialised’ nature of the latter. Based on previous use-wear study, the notched tools have very minimal polish formation along the edge outline compared with unretouched flakes, which show polishes spreading towards the interior of the edge. The difference in polish distribution on unretouched and retouched flakes (Fuentes et al., *in press*) could also suggest different processes or stages in the *chaine opératoire* of the production of plant-based technologies.

The absence of large animal bones in the archaeological record of Leang Sarru as a suitable raw material for a sophisticated organic technology (Ono et al., 2010), also supports the hypothesis that populations on such isolated smaller islands depended more on plants than animals for the production of technology in addition to consumption. No indication of plant management was observed in the Late Pleistocene and Early Holocene deposits of Leang Sarru, and the artefactual context and faunal record clearly indicate the foremost exploitation of marine resources (Tanudirjo, 2005; Ono et al., 2010). Another relevant issue for the archaeology of ISEA is the state of preservation of plant remains. For Leang Sarru, several factors may have contributed to the preservation of plant residues on artefact surfaces. Shell midden deposits in archaeological sites in ISEA seem to provide more favourable conditions for the preservation of organic remains such as bones and plants despite the tropical condition, as seen in Late Pleistocene to Early/Mid Holocene sites in the Philippines and Borneo (Lewis et al., 2008; Barton et al., 2009; Pawlik et al., 2014; Carlos et al., 2018). This is a venue that needs to be explored for ISEA with experiments designed to interaction of micro residues with the environment (Langeans, 2010), given that the tropical environment affects preservation of plant residues (Kumar et al., 2004). Also, fungal growth are present right on the residues and sometimes mixing with the plant remains and forming patterns similar to starch with similar spores were identified as *conidia* (Haslam, 2006). Further research on residue preservation and fungal growth should be conducted in ISEA.

Although taxonomical classification is limited, the identification of plant anatomy provided insights into the functions of notched tools in Leang Sarru. However understanding the role of tool retouching in prehistoric plant processing, requires the implementation of extensive research programs which are lacking for Wallacea. Currently only one traceological reference collection is available for Sunda (Palawan Island, Philippines), mainly focused on the collection and evaluation of ethnographic data for the selection and use of plants in the mountainous hinterland of Palawan Island, Philippines (Xhauflair, 2014; Xhauflair et al., 2016, 2017b). This study complements this data pool and provides new and detailed information on the prehistoric activities and the significant role that stone tools, particularly the previously unexamined notched tools, and fibrous plants played in the prehistory of ISEA.

The locations of plant remains may not be an indicator of use or contamination. Experiments conducted by Xhauflair et al. (2017a) with unretouched flakes showed that the location of residues on the tool surface in relation to use-wear traces is not a direct evidence of use. On the other hand, residues that occur beyond the working sections are not necessarily always a result of contamination. We observed that plant processing with notched tools resulted in plant preservation in both working and non-working areas. The scars on the notches are hereby favourable for the adhesion of plant remains due to their relatively rough and jagged surfaces. Further studies on notched tools need to be conducted because similar tools were mentioned by Tanudirjo (2001), and from sites in East Timor, there labelled as side scrapers and inferred to have been used in woodworking (Glover, 1986). From Song Terus in Java, Indonesia, Borel et al. (2013) reported tools with concave retouched edges, morphologically similar to the notched tools from Leang Sarru that were recovered from Early Holocene contexts. This seemingly simple retouching technique provided the leverage for creating the obtuse-angled tool that works well for scraping activities on plants.

Adaptive strategies and technological innovations may have varied from island to island, for instance with regard to fishing strategies (O'Connor and Veth, 2005; O'Connor et al., 2011; Boulanger et al., 2019; Pawlik and Piper, 2019), therefore generalising concepts of tool function, technological innovation and invention, and the associated cognitive abilities pertaining to this period should be treated with great caution. Aside from long-distance maritime interaction, a number of significant technological innovations, including plant dispersal, management and propagation already took place during the Terminal Pleistocene to Early Holocene, and long before the Austronesian diaspora (Hunt and Rabbett, 2014). Thus, there is a variety of activities related to plant processing, other than producing organic-based technologies. The preservation of plant remains on tools from Leang Sarru has provided us with direct evidence of non-osseous organic technology. The knowledge and strategy behind can be considered as an adaptive response to small insular environments where subsistence and technology depended on limited available resources and where plants, shells, and fish remains substituted for chert and bone as raw materials as seen for instance in the use of stingray spines as projectile points, *Tridacna sp.* shells for the manufacture of edge-ground adzes and flake tools, and *Turbo* sp. opercula that were modified into scrapers (Barton et al., 2009; O'Connor et al., 2011; Pawlik et al., 2015; Pawlik and Piper, 2019). The gradual isolation of Salibabu Island due to rising sea level might have accelerated those adaptations and innovations after the LGM as evidenced by the significant increase of plant-related activities in the 2nd phase of Leang Sarru.

7. Conclusion

Multi-stage traceological analysis using low and high power light microscopy, and scanning electron microscopy coupled with energy-dispersive X-ray analysis (EDX) showed that a consistent use and processing of various plants took place in Leang Sarru during the Late Pleistocene and Early Holocene. Notching is a recurring modification on lithic artefacts and appear to have served a particular plant working process. They were very likely connected with the extraction of fibrous plant matter, used for instance to produce cords, bindings and woven materials, such as baskets, nets and ropes. The dominance of plant processing activities sets the assemblage of Leang Sarru in contrast to other sites in ISEA that reflects a dominantly marine-based subsistence. Our analysis offers insights on technological innovations in relation to island adaptation and maritime interaction from the Late Pleistocene to the Early Holocene. The lifeways and material culture of anatomically modern humans in this part of Wallacea depended largely on exploitation of plants. The absence of bone tool technology at Leang Sarru stands in contrast to other Late Pleistocene and Early Holocene sites across ISEA. No larger terrestrial mammals lived on the small Talaud Islands and most likely various plants had to substitute for bone as raw material, thus adding to the complexity of the 'plant-based technology' in this area. The traces indicating plant processing in Leang Sarru suggest a specialised function of the site and demonstrate a high level of adaptation of those early populations to insular environments with limited faunal resources. We expect that future results will provide us with more and detailed insights on the variability of the prehistoric technologies in ISEA.

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Supplementary Information

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Table 1. Radiocarbon dates of Leang Sarru (Tanudirjo, 2001, 2005; Ono et al., 2010).

Occupation Phase	Age estimate	Spit	Depth (cm)	Layer	Lab. code	Material	Unit	Depth of sample(cm)	14C Age (BP)	Published calibrated age (cal BP)*	Calibrated age using Marine13 (cal. BP; 2 sigma)	References
Modern Period	/	1	0-10	Topsoil	/	/	/	/	/	/	/	Ono et al., 2010
Metal Age	2-1,000 BP	2	10-20	Layer 1	/	/	/	/	/	/	/	Tanudirjo, 2005, Ono et al., 2010
3rd phase	10-8,000 BP	3	20-30	Layer 2B	TERRA-070407a05	Turbo sp.	D3	-30	7660±40	8033-8144	8218-8000	Ono et al., 2010
					ANU-10203	Turbo sp.	B2	-30	9750±90	10,430-10,683	10814-10515	Tanudirjo, 2005
2nd phase	22-17,000 BP	4	30-40	Layer 2A	ANU-10810	Turbo sp.	B2	-40	14,820±80	17,309-17,819	17849-17320	Tanudirjo, 2005
					ANU-10960	Turbo sp.	C2	-50	18,880±140	21,715-22,421	22618-21939	Tanudirjo, 2005
1st phase	35-31,000 BP	5-9	40-90	Layer 3,4	ANU-10499	Turbo sp.	B2	-50	30,850±340	34,988-35,033	35001-33854	Tanudirjo, 2005
					TERRA-070407a04	Turbo sp.	C3	-50	28,460±150	32,223-32,832	32433-31397	Ono et al., 2010
					TERRA-070407a03	Turbo sp.	D3	-60	28,760±150	32,426-33,079	32813-31672	Ono et al., 2010
					ANU-10498	Turbo sp.	B2	-70	29,590±630	32,898-34,087	34368-31622	Tanudirjo, 2005
					ANU-10204	Turbo sp.	B2	-80	29,760±650	33,031-34,201	34592-31750	Tanudirjo, 2005

ANU = The Australian National University Radiocarbon Dating Laboratory

TERRA = Tandem Accelerator for Environmental Research and Radiocarbon Analysis

Note: All uncalibrated radiocarbon dates from Leang Sarru reported herein have been recalibrated with Calib 7.0.4 (Stuiver and Reimer, 1993) using Marine13 for shell (Reimer et al., 2013), and are given as a 95.4% or higher probability range.

*no dates acquired for Metal Age

Table 2. Stone tools with plant remains.

Group/ type	Modern Period	Metal Age	3rd Phase	2nd Phase	1st Phase	Total
Unretouched flakes	1	7	9	4	1	22
Unretouched flakes with concave edge	0	5	2	2	0	9
Notched	0	5	7	7	1	20
Total	**1**	**17**	**18**	**13**	**2**	**51**

Table 3. Stratigraphical distribution of plant remains.

Group	Type	Modern Period	Metal Age	3rd Phase	2nd Phase	1st Phase	Frequency	Relative Frequency
1	Parenchyma cells	0	12	8	5	0	**25**	**43%**
	Vascular parenchyma cells	0	1	3	0	0	**4**	**7%**
	Epidermis/ hypodermis (monocot)	0	0	2	0	0	**2**	**3%**
	Epidermis/ hypodermis (palm)	0	0	2	0	0	**2**	**3%**
	Stomata and long cells	0	1	2	1	0	**4**	**7%**
	Fibre and epidermal-hypodermal cells	1	2	0	1	0	**4**	**7%**
	Leaf cells (monocot)	0	0	0	2	0	**2**	**3%**
2	Phytolith	1	0	1	0	0	**2**	**3%**
	Raphides	0	0	0	1	0	**1**	**2%**
	Starch	0	0	1	0	0	**1**	**2%**
3	Indistinct tissue/ cells	0	3	1	3	0	**7**	**12%**
	Indistinct black material	0	0	0	1	0	**1**	**2%**
	Resinous	0	2	0	0	1	**3**	**5%**
	Frequency	**2**	**21**	**20**	**14**	**1**	**58**	**100%**
	Relative Frequency	**3%**	**36%**	**34%**	**24%**	**2%**	**100%**	

Table 4. Locations of plant remains on tool surface per occupation phase and per type.

		Notched working edge	Unretouched working edge	Medial-proximal	Medial-distal	Notched edge & medial-proximal	Unretouched working edge & medial-distal	Frequency	Relative Frequency
Occupation Phase	Modern Period	0	1	0	0	0	0	**1**	**2%**
	Metal Age	3	9	1	3	1	0	**17**	**33%**
	3rd	6	7	3	2	0	0	**18**	**35%**
	2nd	6	5	0	0	1	1	**13**	**25%**
	1st	0	1	1	0	0	0	**2**	**4%**
	Frequency	**15**	**23**	**5**	**5**	**2**	**1**	**51**	**100%**
	Relative Frequency	**29%**	**45%**	**10%**	**10%**	**4%**	**2%**	**100%**	
Residue type	Parenchyma cells	7	12	2	3	1	0	**25**	**43%**
	Vascular parenchyma cells	2	1	1	0	0	0	**4**	**7%**
	Epidermis/ hypodermis (monocot)	0	1	0	0	1	0	**2**	**3%**
	Epidermis/ hypodermis (palm)	1	0	1	0	0	0	**2**	**3%**
	Stomata and long cells	1	1	1	1	0	0	**4**	**7%**
	Fibre and epidermal-hypodermal cells	0	2	1	1	0	0	**4**	**7%**
	Leaf (monocot)	0	1	0	0	1	0	**2**	**3%**
	Indistinct tissue/ cells	1	4	0	0	1	1	**7**	**12%**
	Phytolith	2	0	0	0	0	0	**2**	**3%**
	Raphides	1	0	0	0	0	0	**1**	**2%**
	Starch	1	0	0	0	0	0	**1**	**2%**
	Indistinct black material	0	1	0	0	0	0	**1**	**2%**
	Resinous	0	2	1	0	0	0	**3**	**5%**
	Frequency	**16**	**25**	**7**	**5**	**4**	**1**	**58**	**100%**
	Relative Frequency	**28%**	**43%**	**12%**	**8%**	**7%**	**2%**	**100%**	

Table 5. Presence or absence of plant remains on experimental tools.

Experiment code	Plant species	Common name	Duration of use (min)	Working angle (degrees)	Tissues/ cells	Dried sap	Stomata & elongated cells	Fibrous material	Starch	Raphides	Phytolith	Fungal growth	White granules/ crystals
NT1	*Dioscorea* sp.	Yam	30	30-45	x	x	x		x				
NT2	*Schizostachyum* sp.	Bamboo	30	45	x								
NT3	*Schizostachyum* sp.	Bamboo	30	30-45	x			x				x	x
NT4	*Colocasia esculenta*	Taro	30	45	x	x		x	x			x	
NT5	*Musa x paradisiaca*	Banana	30	30-45	x		x					x	
NT6	*Bambusa* sp. Schreb	Bamboo	30	45-90	x	x		x	x	x			
NT7	*Pandanus* sp.	Pandan	30	45-90		x		x	x		x	x	x
NT8	*Bambusa sp. Schreb*	Bamboo	30	45-90	x			x				x	
NT9	*Colocasia esculenta*	Taro	30	30-45	x	x		x	x				
NT10	*Musa textilis* Née	Abaca	30	45-90	x			x					
NT11	*Alocasia macrorrhiza*	Giant taro	30	30-60	x				x			x	
NT12	*Calamus* sp.	Rattan	30	45-90	x	x		x	x			x	
NT13	*Flagellaria indica*	Rattan	30	30-45	x				x			x	

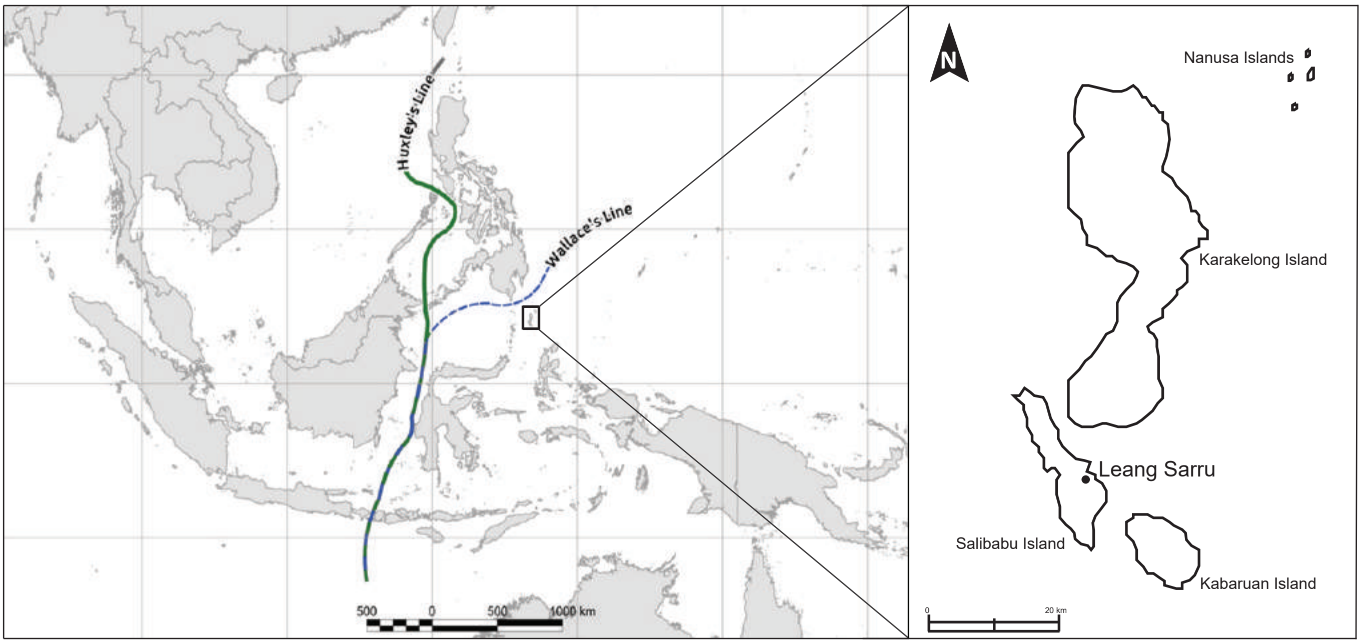
Huxley's Line
Wallace's Line
500
0
500
1000 km
N
Nanusa Islands
Karakelong Island
Leang Sarru
Salibabu Island
Kabaruan Island
0
20 km

Figure 1

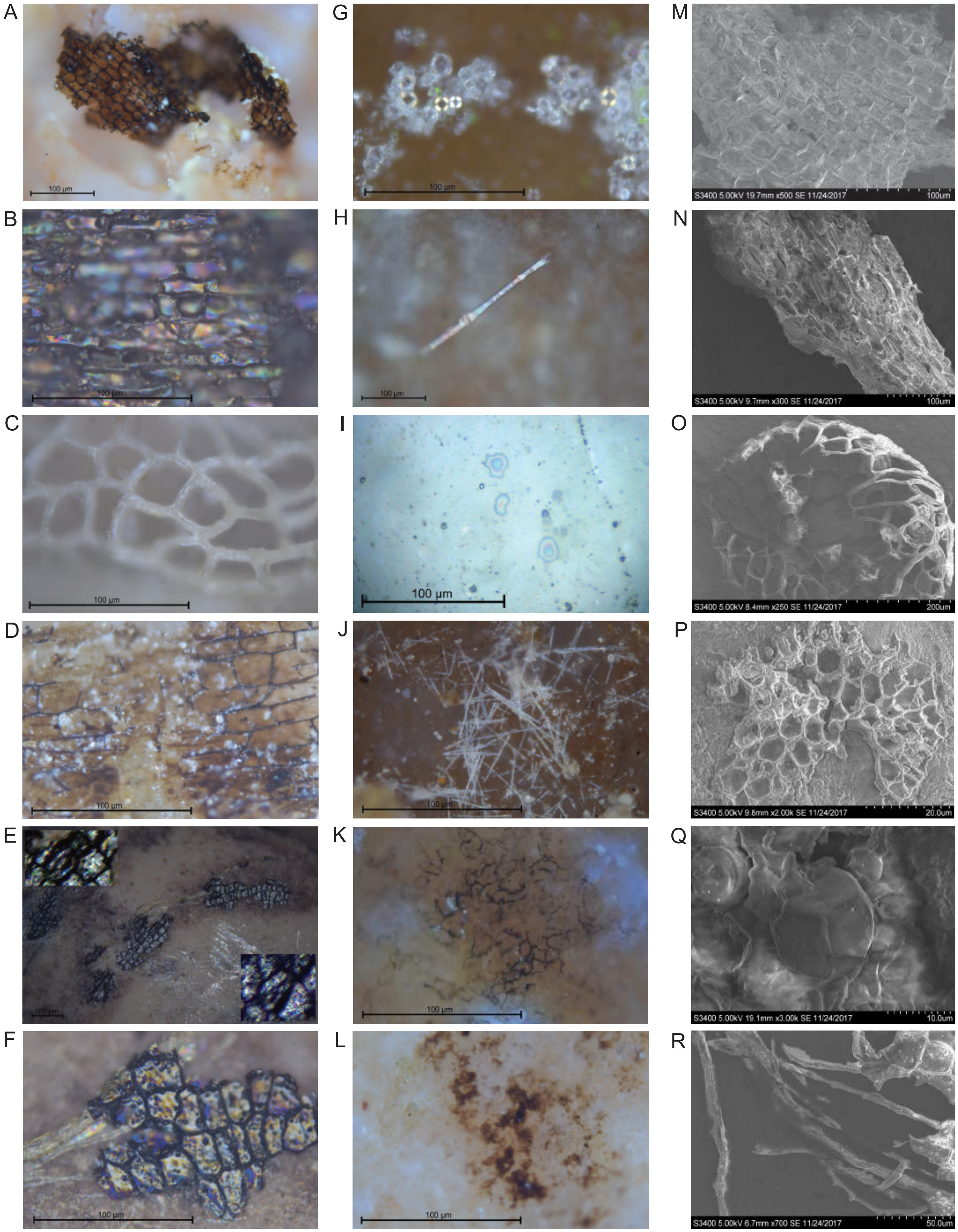
A
100 µm
G
100 µm
M
S3400 5.00kV 19.7mm x500 SE 11/24/2017
100um
B
100 µm
H
100 µm
N
S3400 5.00kV 9.7mm x300 SE 11/24/2017
100um
C
100 µm
I
100 µm
O
S3400 5.00kV 8.4mm x250 SE 11/24/2017
200um
D
100 µm
J
100 µm
P
S3400 5.00kV 9.8mm x2.00k SE 11/24/2017
20.0um
E
100 µm
K
100 µm
Q
S3400 5.00kV 19.1mm x3.00k SE 11/24/2017
10.0um
F
100 µm
L
100 µm
R
S3400 5.00kV 6.7mm x700 SE 11/24/2017
50.0um

Figure 2

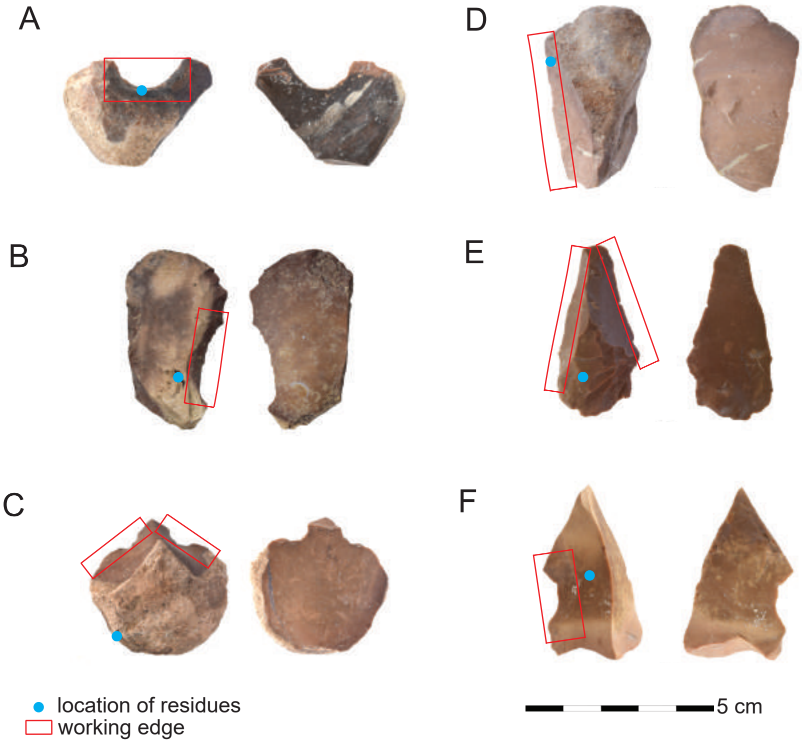

Figure 3

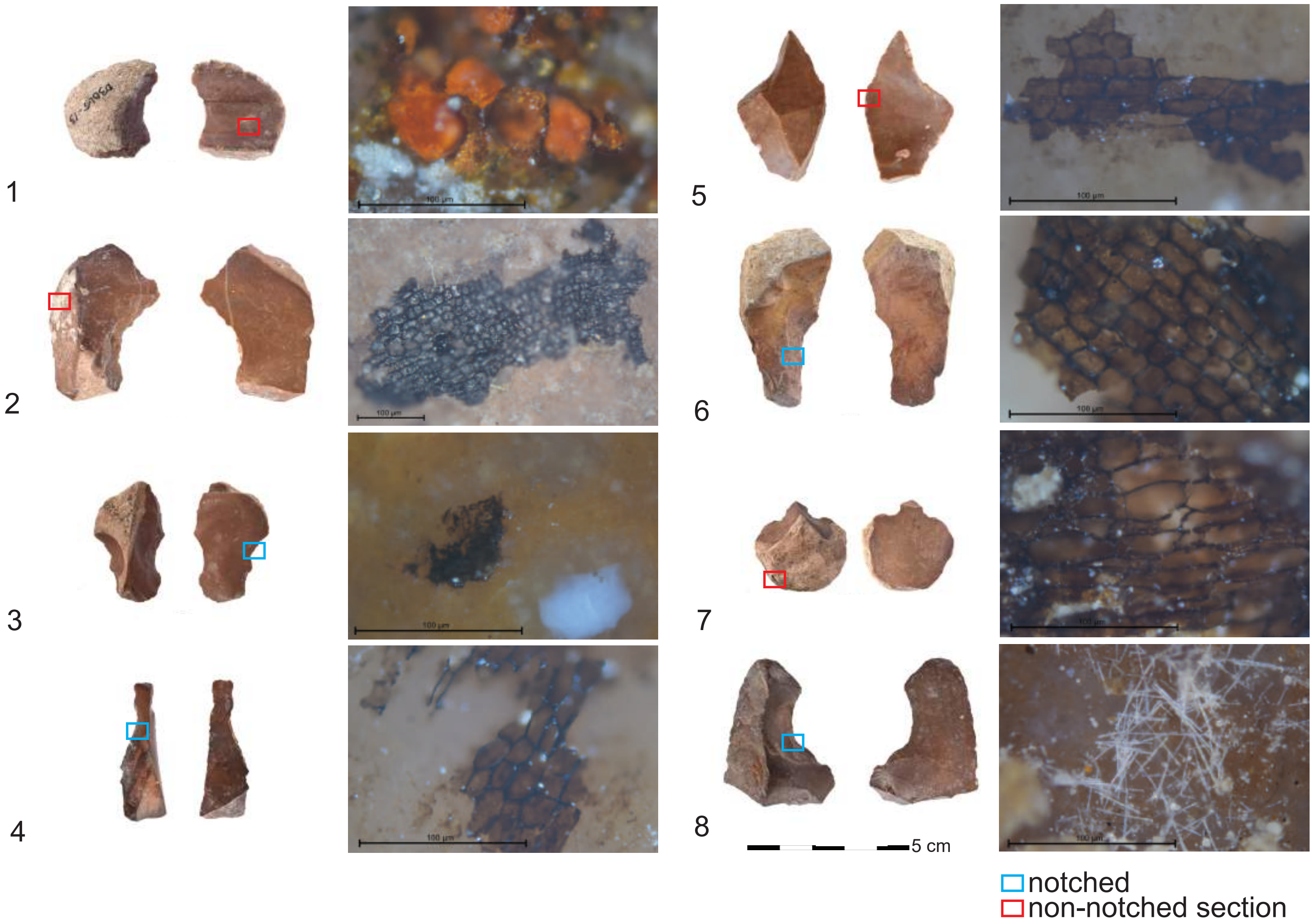

Figure 4A

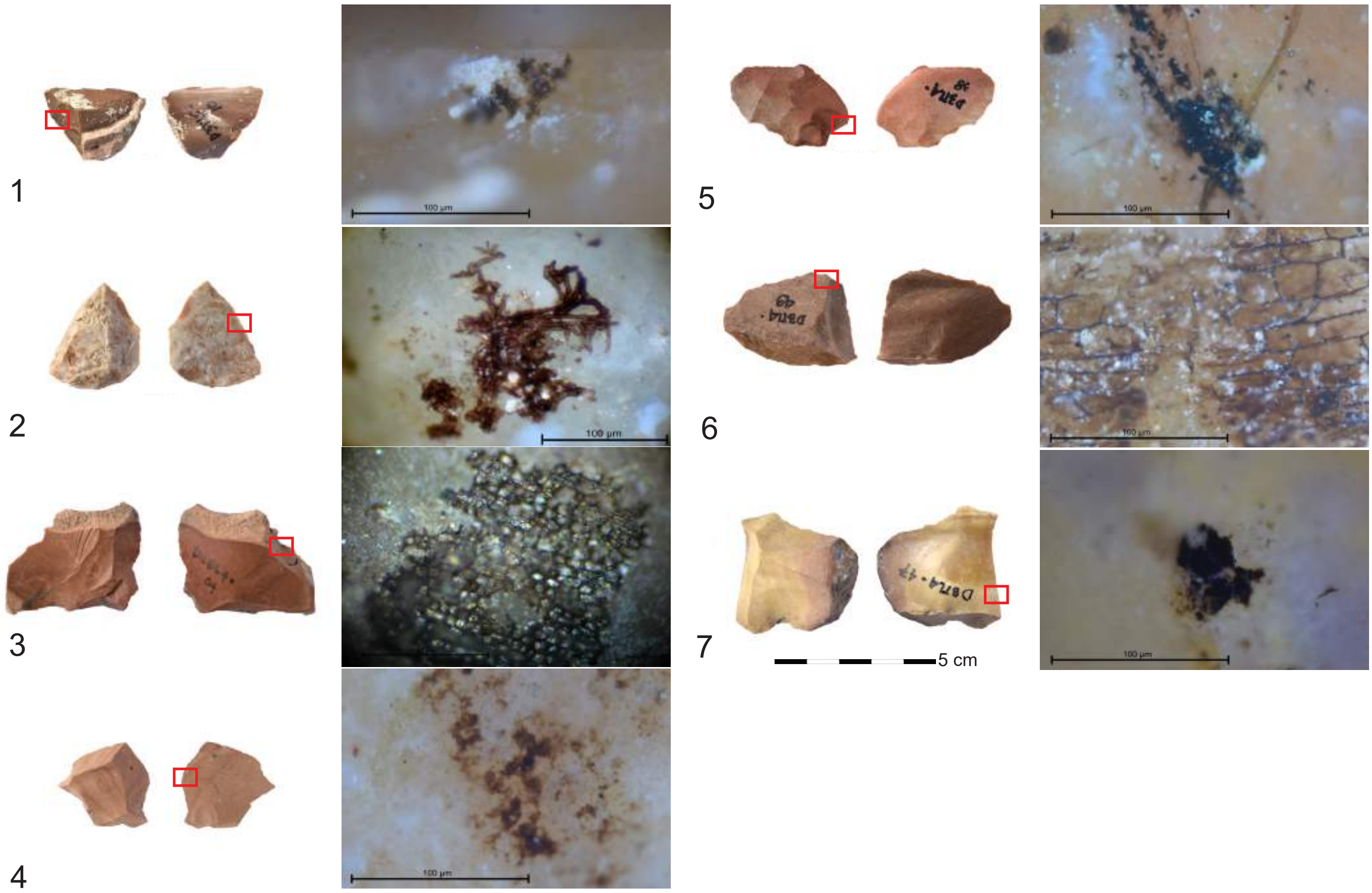

Figure 4B

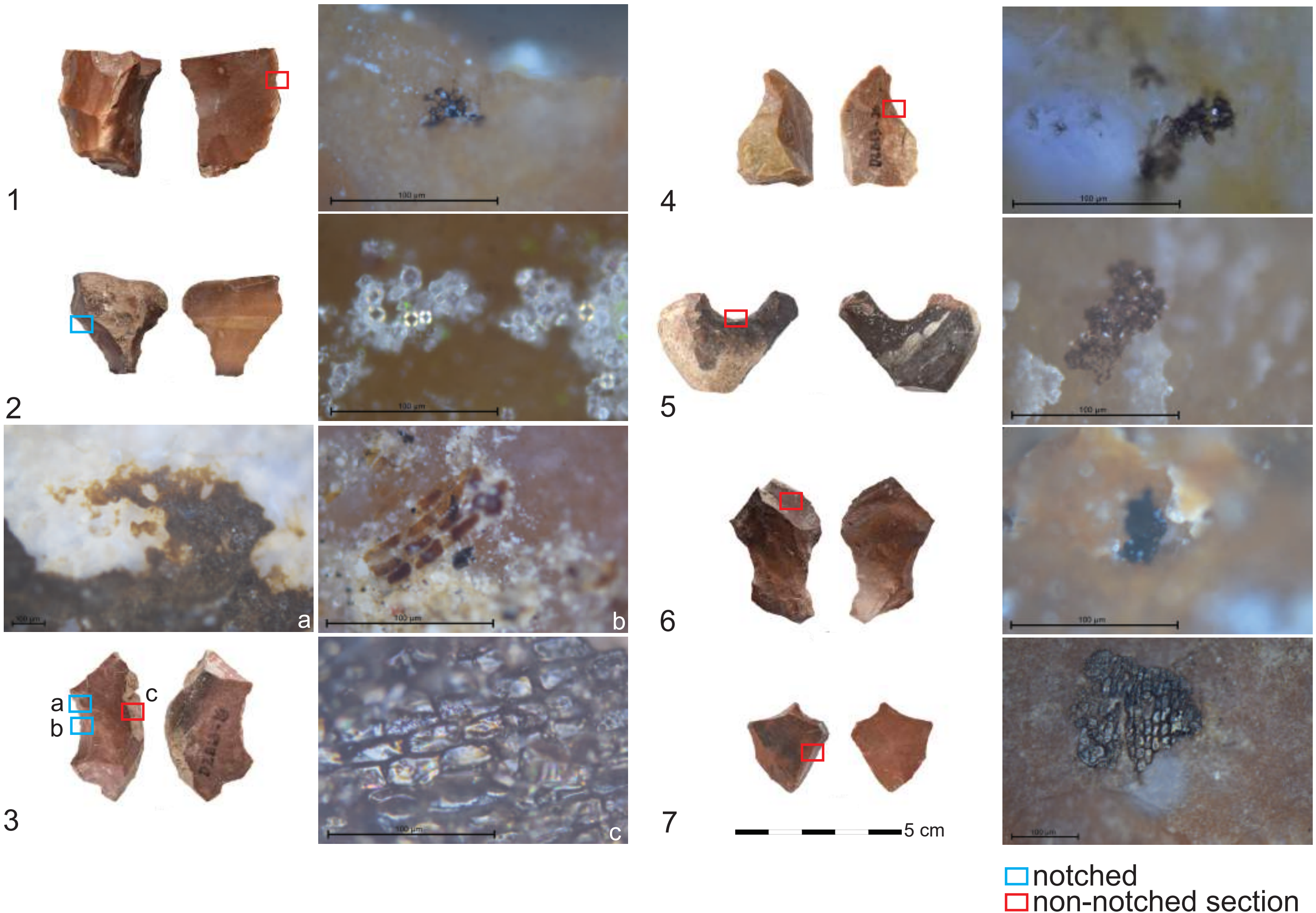

Figure 5A

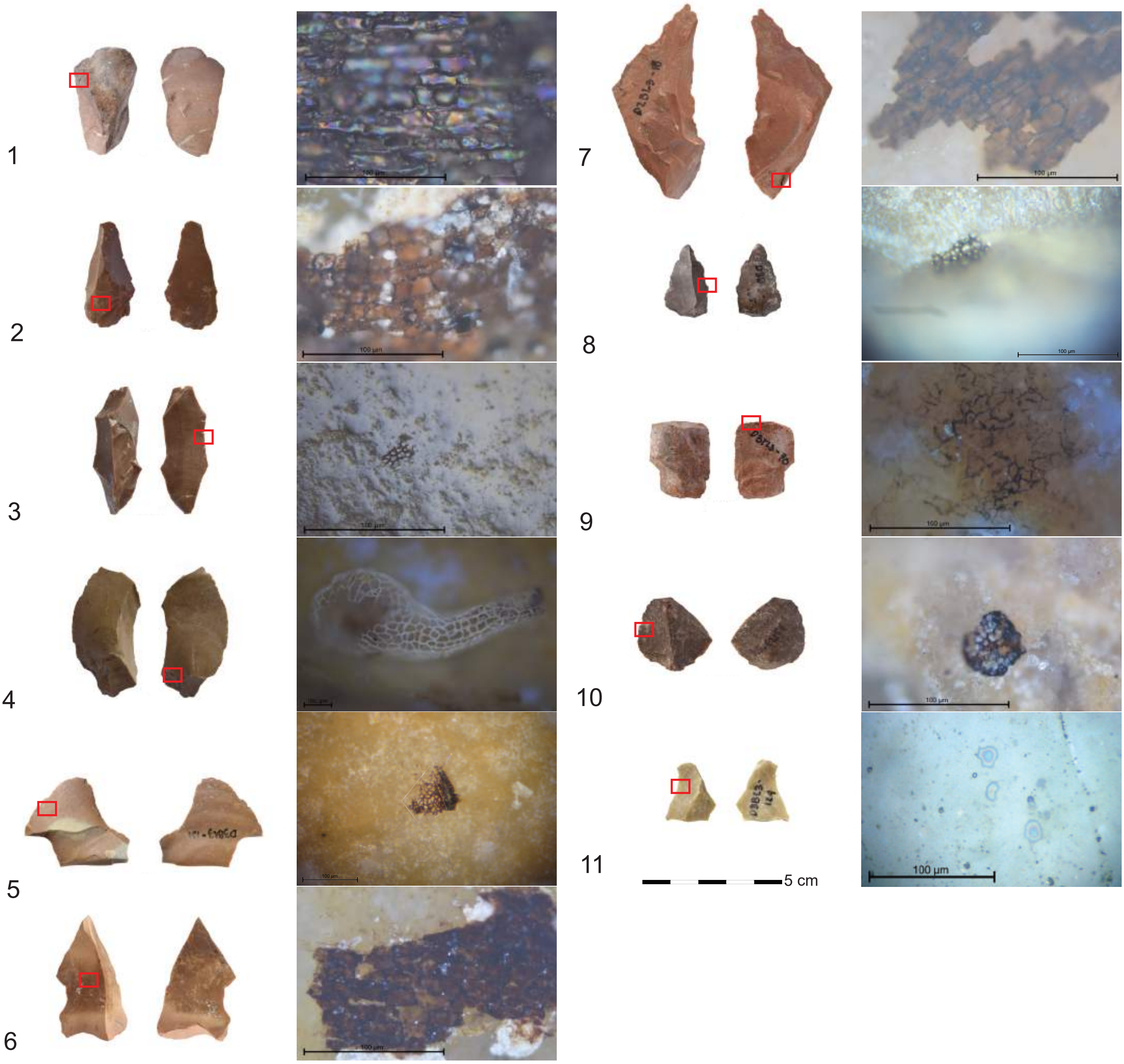

Figure 5B

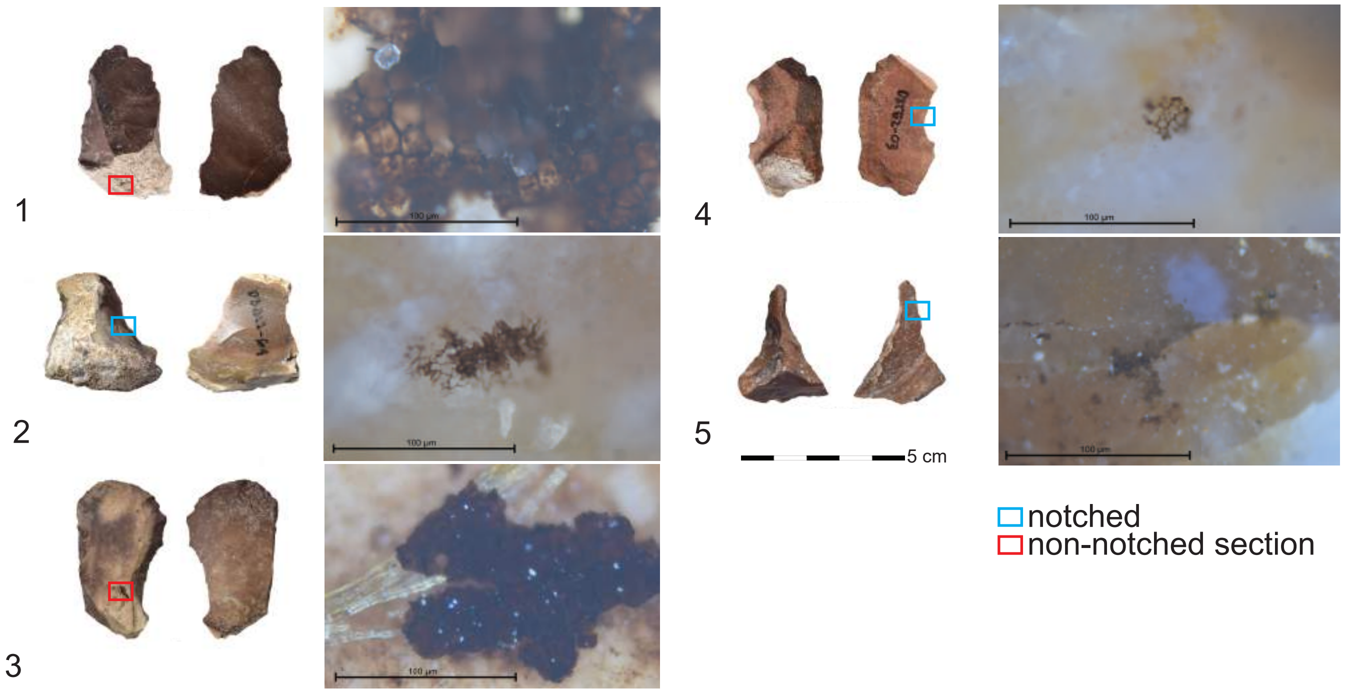
1
2
3
4
5
100 µm
100 µm
100 µm
100 µm
100 µm
5 cm
notched
non-notched section

Figure 6A

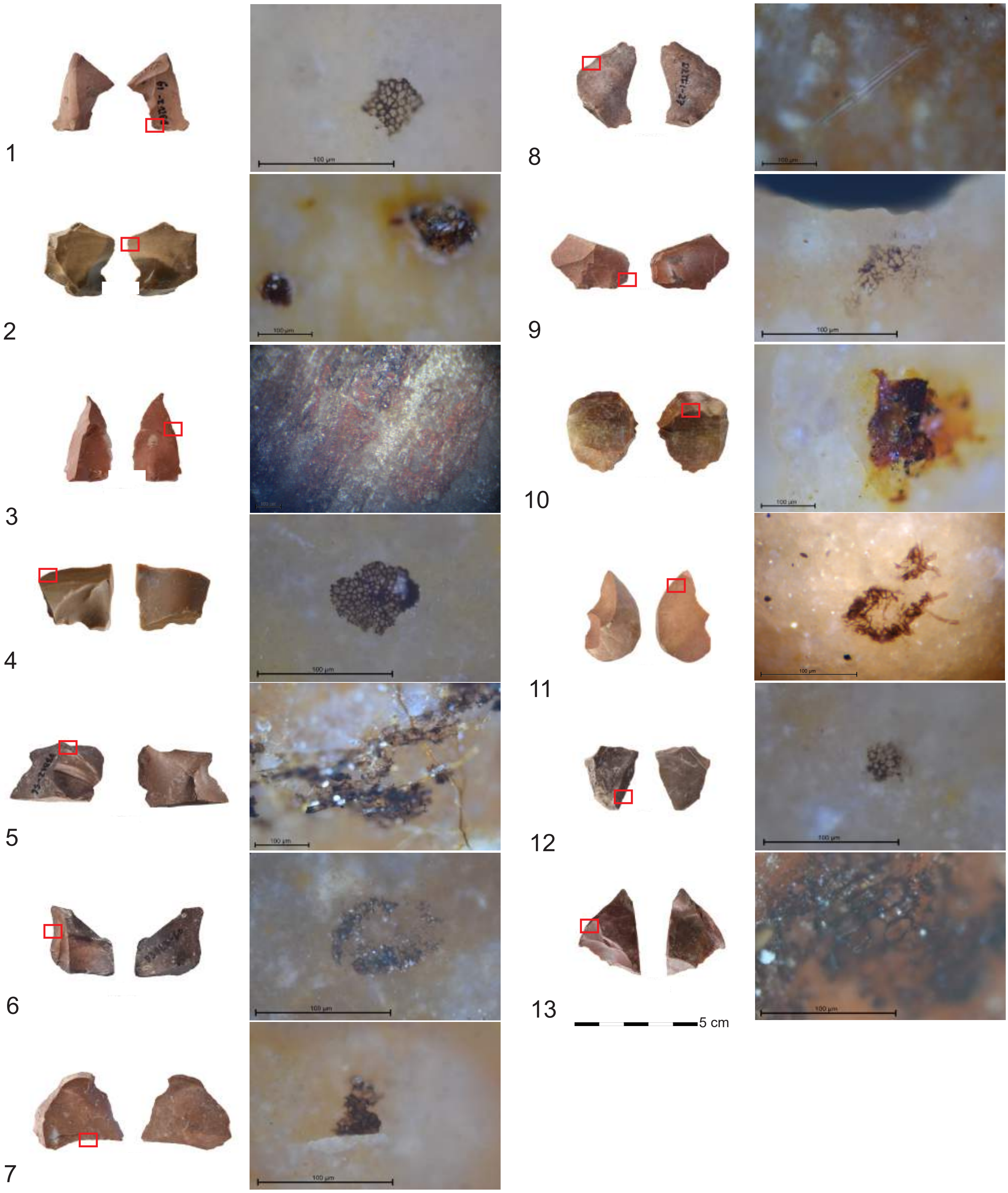

Figure 6B

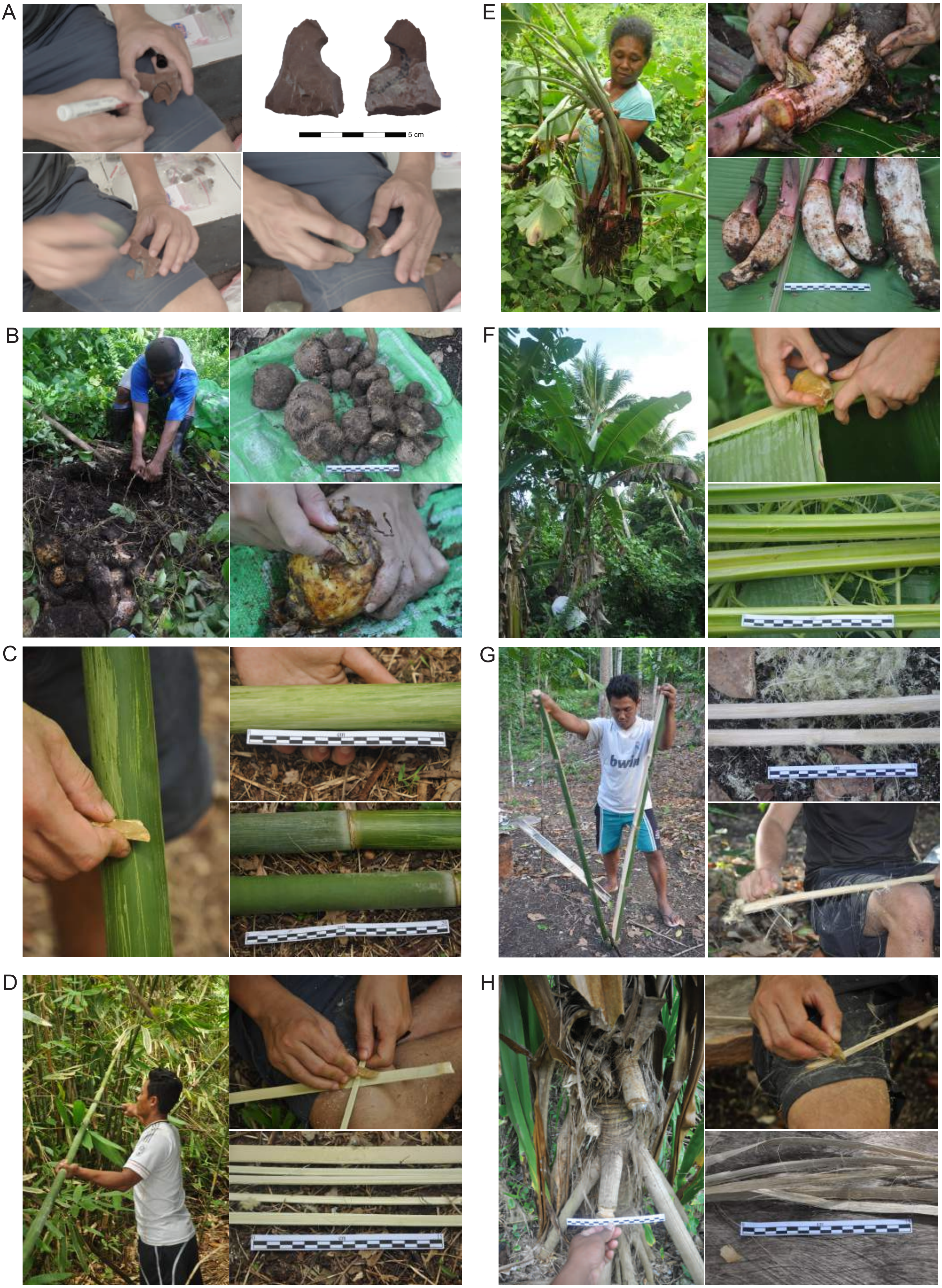

Figure 7

Figure 7 cont.

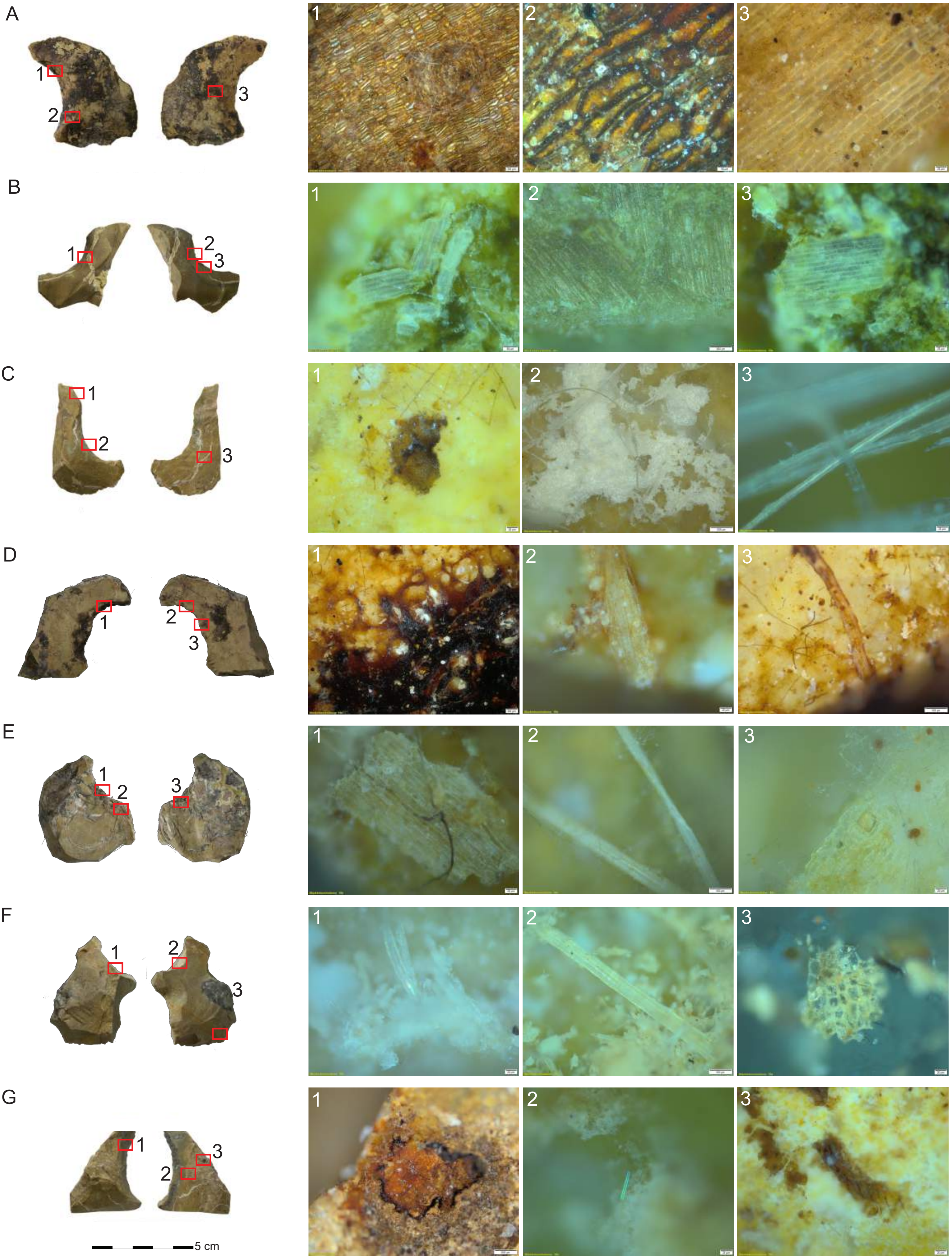

Figure 8

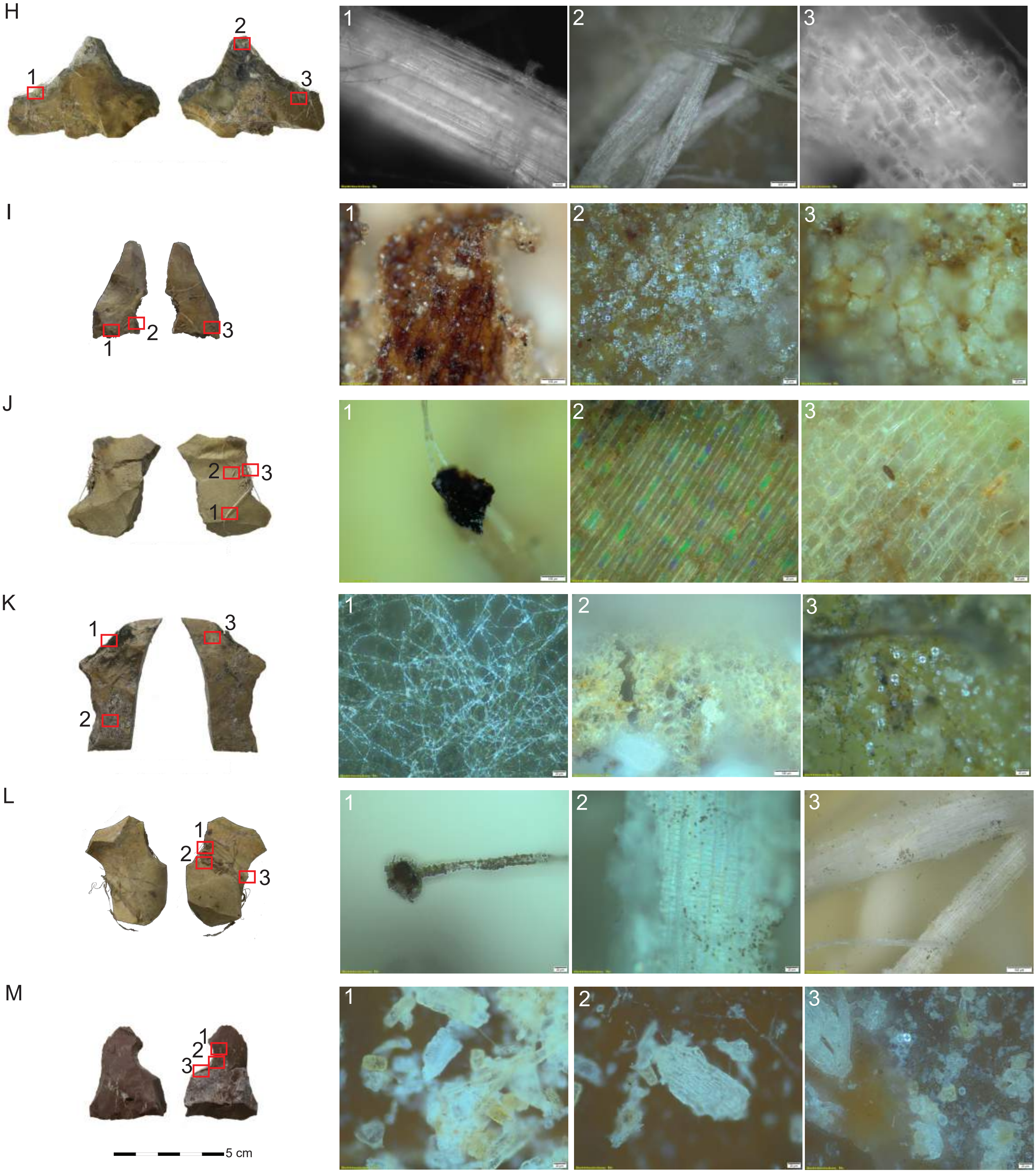

Figure 8 cont.

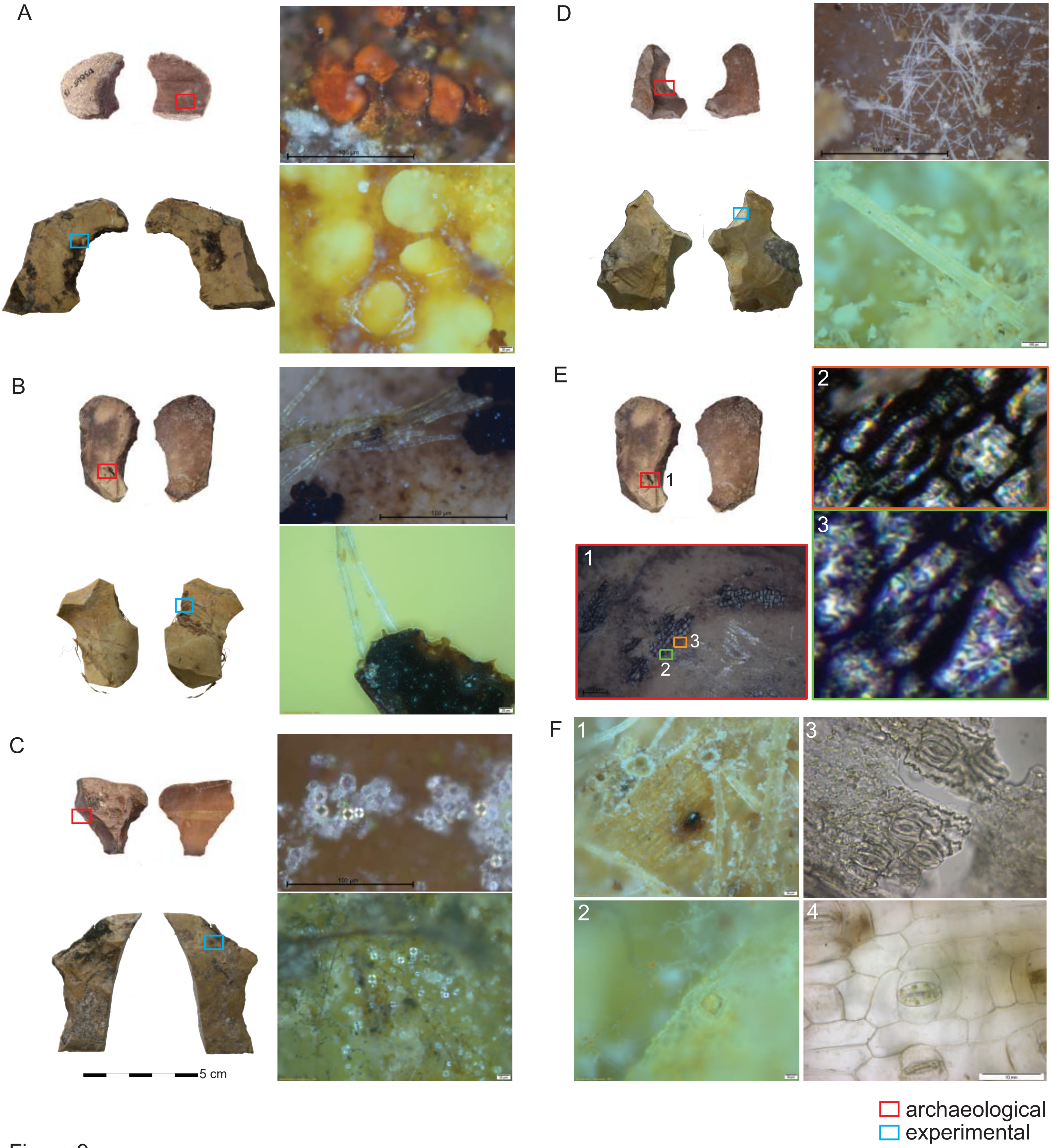

Figure 9

C. Manuscripts ready for submission

1. Ono, R., **Fuentes, R.**, Pawlik, A.F., Sofian, H.O., Sriwigati, Aziz, N., Alamsyah, N., and Yoneda, M. *Island migration and foraging behaviour by anatomical modern humans during the late Pleistocene to Holocene in Wallacea: New evidence from Central Sulawesi, Indonesia.*

2. **Fuentes, R.**, Ono, R., Sofian, H.O., Aziz, N., Sriwigati, Alamsyah, N., Faiz, Miranda, T., and Pawlik, A.F. *Microscopic traces on tools used by anatomically modern humans in Central Sulawesi 30 thousand years ago*.

3. **Fuentes, R.**, Ono, R., Sriwigati, Aziz, N., Sofian, H.O., Miranda, T., and Pawlik, A.F. *Missing or undetected? A review of microwear traces on composite prehistoric lithic tools from ISEA.*

Island migration and foraging behaviour by anatomically modern humans during the late Pleistocene to Holocene in Wallacea: New evidence from Central Sulawesi, Indonesia

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Abstract

Maritime migration and island adaptation by anatomical modern humans (AMH) are among the most significant current issues in Southeast Asian anthropology and archaeology, and directly related to their behavioural and technological advancements. A major research hotspot is Wallacean islands where located between the past Sunda and Sahul continents during the late Pleistocene. The gaps between the Wallacean islands and both landmasses are very likely the major factor for the relative scarcity of animal species originating from Asia and Oceania and the high diversity of endemic species in Wallacea. They are also considered as barrier for hominin migration into Wallacean islands and Sahul continent. We report about new archaeological research on the eastern coast of Sulawesi, which could have been the most potential starting location for the northern routes. Based on the new findings, we discuss the evidence and timeline for migrations of early modern humans into the Wallacean islands and their adaptation to island environments during the late Pleistocene.

Keywords: Southeast Asian prehistory, early modern human migrations, prehistoric lithic technology

1. Introduction

Maritime migration and island adaptation by anatomically modern humans (AMH) are among the most significant current issues in Southeast Asian anthropology and archaeology, and directly related to their behavioural and technological advancements (e.g. Jelinek 1982; Hahn 1986; Dibble 1989; Klein 1995; Mellars 2005; McBrearty and Brooks 2000; Haidle 2006; Habgood and Franklin 2008; Haidle and Pawlik 2010; Pawlik 2012; Kaifu et al. 2015; Pawlik & Piper 2019). A major research hotspot is Wallacea, coined after Alfred Russel Wallace who voyaged through the Malay Archipelago and was the first to recognize the biogeographic divide between Lombok and Bali, Borneo/Kalimantan and Sulawesi, known since as Wallace's Line (Wallace 1863, 1869; Huxley 1868).

Today we know that the Wallace Line is exactly following the boundaries of the Sunda sub-continent, the raised landmass of the Sunda shelf during sea-level regressions in the Pleistocene - consisting of the Malay peninsula, Sumatra, Java, and Borneo/Kalimantan Island. Wallacea is hereby considered as the region east of the (original) Wallace line composed of islands which have never been connected to

Sunda and Sahul (the landmass consisting New Guinea, Australia and associated offshore islands during the Pleistocene) in its west. The gaps between the Wallacean islands and both landmasses are very likely the major factor for the relative scarcity of animal species originating from Asia and Oceania and the high diversity of endemic species in Wallacea. They are also considered as barrier for hominin migration into Wallacean islands and Sahul continent. Currently, no hominin species other than AMH had reached Sahul and Oceania and no fossil evidence currently exists for Wallacea, except for Sulawesi and Flores (Morwood et al. 2004; O'Connor et al. 2011; van den Bergh et al. 2016). From this perspective, one of the most enduring questions for the peopling of Wallacea and Sahul is about the technologies and the maritime, nautical and behavioural capacities of AMH that enabled them to cross the open sea over distances of at least 20 km to up to 100 km and successfully adapted to remote insular environments.

Two major routes have been suggested for the initial maritime migration via Wallacea into Sahul or Oceania, (Fig.1), a 'northern' route after Birdsell (1977) into the region of New Guinea and a 'southern' route leading into northern Australia (Birdsell, 1977; Sondaar, 1989; Morwood and Van Oosterzee, 2007; Kealy et al., 2015). Previous studies have mainly focused on southern routes since they seem more directly related to human migration into Australia. Archaeological studies have been conducted in Flores, Alor, and Timor Island (mainly in Timor-Leste) since the early 21st century and have so far discovered the older sites possibly associated with AMH, dating back to around 50,000 to 43,000 cal BP (O'Connor 2007; O'Connor et al. 2011; Hawking et al. 2017; Sutikna et al. 2017, see also Fig.1).

Along the northern routes, on the other hand, recent research in south Sulawesi, the largest island in Wallaeca was able to find possible AMH traces dating to 42,000 to 36,000 cal BP (Aubert et al. 2014; Blume et al. 2017), but evidence of initial AMH migration remains very limited in other islands. Theonly three sites are known as older than 30,000 cal BP (Fig.1); Golo cave in Gebe Island dated to c. 36,000 cal BP (Bellwood 2017, 2019; Bellwood et al. 1998), Bubog site in Mindoro Island dated > 35, 000 cal BP (Pawlik et al. 2014), and Leang Sarru site in Talaud Islands with dates as early as 35,000cal BP (Fuentes et al. in press; Ono et al. 2010, 2015; Tanudirjo 2001, 2005).

Figure 1 Major possible dispersal routes by early modern humans via Wallacea into Sahul (Oceania)

The current archaeological evidences suggest a much older antiquity of the southern routes than the northern routes for early AMH traversing from Sunda into Sahul or Oceania (O'Connor 2007; Hawking et al. 2017;). Considering intervisibility between islands, however, the northern route would have provided an easier path for AMH for initial colonization of Sahul (Kealy et al. 2017). Therefore, both routes have the potential to be used as initial paths to reach Sahul by AMH and more archaeological and anthropological data needs to be acquired, particularly along the northern routes in Wallacea.

In this paper, we report about new archaeological research on the eastern coast of Sulawesi, which could have been the most potential starting location for the northern routes. Based on new findings from the cave site of Goa Topogaro in Central Sulawesi, East Indonesia (Fig.1), we discuss the evidence and timeline for early AMH migration into the Wallacean islands along the northern routes as well as indications for human adaptation to the fast changing ecological conditions during the late Pleistocene until the Mid-Holocene. We report on the excavated lithic and bone artefacts as well as faunal remains that provide information about the technological and cognitive aspects of human adaptation, evidence of changing human foraging behaviour, and temporal changes of the ecological conditions during the late Pleistocene to Holocene.

2. Materials and Methods

2.1. Excavation and chronology of the Topogaro sites

Archaeological survey and excavation were conducted in Goa Topogaro, Central Sulawesi. Goa Topogaro (*Goa* meaning “cave” in Bungku and Ta’a as the local languages around the site) is an extensive cave complex composed of three larger caves, Topogaro 1-3, within a large doline (sinkhole) formation in the lower part of a limestone hill that belongs to the ultramafic Neogene Tomata Formation. It is located in c. 3.5 km distance from Topogaro village in the West Morowali District along the eastern coast of Sulawesi at coordinates S02°06’55-4”, E121°19’58-5” (Figure 2), and elevated about 75m above current sea level, while the rockshelters Topogaro 4-7 are located along the wall of the upper doline are located at 90m above sea level. The limestone hill is well visible from the current coast, and the nearest fresh water source is Folili river in c. 200 m distance from the cave complex (Fig. 1).

Figure 1 Locations of Goa Topogaro and Kolonodale in Morowali, Central Sulawesi

Figure 2 Current locations of the limestone hill and Goa Topogaro complex with the nearest river-streams (A-C) where a variety of chert pebbles can be found and was possibly a source of the Topogaro lithics

Our initial surveys in the complex showed that the two caves Topogaro 1 and 2 seem to have the highest potential for Pleistocene archaeological deposits, while the four rockshelters (Topogaro 4-7) located in upper level of the limestone hill contain secondary burials and jars with dentate-stamped designs together with possible burial goods including shell ornaments (Ono et al. 2019). Another large cave, Topogaro 3, located next to Topogaro 2, has a very small entrance and is very dark and showed little potential for archaeological evidences. No archaeological material was observed on the cave’s surface. Our excavations therefore focused on Topogaro 1 and 2. Topogaro 1 is the slightly larger cave with about 500m^2 of floor area. The cave is 24 m wide and 25 m deep with a maximum height of about 20 m and faces northwest (Figure 4A). Over 30 broken wooden coffins with human skeletal remains were found on the surface in the central to northern part of the cave floor. The surface is generally dry and contains fragments of prehistoric pottery, Chinese and European ceramics, chert flakes, including finely retouched tools, and shell. This indicated at first sight that the cave had been used as a prehistoric habitation and tool production site, while the wooden coffins and the variety of Chinese and European ceramics indicate a use of the cave as a cemetery in more recent times.

Topogaro 2 is located south-west of Topogaro 1 and both caves are connected to each other by a narrow passage at the southern wall of Topogaro 1 (Fig. 4B). The mouth of Topogaro 2 faces north and the cave’s length is about 24 m with a width of about 15 m and a maximum height of about 12 m. The floor area of Topogaro 2 is about 360 m^2, flat and has lesser rockfall than Topogaro 1. Unlike Topogaro 1, this cave had no wooden coffins during our visit in 2016 (though a few coffins were observed by Sriwigati and Aziz who visited the site in 2015) and far less artefacts appeared on its surface although we were able to observe some potsherds, ceramics, chert flakes and broken human bones.

Figure 3 Floor plan and excavated area in Goa Topogaro 1 & 2

Two trenches in the northern (Trench A, 1 x 4 m trench area) and southern part (Trench B, 2x3 m trench area) of the cave were excavated in Topogaro 1 with a total excavated area of 10 m^2. In Topogaro 2, Sector A, a 2x3 m trench along the eastern wall and Sector B, a 2x2 m square along the western wall were excavated (total excavated area of 10 m^2). Excavation was generally carried out in horizontal spits of 5cm, but followed the stratigraphy whenever it was feasible. All excavated sediments were dry-sieved through 5 mm and 2 mm screens. With access to water being difficult at the site, wet sieving was not attempted. The recovered materials were sorted into general classes (e.g. vertebrates, crustaceans, molluscs, pottery, stone artefacts) in the field. They were later re-sorted and analysed at the National Archaeological Research Centre in Jakarta and at the Sulawesi branch in Manado. In this article, we select to report on the materials from Trench B in Topogaro 1 and Sector A in Topogaro 2, since both trenches produced larger amount of artifacts and contain deeper deposits in each cave.

For Topogaro 1, our excavation in both Trench A and Trench B exposed limestone rockfall at about 100 cm depth from the surface, and we temporally had to stop our excavation due to the density of the fallen rocks. However, it appeared that more sediment deposits are still underneath the rockfall, and we plan to remove these limestones in later campaigns and to reach those deeper deposits. Until the heavy rockfall appeared, our excavation of both trenches identified three layers (Fig. 5) with significant amounts of lithics, human and animal bones, shell remains, bone projectiles, as well as ceramics, potsherds, glass ornaments (variety of beads), and metal objects in the upper layers associated with the burials. The top layer (Layer 1) contains numbers of fragmented human bones with possible burial goods including ceramics, pottery, glass ornaments, and metal goods. Layer 1 also contains a few bone projectiles, shell remains and lithics although their numbers increase in Layer 2 and the lower Layer 3. On the other hand, pottery, ceramics, metal goods and glass beads dramatically decrease or disappear in Layer 2 and were completely absent in Layer 3.

Figure 4 Cultural layers of Trench B in Topogaro 1

We encountered much lesser rockfall in Topogaro 2 and were able to excavate both sections down to a depth of 300-310 cm (Spit 60-62) at the end of our latest excavation in March 2018. Currently eleven layers were identified within Section A (Fig. 6), containing shells, small animal bones, and lithic flakes (n<100). Since our excavation in Topogaro 2 is still ongoing and we expect more cultural deposits underneath, the dates for the initial human use of the site are potentially older than the chronology that we report and discuss here. Among the upper layers, Layer 2 (mainly Spit 8-10) produced a large number of shell remains, while they were very few in the other layers. Layers 3, 5, 7, 8 and 10 produced significant amounts of lithic artefacts, mainly chert flakes while Layer 4, 6 and 9 contained very few or no artefacts, pointing at a discontinuous occupation of the cave.

Figure 5 Cultural layers and location of dating materials in Sector A in Topogaro 2

In situ charcoal and shell samples were dated at the Radiocarbon Dating Centre, the University of Tokyo. A total of 19 charcoal and shell samples from Trench B in Topogaro 1 (n=5) and Sector A on Topogaro

2 (n=14) were dated by AMS/C14 methods and calibrated against Marine13 (Reimer et al. 2013) using OxCal v.4.2.4 (Bronk Ramsey and Lee 2013). The results suggest three occupational phases for Trench B in Topogaro 1 (Table 1), during the early Holocene (c. 9000 cal BP), Mid-Holocene (c. 5000 cal BP) and late Holocene (ca. 3000-2000 cal BP). The results for Sector A in Topogaro 2 indicate four occupational phases: 1) late Pleistocene (c. 29000-26000 cal BP/ Layer 9-11); 2) post LGM (c. 16000 cal BP/ Layer 6-8); 3) early Holocene (c. 10,000 cal BP/ Layer 3-4); and 4) early Metal Age (c. 2300 cal BP/ Layer 1-2). The comparison of the different periods and their excavated remains allows us to discuss the changes of ecological conditions, resource use, and human foraging behaviour, including lithic and bone tool technology from the late Pleistocene to the Holocene and over the past 30,000 years.

Table 1 List of charcoal and shell dates from Goa Topogaro 1 & 2

2.2 Morphological and use wear analysis of stone and bone artefacts

Morphological and use wear analysis of stone artefacts are part of our major study topic in Topogaro excavation since the site produce larger number of them. For morphological analysis of flake tools, we classify into the five six categories: (1) complete flake, (2) non-complete flakes, (3) retouched flake, (4) core and core fragment, (5) shatters, and (6) non-chert materials. For other stone artefacts, we also categorised hummer stone and stone blank. The methods of bone point analysis are similar to those employed by lithic analysts to emphasize aspects of raw material selection, methods of modification, basic metric attributes, the morphology of functional edges or points, and patterns of use-wear and damage as described by Pasveer (Pasveer 2006; Pasveer and Bellwood 2004). For use-wear analysis of stone and bone artefacts, both microscopic analysis and experimental approach analysis are essential. The laboratory analysis by use of microscope were mainly conducted at Balai Arkeologi Northern Sulawesi in Manado, while experimental analysis by making some stone tools with similar source materials around the sites was conducted during the excavation by R. Fuentes. For use-wear analysis, such experimental analysis to use these newly made stone tools to cut various materials to check their use wear for further comparison with the excavated tools. Samples were brought to the University of Tübingen for SEM-EDX and LSCM analysis, for future research.

2.3 Analysis of excavated faunal remains

Skeletal remains were identified at the lowest taxonomic level possible. Fish bones were identified through comparison with the reference collection of National Museum of Ethnology, while mammalian and reptile skeletal remains were preliminary identified using the somewhat limited reference collection (mainly collected by R. Ono in Sulawesi) at Balai Arkeologi Northern Sulawesi. Some remains of anoa and Babirusa were identified with the aid of Prof. Philip Piper at the Australian National University. Further and more detailed identification and analysis will require the use of a larger reference collection. Mollusca remains were sorted in each taxon but currently identified in family level counted in NISP and weight.

3 Results

3.1 Variation and possible function of the stone and bone artefacts in Goa Topogaro 1

The majority of the stone and bone artefacts from Trench B in Topogaro 1 date into the early to mid-Holocene, between 10,000 to 8,500 cal BP (Table 1). For stone artefacts from Topogaro 1, we select a 1 x 1 m square of Trench B (B-5) for the results of our morphological and use-wear analysis. The square produced 4,409 and 15,217g of flaked stone artefacts (Table 2). Most of them were made of chert with yellow to reddish colour. Other squares also produced similar volumes in Trench B. Artefacts were identified throughout the sequences but mostly concentrated in the upper layers. Similar colour and texture of chert nodules can be found along the streams within 3 km of the caves, and these chert pebbles were likely selected as flake cores. Complete flakes are counted as 225 in number and the assemblage mainly composed of both unretouched and retouched flakes with pointed edges (Fig. 6-A) and concave edges (Fig. 6-B). The assemblage also contains 131 cores or core fragments.

Unifacially retouched tools were recovered from the early Holocene in Topogaro 1, c. 9,000 cal. BP (Spit 15, 75 cm from surface level). This type of retouch was done through direct percussion while creating concave edge, characterised by steep working angles. Shallow feather-terminated scars were formed through pressure flaking from a unifacial orientation. The working edges show contact with hard material on low power microscopy but no clear indications at higher magnifications such as well-developed polishes - possibly due to continues retouching even after use. An ongoing experimental program shows that reddish and yellowish chert are readily available at the periphery of the site. After collecting raw materials, replicas of notched tools were produced through direct percussion technique initiated from the ventral face. The steep angle of these tools shows that it was intended to be used in scraping motion with the initiation point of the retouch as the contact face or rake. The retouched tools were recovered in the same context with bone points. The notched tools were unifacially modified, with the use of probably soft hammer percussion due to the shallow negatives on the edges and at times also hard hammer technique as shown by the secondary step scarring with step-terminated scars. We were able to reproduce similar retouched scrapers using chert from the periphery of the site, with the use of direct percussion hard hammer technique.

Table 2 List of lithic artefacts from Trench B-5 (1x1m) in Goa Topogaro 1

Figure 6 Unretouched and retouched flakes with concave edges from Trench B in Topogaro 1

Most of the bone tools were found in Topogaro 1 (n= 120) and appeared in all squares of Trench A and B. They can be assigned to four major categories: bipoint, unipoint, spatula and edged tool (Figure 7). Since Trench B produced the larger number (n=68) and variety of bone tools, we selected this assemblage for further discussion in this paper (Table 3). Among them, 57 can be identified as bipoints (complete & 2/3 complete bipoint = 41, 1/2 broken but possibly bipoint = 26) and seven can be as unipoints (complete unipoint=3, 1/2 broken possible unipoint=4). The length of the complete bipoints (n=14) ranges between 58.13 and 21.57 mm, with a mean length of 35 mm. On the other hand, the length of the unipoints (n=3) ranges between 28.19 and 16.91 mm, with a mean length of 20 mm. The raw materials used for the manufacture of points are cortex bone slivers, narrow unsplit shaft bones, and the dentin of incisor roots of wild pigs. In addition, a broken spatula-like tool and two fragmented edged tools, both of which are probably made of the split long-bone shafts of a large mammal, possibly

Sus species were excavated. Almost all the points are burnt to some degree, though it is not sure whether the tools were originally made from burnt or intentionally heat-treated bones or whether the burning occurred subsequent to discarding.

Table 3 List of bone artefacts from Trench B in Topogaro 1 (n=68)

Figure 7 Bone tools from Trench B, Topogaro 1 (Holocene level)

3.2 Variation and temporal change of the stone artefacts in Goa Topogaro 2

Goa Topogaro 2 produced the Pleistocene stone artefacts both dated around 29,000-26,000 BP and 16,000 BP in Sector A. The deepest found stone artefacts are two chert complete flake tools (Fig. 8A, B) from spit 60 of A-3 (~300 cm from the surface). They are associated with a phalange of Anoa and few charcoals (one of which is dated to 29,000 cal BP as in Table 1). The middle layers in Sector A dated around 16 ka produced some micro blades and blade-like flakes of white and yellowish color chert (Fig. 8C-I). The upper Holocene layers (Layer 1-4) produce yellowish color chert flakes, while the number and percentage of non-chert materials including limestone also increase in the lower layers of the Pleistocene deposits. The detailed analysis of stone artefacts in Topogaro 2 is still in progress, we select a 1 x1 m square on Sector A (A-2) here (Table 4). The upper Holocene dated layers in Sector A do not produce such small blades, while more variety of retouched tools including notched and pointed flakes similar to the ones from Topogaro 1 (Fig. 6). Sector B in Topogaro 2 produced only very few bone tools (n=6). These bipoints and unipoints are similar to the ones retrieved from the Holocene layers in Topogaro 1. Because of the similarity and their very limited number, we excluded them from the discussion and focussed on the bone artefacts from Topogaro 1.

Figure 8 Pleistocene lithic artefacts from Sector 2 in Topogaro 2

A total of 252 lithic artefacts weighing 1920 gms were recovered from the A-2 square in Sector A. These were composed of complete chert flakes, 21 incomplete chert flakes, 5 cores/core fragments, 6 shatters, and 175 non-chert artefacts mostly composed of limestone (Table 4). Lithic artefacts were recovered beginning from Spit 57 (285 cm from surface level). At Spit 55 (275 cm from surface level), complete chert flakes and a core were recovered. No retouched pieces were recovered in TP2. From the lowest level of Topogaro 2/ Sector A, large chert flakes and smaller limestone flakes show impact with hard materials such as animal bones. Production and use of both chert and limestone were identified as early as 30 kya. Animal bones were also recovered from the same context with the stone tools that show impact traces along the outline of working edge. From 18kya, we recovered tools that show contact with phytolith rich plants using continuous transversal action. We inferred these to have been used for processing plant materials, forming sickle polish along the working edges that are comparable with the results obtained from Leang Sarru, North Sulawesi (Fuentes et al. in press). Although flake tools were continually produced in Topogaro 2, no clear boundaries were identified in terms of appearance of lithic technology during the Holocene as compared with Topogaro 1 with the appearance of notched tools associated with bone points. Lithic use-wear analysis from the selected retouch flakes in Topogaro 2 confirms many of these retouched flakes were heavily used in the edge parts (Fig. 9). The ones from the Holocene layers shows much heavy use traces.

Figure 9. Traces identified on artefacts from Topogaro 2. A. Pleistocene. B. LGM. C. Holocene period of Topogaro 2.

3.4 Variety and temporal changes of faunal remains

Both caves produced a rich variety of faunal remains including molluscs, vertebrates, and crustaceans. Topogaro 1, where we exposed only Holocene deposits so far, produced larger amounts of molluscs and crustaceans than Topogaro 2. For vertebrates remains, both caves have a similar record that is composed of small-sized mammals like chiropterans (bats/Pteropodidae) and rodents (rats/Muridae), wild pigs (Suidae) and anoa (Bubalus sp) as middle to large sized mammals, marsupials (mainly Phalangeridae), reptiles like snakes (Serpentes) and lizards (Lacertila), as well as fishes (Osteichthyes) and molluscs. Since the identification was based on the limited reference collection in Manado at this stage, the vertebrates were mainly identified on a higher order level.

3.4.1 *Faunal remains in Topogaro 1*

Table 5 shows the number of identified specimen (NISP) of all identified vertebrates from a selected 1 x 1 m sampling square of Trench B (B-5). Table 6 shows the minimum number of individuals (MNI) of the same vertebrate assemblage. The NISP of currently identified vertebrates from the square is 1192, while their MNI is 463. The major taxa are represented by small mammals as chiropteran (bats) and murid (rats) species. The bone elements for these small mammals include femur, humerus, tibia, ulna, radius, pelvis, mandible, premaxilla, teeth and canine. For chiropteran bones, at least one fruit bat species (Pteropodidae) and one insectivorous taxa were identified but the exact species is yet unknown. For murid remains, rather small species dominate the assemblages, while some of the murid mandibulars are large in size and possibly belong to a giant rat species. Since some chiropteran and small murid species have their habitat in limestone cave, it is unclear whether these remains were naturally accumulated (including as owl preys) or food remains discarded by humans in the past, while some larger specimens could very well have been human prey and used as food source. The recovered Suidae bones include mandibles, vertebrae, humerus, canines, pre-molars and incisors.

Table 5 List of vertebrates from Square 1/ Trench B in Topogaro 1 (NISP)

For the molluscs remains, 32 taxa were identified including both Bivalvia and Gastropods from a selected 1 x 1 m sampling square of Trench B (B-5). Among them, the major families are Cyrenidae and Arcidae for bivalvia, and Potamididae, Neritidae, and Thiaridae for gastropods. Cyrenidae, Potamididae, and Thiaridae shell mainly inhabit river, mangrove and coastal environments while Arcidae and Neritidae are mainly found in coastal environments. Figure 10 shows the temporal changes of major shell families per spit. The largest family from Topogaro 1 is Potamididae, followed by Neritidae and Arcidae as marine to brackish water species, especially in the upper layers and the Mid-Holocene.

Figure 10 Molluscs remains from Square 1/ Trench B in Topogaro 1 (NISP)

3.4.2 Faunal remains in Topogaro 2

Table 6 shows the NISP and MNI of all the identified vertebrates from a selected 1 x 1 m sampling square of Sector A (A-1). Like Topogaro 1, the major taxa are small mammals like chiropteran (bats) and murid (rats) species. The bone elements for these small mammals include femur, humerus, tibia, ulna, radius, pelvis, mandible, premaxilla, teeth and canine. Rather small murids are dominant in the assemblage, although some murid mandibles are large in size and possibly belong to a giant rat species. For chiropteran bones, at least one fruit bat species (Pteropodidae/Terebralia) and insectivorous taxa are part of the Topogaro 2 fauna but like for Topogaro 1, the exact species is yet unknown.

Table 6 List of vertebrates from Sector A (1 x 1 m) in Topogaro 2 (NISP/MNI)

The analysed molluscan assemblage of Topogaro 2 was taken from a 1 x 1 m sampling square of Sector A (A-5). It contained as well both bivalvia and gastropod species. Here, most gastropods are Thiaridae while Cyerenidae are the dominant bivalvia species. They are both occupying fresh and brackish water habitats in river and mangrove environments. Limited numbers of Arcidae, Conidae, Neritidae, Potamididae shells also indicate shellfishing of marine and brackish water species to some extent. Also oyster shells appear after the Mid-Holocene level, similar to Topogaro 1. The number of land snail species in Topogaro 2 exceed the count from Topogaro 1, although most of them could have died naturally in the cave. The numbers and volume of molluscs are quite limited in the Pleistocene layers and significantly increase in the middle and late Holocene layers (Figure 10).

Figure 10 Temporal change of major molluscs remains from Sector A (1 x1 m) in Topogaro 2

4. Discussions

4.1 The Initial Island Migration into Wallacea and Oceania by AMH

Distances between islands were a major factor for early human migrations and dispersals in Wallacea as were the particular island environments. Except for the above mentioned cases of Sulawesi and Flores, all traces of human presence in Wallacea and Oceania were possibly left by anatomically modern humans. They were probably also the first to reach Sahul which required significant open sea crossings and traversing a distance of at least 80 km from the Wallacean islands to Sahul taking the lower sea levels during the late Pleistocene into consideration (Bird et al. 2019). This was followed by the migration into Oceania and the first true long-distance ocean voyages in the world. Maritime interaction and island adaptation in Wallacea and Oceania becomes evident in the archaeological record beginning with the drastic sea level rise and increase of coastal distances in the Holocene after 12,000 years ago.

Regardless of the initial timing of AMH dispersal into Wallacea and Sahul, it should be noted that in the area of Mata Menge on Flores Island much older human traces have been found, dating back to around 880 kya (Morwood et al. 1997, 1998), while a recent excavation in the Walanai valley in south Sulawesi recovered lithic artefacts associated with large mammals including Stegodon, dated to around 200 to 100 kya (van den Bergh et al. 2016). However, no early hominin fossil remains were found in Sulawesi, so far. To the north in the Philippines, Luzon is another oceanic island that has delivered evidence for early hominin presence in the form of a rhinoceros with cutmarks and butchering traces and associated stone tools, dated to over 700 kya (Ingicco et al. 2018) and the possible presence of *Homo luzonensis* as small-bodied hominin in Callao Cave, Northern Luzon dated to 66 kya (Détroit et al. 2019). Again in Flores, skeletal remains of *Homo floresiensis*, an enigmatic small-bodied hominin were found in Liang Bua and are now dated to between 95-60 kya (Brown et al. 2004; Morwood et al. 2004, 2005; Sutikna et al. 2016).

It is yet unknown what happened between the time those hominins existed and the appearance of AMH in Island Southeast Asia. The record of Liang Bua in Flores suggests as time for the disappearance of *Homo floresiensis* and the potential arrival of AMH after around 50 ka (Sutikna et al. 2016) while recent research at the site of Madjedbebe in Australia has significantly pushed back the arrival of AMH in Sahul to over 60 kya (Clarkson et al. 2017; Robert et al. 1994). However, the accuracy of the applied OSL dating which usually provides older ages than radiocarbon dating, and the stratigraphic context of the artefacts have been questioned and the arrival of AMH in Sahul before 50kya was considered as unlikely (O'Connell et al. 2018). The oldest radiocarbon dates from Australia date after 50 ka cal BP and are mostly younger than 45 ka (O'Connell and Allen 1998, 2004).

A study by Habgood and Franklin (2008) on behavioural modernity in Sahul also stated that across all Pleistocene sites in Sahul associated with AMH, a cohesive 'package' of cultural innovations did not exist in the Indo-Pacific at the beginning of human expansion into the Sahul region and that modern "components were gradually assembled over a 30,000 year period" (Habgood and Franklin 2008: 214). This is in sharp contrast to the archaeological record of Madjedbebe where the entire modern package is already present in the archaeological record (Clarkson et al. 2017). Similarly in Flores, the earliest radiocarbon date for the possible initial appearance of AMH is a single charcoal date of around 46 kya, however, the oldest dated AMH fossil remains dated by laser ablation uranium-series isotope measurement analysis (234U/230TH) and AMS radiocarbon dating resulted to an age of only 6.4 -9.5 ka (Sutikna et al. 2016).

In conclusion, the chronology for the earliest appearance of AMH in Wallacea and Sahul continent is still unclear and might have happened somewhere between 60 and 40 kya. The oceanic voyages of early AMH into Wallacea and Sahul were possible along both, the southern and northern routes (Bird et al. 2018, 2019, Kealy et al. 2017, 2018; Norman et al. 2018). While the former route had more visible land mass with a possible availability of higher biomass prey like *Stegodon* and larger reptiles (cf. Veneridae / monitor lizard) until the terminal Pleistocene (e.g. Louys et al. 2007; van den Bergh et al. 2008, 2009), the northern route on the other hand, led through a much wetter environment with dense rain forests and a variety of land fauna, although the Moluccan islands had less suitable mammal and reptile species as prey for AMH except for marsupials and rodents (Bellwood 2019; Bellwood et al. 1998). More multidisciplinary investigations on the particular environmental and geographical conditions of the islands along the southern route are needed to understand the migration strategies of early AMH to reach these islands and consequently the northern part of Sahul, mainly the coastal area of New Guinea. The paleogeography and inter-visibility models proposed by Kealy and others (2017) already indicate that AMH exploration of the Wallacean Archipelago could have been far more extensive than previously suggested between 65 and 45 ka, and inter-visibility between islands could have been better along the northern route. In fact, they also suggested that the northern route would have provided an easier migration path for AMH from Sunda to Sahul, thus being the more likely route for the initial colonization of Sahul (Bird et al. 2019; Kealy et al. 2017, 2018).

However, as they also point out, there is currently little archaeological data to discuss this hypothesis, and what it is necessary to obtain more archaeological evidence along the northern route as well as the southern route through on-going and future studies in Wallacea region. Our on-going excavation in Goa Topogaro site which locates along the northern route from Sulawesi to the Moluccan islands now shows the direct archaeological evidence of AMH appearance in eastern coast of Sulawesi by 29 kya. Although, this date is yet not older than some other late Pleistocene sites in Wallacea, the site seems to contain much deeper deposits and we plan to continue our investigation to find much deeper deposits which may contain earlier AMH colonization.

4.2 The late Pleistocene foraging behaviour and faunal resources in Wallacea

The chronostratigraphic record and the excavated faunal remains, lithic artefacts, and bone tools of Topogaro provide information on long-term trends in site use and human foraging behaviour during the late Pleistocene and Holocene. Although the faunal remains from the oldest Pleistocene layers so far, dated between about 29-21 kya, are limited in number, the existence of some bat taxa including fruit bat and murid rodent taxa suggests a certain degree of forest cover in the area surrounding Topogaro. The existence of a currently unidentified large murid species at least 16 kya also suggests the presence of forested habitats shortly after the end of LGM. So far, no clear evidence of murid and bat consumption was observed in Topogaro, although the existence of such large murid and fruit bat species has been suggested to indicate human consumption of these fauna, while the smaller species could have been also brought in by owls (Hawkins et al. 2017a, 2017b).

Topogaro 2 produced late Pleistocene evidence for large to middle sized mammal remains in the form of a phalange of anoa (*Bubalus* sp) from Layer 11 dated to 29 kya, and another phalange of a marsupial species, possibly bear cuscus (*Ailurops* sp.) from Layer 10 dated to around 27 kya. Both are associated with flaked stone artefacts mainly made of white-pinkish coloured chert. On the other hand, all the Suidae remains, mainly Babirusa, were so far only recovered from Holocene layers, both in Topogaro 1 and 2. In southern Sulawesi, extant endemic wild boars (suids) together and bovids (anoa) dominate in the Pleistocene deposits of the Walanae river (Bullbeck et al. 2004). The use of marsupial phalanges (Sulawesi bear cuscus) for the manufacture of ornaments around 20 kya was reported from the Maros area (Brumm et al. 2017). Evidence for the active use of anoa and Celebes warty pigs (*Sus celebensis*) with minor use of cuscus and monkey (*Macaca maura*), as well as river shellfish in the late Pleistocene was also found at Leang Burung 2 (Glover 1981; Clason 1989; Brumm et al. 2018) and Leang Sakapao (Bullbeck et al. 2004) in southern Sulawesi. Although fragmentary, these evidences clearly indicate the frequent capture and use of these medium to large-bodied mammals by early AMH as well as other hominins in Sulawesi.

Another potential large mammal prey of hominins until the late Pleistocene in the larger islands of Wallacea is *Stegodon*. In Sulawesi, the potential exploitation of *Stegodon* species have been reported so far from the open sites in the Walanae region dated ∼ 200 kya (van den Bergh et al. 2016) and from the lower deposits of Leang Burung 2 in Maros, which possible dated to around 70 kya (Brumm et al. 2018). At Topogaro and other prehistoric sites in Sulawesi dated after 32 kya, *Stegodon* remains are completely absent, thus suggesting that they became extinct before 30 to 40 kya (Larick and Ciochon 2015). So far, no archaeological evidence has been found for the exploitation of *Stegodon* by the time of the initial migration of AMH into Sulawesi along both routes.

Other sites in Indonesia, where *Stegodon* was found associated with early hominin species (*H. erectus* and *H. floresiensis*) are located in Java and Flores along the dry savannah environment corridor (van den Bergh et al. 2001, 2008, 2009; Morwood et al. 2004; Louys et al. 2007). It is possible that the *Stegodon* population might have been larger in such open environments along Java and the Sunda Islands well as part of Sulawesi.

Also in Timor where *Stegodon* fossils were found but did not appear in any of the possible AMH sites so far, it could be that those larger mammals have been already gone extinct before the initial arrival by modern humans (Louys et al. 2016; O'Connor and Aplin 2007). If none or very few large sized animal resources existed by the time of their initial migration into Wallacea, then it was perhaps the variety of other available resources of terrestrial and marine origin and the visibility and accessibility to those resources that drew early AMH's attention to the Wallacean region. In this case, both routes could have been equally attractive for them. For instance, along the Southern routes the coastal sites of Lene Hara, Jerimalai and Tron Bon Lei in Timor and Alor delivered large amounts of fish and shellfish remains together with possible fish hooks made of shell from the late Pleistocene and early Holocene layers and dated to around 42 to 10 kya (O'Connor and Veth 2005; O'Connor et al. 2002, 2011; Samper Carro et al. 2015). All of these sites are located within 1 km distance from the current coast, and were probably within 1-3 km distance from the Pleistocene coastline even during the LGM.

On the other hand, these coastal sites only produced small terrestrial animal resources including rodents, reptiles and bats during the Pleistocene occupation, demonstrating maritime adaptation and a high demand for marine resources for the early AMH population that has migrated to the coastal areas of Timor and Alor. In contrast, the inland sites in these islands mostly produced mostly terrestrial resources such as murids and bats and very few or no marine resources. For instance, Uai Bobo2 located over 80 km from the current coast in Timor and dated to around 16 kya only produced large numbers of murid and bat remains (Glover 1986). Matja Kuru 2 site located about 10 km inland but close to the largest freshwater lake in East Timor produced an abundance of giant and small murids together with freshwater turtles (O'Connor and Aplin 2007).

Laili Cave, so far the oldest site in East Timor dated from 44 to 11 kya is located about 4.3 km from the current coast and has produced 16 different mammal taxa, mainly rodents (four extinct small rat species and four extinct giant rat species) and bats (including a fruit bat species) together with some reptile, amphibian, and bird remains (Hawkins et al. 2017a). The site has also delivered fish, molluscs, and crustacean remains, mainly freshwater and mangrove species. Their volume significantly increases after the LGM and terminal Pleistocene. A similar tendency is seen for the inland sites of Flores with a high number of terrestrial fauna including freshwater and mangrove mollusc species, and very few or no marine resources (van den Bergh et al. 2008). Although the current limited archaeological record issuing definite statements on the level of marine exploitation by early AMH in a wider perspective, the record from Timor shows that early AMH developed maritime adaptation and nautical skills to successfully exploit the coastal areas of remote islands with limited terrestrial resources such as Timor and Alor.

Along the northern routes, on the other hand, none of the coastal Pleistocene sites excavated produced marine fish remains in noticeable quantity, while many of them show the extensive use of marine and fresh-brackish water molluscs (Bellwood et al. 1998; Ono et al. 2010; Szabo and Amesbury 2011). For example, Golo Cave on Gebe Island in the northern Moluccas, dated to as early as 36 kya, is one of the oldest dated sites along the northern routes currently and located less than one km from the current coast. The site produced large numbers of marine molluscs as well as possible shell tools made of *Turbo marmoratus* opercula during the late Pleistocene (Szabo et al. 2007). Tridacna and Cassis shell adzes are also excavated from the early Holocene levels in Golo Cave (Bellwood 2017, 2019). They are so far the oldest dated shell adzes in Island Southeast Asia, although questions have been raised whether those early Melanesian and Moluccan shell adzes were produced on 'old shell' and rather belong into the early Holocene (Fredericksen et al. 1993; Pawlik et al. 2015). Despite the large amount of marine shells, the site has delivered only few fish remains and no fishhooks have been found, yet. Similarly, Leang Sarru on the coast of Salibabu Island of the remote Talaud Islands group located between Sulawesi and Mindanao produced large numbers of marine molluscs back to 35 kya, while no fish remains and fishhooks appeared at the site (Ono et al. 2010).

Although the reasons for the absence of marine fish remains in the sites along the northern routes are still unclear, the concurrent absence of fishhooks in these sites shows that there is a strong difference to the sites in Timor and Alor along the southern routes. Topogaro on the eastern coast of Sulawesi shows a similar tendency with marine fish and fishhooks being absent in the Pleistocene deposits, while they contain numerous terrestrial animal remains. Topogaro is at present about 3.5 km inland, and its distance from the coast is similar to Laili Cave (4.3 km inland) on Timor Island (Hawkins et al. 2017a). Both sites did not produce fishhooks nor significant amounts of fish remains, while the amount of molluscs and terrestrial animal remains, as well as lithic artefacts, are high. Such cases might indicate the behavioural variability of early AMH and the capacity to exploit different resources in different (and changing) surroundings and environments in the past.

For instance, Bubog 1 rockshelter further north on Ilin Island, Mindoro, is a coastal site located east of Wallace's Line modified after Huxley in the oceanic part of the Philippines. It has produced a dense and well-stratified shell midden dated from c. 33,000 to 4,000 cal BP, followed by terrestrial silty deposits underneath (Pawlik et al. 2014). Throughout the archaeological deposits appear fish remains and a variety of terrestrial mammals, mostly endemic pigs but also Tamaraw, a bovid endemic to Mindoro, and cloud rats (Reyes et al. 2018). While an edge-ground Tridacna shell adze and Tridacna flaked artefacts were retrieved from its mid-Holocene Layers (Pawlik et al. 2015), the lowest shell midden layer contained an assemblage of worked *Geloina coaxans* shells used as tools. They are directly dated to 28-33,000 cal BP and are the currently earliest shell tools in the region (Pawlik and Piper 2019). Below the midden, a fully worked bone fishing gorge and the remains of pelagic fishes indicate open sea bait fishing before 30 kya (Boulanger et al. 2019; Pawlik and Piper 2019). The antiquity of the site of >35 kya provides another argument that the northern route has been used by AMH earlier than previously thought. The Philippine route and the northern route share both the same starting point in Borneo where Niah Cave has already delivered an over 40 kya long record of AMH presence (Barker et al. 2007).

4.3. Changing foraging behaviour and technologies from the late Pleistocene to mid-Holocene

In terms of temporal changes of forging behaviour from the late Pleistocene to Holocene, the amount of mangrove and coastal mollusc species in archaeological sites of Wallacea dramatically increased after the Pleistocene, in Topogaro particularly during the early to middle Holocene levels around 10-5 kya (see Figure 9, 10). The increase in the amounts of these molluscs coincides with warmer temperatures and sea level rise during this period and the spreading of coastal and mangrove forests around the site, providing ideal habitats for marine, fresh and brackish water species that were easily accessible to the foragers of Topogaro. A similar trend was reported from Laili Cave on Timor where the increase of freshwater and mangrove mollusc species after the LGM into the early Holocene levels is connected to gradually warmer and wetter conditions (Hawkins et al. 2017a). At Golo Cave in northern Moluccas, brackish-water mollusc foraging also became more dominant during the post-glacial sea level rise (Szabo and Amesbury 2011), while coral dwelling marine mollusc species including Tridacna, Conus, and Trochus species dramatically increased at Leang Sarru on the Talaud Islands during the same period (Ono et al. 2010).

Foraging of terrestrial animals, mainly giant rats and fruit bats is visible in Topogaro 2 throughout the stratigraphy from the Pleistocene to Holocene layers, although particularly the small sized species might not necessary have been hunted, exploited and discarded by humans. Hunting of babirusa and Celebes warty pig is currently confirmed only for the Holocene layers of Topogaro. A few dog teeth were excavated both from the lower and upper layers, their exact date hasn't been determined as of now. Since there is no endemic *Canis* species known in Sulawesi, those dogs were most likely introduced by humans possibly after the mid-Holocene. The possible dog mandibular was excavated from Gua Mo'ohono in Walandawe region of southwest Sulawesi which is located about 100 km inland from Goa Topogaro and the direct dates of a dentine dated to around 4400 cal BP, however it is now suspected as mandibular canine of brown palm civet (O'Connor et al. 2018).

In Java, the Holocene layers of Song Gupuh, Gua Braholo and Song Keplek produced a large volume and wide range of animals remains that include deer, pig, bovid, elephant, bear, rhino, and tapir as well as mollusc remains (Morwood et al. 2008: 1784). Although the active use of monkey is not confirmed in the Topogaro case, we observed the exploitation of a wide array of animals including smaller-bodied species, rodents and molluscs in Topogaro which appears to follow this trend of Holocene sites in Indonesia. Such increase of foraging variability could be directly related with the technical and cognitive development of hunting and gathering skills and an increasing knowledge for creating the necessary strategies and tools.

Lastly, regarding the stone and bone artefacts and their use, a variety of activities and processed materials were identified. Throughout the sequence, we were able to infer production and use of stone tools from c. 29 kya, mainly on harder materials such as animal bones. Limestone artefacts were also produced indicating utilisation of raw materials from both the cave site other than from rivers and streams, in the case of chert. Unretouched complete flakes were produced through direct percussion technique from the Terminal Pleistocene. At around 20 kya, during the LGM, we identified tools which were unifacially retouched, resembling a point which denticulated left and right lateral sections. Initial analysis reveals the use as possibly hafted tool similar to the case in the Talaud Islands about 100 km away from northern Sulawesi coasts (Fuentes et al, in press). The combination of utilisation of both retouched and unretouched tools continued until the Holocene period. In Topogaro 1, bone points and lithic artefacts were recovered from the same context, implying the associated production of both concave-retouched tools and osseous technology. Basing on use-wear analysis, distinct traces from plant working and bone processing showed well-developed polishes. Technological production and material processing indicate not just plant working but also processing of bones. Possibly hafted retouched tools were also present in the site and traces indicating lateral action through impact with the formation of micro linear impact traces (MLIT).

Bone tools are major tools regularly found in the Holocene archaeological sites in Southeast Asia including Wallacea. A few Pleistocene sites such as Niah Cave in Borneo, Lang Rongrien in peninsular Thailand, Matja Kuru 2 in East Timor also produced some bone tools dated to >30 kyr (Olsen and Glover 2004; O'Connor et al. 2014). In Sulawesi, however, bone points and awls are all from the Holocene layers between 10 to 4 kyr, and the major tools are occupied by small sized bipoint or pointed implements; Ulu Leang 1 (n=127/134) and Leang Burung 1 (n=21/26) in Maros, Southern Sulawesi (Olsen and Glover 2004), and some sites in Walandawe (n= 137/149), Southeast Sulawesi (Aplin et al. 2016), as well as in Goa Topogaro (n=64/68 from Trench B) in Central Sulawesi reported here. The predominant of pointed tools possibly used as projectiles (Olsen and Glover 2004) in these sites may represent similar bone tool tradition were widely shared in Sulawesi during the Holocene. The Topogaro bone tool assemblages particularly show high similarity with those in Walandawe region in the selection of raw materials, possible manufacturing methods employed, and tool usage. The appearance of such similar bone tool tradition may have strong relation with predominant of concave-retouched tools in Goa Topogaro and general increase of variation in exploited animals especially of small-middle sized species and aquatic resource including fish and molluscs after the Holocene in Sulawesi and Wallacea.

Bone tools also become dominant in other islands in Wallacea particularly among the islands including the North Moluccan islands, the Aru islands along the northern route as well as the Bird's Head in New Guinea. In the Northern Molucca, Golo cave produced the largest sample of points (n=108) with dominant of bipoints (n=75) dated between 7.4 to 3.2 kyr (Pasveer and Bellwood 2004). Liang Lemdubu and Liang Nabulei Lisa produced 47 points dated widely between 25 to 2 kya in the Aru islands, while the largest sample (n=34) comes from the upper layer of Liang Lemdubu dated around 2 kyr (Pasveer 2005). In the Bird's Head, Kria cave produced 92 points including both bipoints and unipoints dated to 7 to 4.3 kyr (Pasveer 2004). The Kria Cave points resemble the North Moluccan points in their method of manufacture, and both bipoints were mainly hafted and used as bores or engravers (Pasveer and Bellwood 2004). The Topogaro bone points are generally correspond with those points in Golo cave and Kria cave, and highly possibly hafted to use as projectile tool.

Rabett and Piper (2012) conclude the pattern of use of osseous materials in Southeast Asia become more standardized to be used as hafted components of composite tools after 15 kyr, and such developments appear to have occurred earlier in Island Southeast Asia, especially in Wallacea. The increased prominence of osseous technologies could be one of the AMH foragers adaptation to the far-reaching environments and demographic changes (Rabett and Piper 2012: 37) particularly after the Holocene. Similar to other cases in Sulawesi (Aplin et al. 2016; Olsen and Glover 2004), the Topogaro assemblages with increase of concave-retouched flake tools, bone points, small to middle sized animals and shells are highly relevant to such scenario. For further study, we need more comprehensive analysis as focusing on both lithic and bone tools including their use-wear analysis as well as zoo-archaeological analysis on the faunal remains to reconstruct more details of the past AMH foraging behaviour and technologies from the late Pleistocene to mid-Holocene.

5. Conclusions

The differences in the assemblages and the potential uses of these sites across ISEA is quite intriguing, however, the number of Pleistocene sites in Wallacea, especially along the northern route is still too small and more sampling data is needed for a more detailed comparative analysis of different subsistent strategies and resource used by early AMH along the both northern and southern routes in Wallacea.

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List of Tables

Table 1 List of charcoal and shell dates from Goa Topogaro 1 & 2

Site	Location	Spit	Layer	Ref-No	C14 Dates	Calibrated Cal BP*	Material Dated
TPGR1	Trench B	6	2	TKA-18864	8168 ± 28 BP	8763 - 8547	Cyrenidae sp.
	Trench B	10	2	TMNA1-1	3097 ± 23 BP	3373 -3242	charcoal
	Trench B	16	3	TKA-18865	9922 ± 31 BP	11037 - 10732	Anadara sp.
	Trench B	20	3	TKA-18866	8107 ± 27 BP	8660- 8660	Cyrenidae sp.
	Trench B	20	3	TMNA1-2	8742 ± 31 BP	9888 - 9595	charcoal
TPGR2	Sector A/1	19	95cm	TKA-17034	9454 ± 30 BP	10760 - 10587	charcoal
	Sector A/6	18	90 cm	TMNA2-6	9407 ± 33 BP	10729 - 10561	charcoal
	Sector A/7	26	130 cm	TMNA2-8	13202 ± 43 BP	16050- 15700	charcoal
	Sector A/7	28	140 cm	TMNA2-9	9489 ± 33 BP	10805 - 10651	charcoal
	Sector A/5	32	160 cm	TMNA2-1	13488 ± 41 BP	16431 - 16048	charcoal
	Sector A/5	41	205 cm	TMNA2-2	21778 ± 101 BP	26213 - 25813	charcoal
	Sector A/5	42	210 cm	TMNA2-3	12690 ± 37 BP	15275 – 14921	charcoal
	Sector A/7	44	220 cm	2017J	5870 ± 26 BP	6366 - 6213	Telescopium sp.
	Sector A/5	46	230 cm	2017I	22355 ± 67 BP	26377 - 25958	Telescopium sp.
	Sector A/1	55	275cm	TKA-16906	24642 ± 62 BP	28864 – 28464	charcoal
	Sector A /7	56	280 cm	TMNA2-10	19647 ± 59 BP	23914 - 23435	charcoal
	Sector A /7	58	290 cm	TMNA2-11	23540 ± 106 BP	27864 - 27485	charcoal
	Sector A/6	59	295 cm	TMNA2-7	21816 ± 72 BP	26199 - 25866	charcoal
	Sector A/5	60	300 cm	TMNA2-5	25424 ± 83 BP	29802 - 29212	charcoal

Table 2 List of stone artefacts from Square B- 3 (1 x 1m), Trench B in Goa Topogaro 1

Spit	Complete Flakes	Incomplete Flakes	Retouched Pieces	Core/ fragments	Shatters	Non-chert Materials	N	W(g)
1	12	31	3	11	166	29	**252**	1059
2	19	27	3	7	143	16	**215**	883
3	14	33	3	7	209	37	**303**	1356
4	4	60	13	9	328	39	**453**	798
5	18	76	6	13	329	22	**464**	2054
6	32	33	17	15	560	13	**670**	1617
7	37	98	16	16	431	17	**615**	1989
8	22	42	2	2	246	16	**330**	527
9	27	20	1	16	233	24	**321**	1099
10	8	23	0	6	72	23	**132**	683
11	6	18	4	9	88	11	**136**	569
12	8	20	1	4	125	37	**195**	728
13	4	10	1	4	70	31	**120**	751
14	8	22	2	4	64	20	**120**	449
15	4	5	0	6	14	21	**50**	462
16	0	0	0	0	0	2	**2**	8
17	1	0	0	1	8	6	**16**	111
18	1	2	0	1	2	9	**15**	74
Total	**225**	**520**	**72**	**131**	**3088**	**373**	**4409**	15217

Table 3 List of stone artefacts from Square A-2 (1 x 1 m), Sector A in Goa Topogaro 2

Spit	Complete Flakes	Incomplete Flakes	Retouched Pieces	Core/ core fragments	Shatters	Non-chert Materials	N	W(g)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	1	0	0	0	0	0	1	16
13	2	0	0	0	0	0	2	6
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	1	2	3	25
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	4	4	17
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0

23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	10	10	46
25	0	0	0	0	0	8	8	43
26	2	1	0	0	0	25	28	251
27	0	2	0	0	0	1	3	33
28	5	2	0	0	0	15	22	250
29	6	0	0	0	2	9	17	166
30	1	2	0	1	1	11	16	80
31	5	1	0	1	1	2	10	67
32	6	4	0	0	0	4	14	162
33	1	2	0	0	0	0	3	32
34	3	0	0	0	0	0	3	20
35	1	1	0	0	0	0	2	39
36	0	0	0	0	0	0	0	0
37	1	1	0	0	0	0	2	13
38	1	0	0	0	0	1	2	1
39	0	0	0	0	0	2	2	8
40	1	0	0	0	0	4	5	17
41	0	0	0	0	0	0	0	0
42	1	1	0	1	1	1	5	36
43	0	1	0	0	0	0	1	2
44	2	3	0	0	0	7	12	46
45	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0
48	1	0	0	1	0	2	4	144
49	0	0	0	0	0	0	0	0
50	1	0	0	0	0	0	1	11
51	0	0	0	0	0	1	1	7
52	0	0	0	0	0	0	0	0
53	0	0	0	0	0	14	14	71
54	1	0	0	0	0	11	12	26
55	3	0	0	1	0	2	6	87
56	0	0	0	0	0	20	20	142
57	0	0	0	0	0	19	19	58
58	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
	45	**21**	**0**	**5**	**6**	**175**	**252**	**1920**

Spit	Complete Flakes	Incomplete Flakes	Retouched Pieces	Core/ core fragments	Shatters	Non-chert Materials	N	W(g)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0

11	0	0	0	0	0	0	0	0
12	1	0	0	0	0	0	1	16
13	2	0	0	0	0	0	2	6
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	1	2	3	25
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	4	4	17
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	10	10	46
25	0	0	0	0	0	8	8	43
26	2	1	0	0	0	25	28	251
27	0	2	0	0	0	1	3	33
28	5	2	0	0	0	15	22	250
29	6	0	0	0	2	9	17	166
30	1	2	0	1	1	11	16	80
31	5	1	0	1	1	2	10	67
32	6	4	0	0	0	4	14	162
33	1	2	0	0	0	0	3	32
34	3	0	0	0	0	0	3	20
35	1	1	0	0	0	0	2	39
36	0	0	0	0	0	0	0	0
37	1	1	0	0	0	0	2	13
38	1	0	0	0	0	1	2	1
39	0	0	0	0	0	2	2	8
40	1	0	0	0	0	4	5	17
41	0	0	0	0	0	0	0	0
42	1	1	0	1	1	1	5	36
43	0	1	0	0	0	0	1	2
44	2	3	0	0	0	7	12	46
45	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0
48	1	0	0	1	0	2	4	144
49	0	0	0	0	0	0	0	0
50	1	0	0	0	0	0	1	11
51	0	0	0	0	0	1	1	7
52	0	0	0	0	0	0	0	0
53	0	0	0	0	0	14	14	71
54	1	0	0	0	0	11	12	26
55	3	0	0	1	0	2	6	87
56	0	0	0	0	0	20	20	142
57	0	0	0	0	0	19	19	58
58	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
	45	**21**	**0**	**5**	**6**	**175**	**252**	**1920**

Table 4 List of bone artefacts from Trench B (6 m^2) in Topogaro 1 (n=68)

Square	Spit	Category	Length	Width	Weight	Material
B-3	4	1/2bipoint	26.87	4.94	0.73	cortex
n=14	4&5	bipoint	58.13	6.71	1.45	cortex
	5	bipoint	37.49	4.89	0.87	shaft
	7	2/3bipoint	39.65	6.64	1.04	shaft
	7	bipoint	25.03	3.72	0.25	cortex
	7	unipoint	16.91	2.74	0.08	dentin
	8	1/2bipoint	26.78	5.83	0.47	shaft
	9	bipoint	21.57	3.09	0.15	cortex
	9	1/3bipoint	20.43	4.93	0.7	cortex
	9	1/2bipoint	14.36	3.63	0.12	cortex
	10	2/3bipoint	37.49	4.87	0.75	cortex
	11	1/2bipoint	12.25	5.57	0.22	cortex
	13	unipoint	28.19	3.49	0.3	dentin
	14	1/2bipoint	17.08	4.62	0.18	cortex
B-4	5	bipoint	32.79	4.56	0.6	cortex
n=10	5	2/3bipoint	36.66	4.89	0.71	cortex
	5	2/3bipoint	48.77	7.09	1.44	shaft
	5	1/2bipoint	30.82	6.27	0.85	shaft
	5	1/2bipoint	24.73	4.62	0.3	cortex
	5	bipoint	41.01	5.11	1.01	dentin
	6	1/2bipoint	28.31	3.11	0.34	cortex
	7	bipoint	50.7	4.71	0.92	shaft
	7	1/2bipoint	23.59	4.52	0.55	cortex
	10	2/3bipoint	36.16	5.16	0.74	shaft
B-5	3	bipoint	30.06	5.26	0.37	cortex
n=15	3	2/3bipoint	40.11	5.35	0.92	shaft
	3	tib/bipoint?	14.45		0.1	cortex
	5	1/2bipoint	25.14	5.86	0.46	shaft
	5	1/2bipoint	20.11	5.85	0.33	shaft?
	6	2/3bipoint	35.79	5.71	0.9	cortex
	6	1/2unipoint?	32.72	3.67	0.46	cortex
	9	1/2bipoint	15.64	3.84	0.15	shaft?
	11	1/2bipoint	27.01	4.87	0.65	cortex
	11	1/2unipoint?	26.59	5.69	0.57	cortex
	11	1/2unipoint?	20.99	5.75	0.33	cortex
	11	1/2edge tool?	32.29	6.22	0.67	shaft
	13	1/2spatula	25.62	9.35	0.74	shaft
	13	1/2bipoint	37.51	5.85	0.72	shaft
	17	1/2bipoint	31.31	4.68	0.55	cortex
B-6	1	bipoint	46.62	4.95	0.81	cortex
n=4	2	bipoint	47.56	6.59	1.92	dentin
	3	bipoint	42.87	5.16	0.76	cortex
	4	1/2bipoint	20.86	3.93	0.25	dentin
B-7	6	1/2bipoint	25.19	6.34	0.41	shaft
n=7	8	bipoint	36.39	5.29	0.83	shaft

	8	unipoint	23.87	3.35	0.21	cortex
	11	unipoint	43.78	5.52	0.93	shaft
	13	1/2bipoint	32.68	5.81	0.75	shaft
	13	1/2bipoint	19.97	4.23	0.26	cortex
	15	bipoint	31.72	4.02	0.39	cortex
B-8 n=18	5	2/3bipoint	27.49	4.39	0.38	cortex
	5	1/2bipoint	16.46	3.72	0.17	dentin
	7	bipoint	33.71	4.24	0.5	cortex
	7	2/3bipoint	31.79	5.67	0.7	cortex
	9	1/2bipoint	23.37	4.38	0.34	cortex
	11	bipoint	43.41	5.62	0.85	dentin
	11	2/3bipoint	31.95	5.29	0.91	dentin
	11	2/3bipoint	41.96	4.89	0.73	shaft
	11	2/3bipoint	29.42	4.02	0.32	shaft
	13	1/2bipoint	28.49	5.97	0.67	cortex
	13	1/2spatula	38.46	7.69	1.15	shaft
	13	edged tool	60.92	9.84	2.33	shaft
	13	1/2bipoint	33.07	5.96	0.84	cortex
	13	1/2bipoint	23.21	5.07	0.41	cortex
	13	bipoint	41.74	4.47	0.75	cortex
	13	bipoint	28.47	4.36	0.31	cortex
	13	1/2bipoint	37.39	5.42	0.85	cortex
	15	bipoint	36.43	5.62	0.7	shaft

Table 5 List of vertebrates from Square B-5 (1 x1 m), Trench B in Topogaro 1 (NISP)

Spit	bat	rodents	Suidae	marsupials	dog	anoa	snake	lizard	fish	Total
1	31	5	0	0	1	0	0	0	1	**38**
2	1	1	0	0	0	0	3	2	0	**7**
3	51	6	2	0	0	0	1	0	0	**60**
4	12	3	0	0	0	0	1	1	2	**19**
5	9	3	5	0	0	0	1	1	0	**19**
6	20	1	0	0	0	0	1	0	0	**22**
7	16	6	2	1	0	0	3	0	0	**28**
8	10	2	1	1	0	0	1	0	0	**15**
9	4	3	0	2	0	0	0	0	0	**9**
10	35	3	1	0	0	0	0	0	1	**40**
11	87	10	2	0	0	0	11	0	1	**111**
12	90	6	0	0	0	0	1	0	1	**98**
13	105	9	2	1	0	0	2	0	1	**120**
14	157	17	1	6	0	0	1	0	0	**182**
15	112	12	4	0	0	0	6	0	4	**138**
16	78	4	3	0	0	1	3	0	1	**90**
17	78	7	2	0	0	1	5	2	2	**97**
18	28	0	3	0	0	0	1	0	2	**34**
19	27	2	1	0	2	0	0	0	0	**32**
20	29	2	0	0	0	0	1	1	0	**33**
Total	**980**	**102**	**29**	**11**	**3**	**2**	**42**	**7**	**16**	**1192**

Table 6 List of vertebrates from Square B-5 (1 x1 m), Trench B in Topogaro 1 (MNI)

Spit	bat	rodent	Sunidae	marsupial	dog	anoa	snake	lizard	fish	Total
1	4	2	0	0	1		0	0	1	**8**
2	1	1	0	0	0		1	1	0	**4**
3	15	2	1	0	0		1	0	0	**19**
4	3	1	0	0	0		1	1	1	**7**
5	9	3	1	0	0		1	1	0	**15**
6	4	1	0	0	0		1	0	0	**6**
7	6	1	2	1	0		3	0	0	**13**
8	3	2	1	1	0		1	0	0	**8**
9	1	3	0	2	0		0	0	0	**6**
10	15	3	1	0	0		0	0	1	**20**
11	32	4	2	0	0		3	0	1	**42**
12	32	1	0	0	0		1	0	1	**35**
13	38	2	2	1	0		2	0	1	**46**
14	62	5	1	6	0		1	0	0	**75**
15	35	4	4	0	0		6	0	4	**53**
16	22	2	3	0	0	1	3	0	1	**32**
17	21	2	2	0	0	1	5	2	2	**35**
18	8	0	3	0	0	0	1	0	2	**14**
19	8	2	1	0	1		0	0	0	**12**
20	10	1	0	0	0	0	1	1	0	**13**
Total	**329**	**42**	**24**	**11**	**2**	**2**	**32**	**6**	**15**	**463**

Table 7 List of vertebrates from Square A-1 (1 x1 m), Sector A in Topogaro 2 (NISP/MNI)

Taxa		**rodent(s)**		**rodent(L)**		**bat**		**Suidae**		**marsupial**		**anoa**		**fish**	
Layer	**cal BP**	**NISP**	**MNI**	**NISP**	**MNI**	**NISP**	**MNI**	**NISP**	**MNI**	**NISP**	**MNI**	**NISP**	**MNI**	**NISP**	**MNI**
1		52	8			7	4	1	1						
2		17	4			2	2								
3	**6000?**	6	1			0	0	1	1						
4	**10729 - 10561**	133	14			26	4								
5		111	12	1	1	26	4								
6	**16431 - 16048**	51	7			11	3								
7		75	17	2	2	7	4								
8	**15275 – 14921**	97	14	2	2	50	3							1	1
9	**26377 - 25958**	23	5			4	1								
10	**27864 - 27485**	19	5			0	0			1	1				
11	**29802 - 29212**											1	1		
Total		**584**	**87**	**5**	**5**	**133**	**25**	**2**	**2**	**1**	**1**	**1**	**1**	**1**	**1**

List of Figures

Figure 1 Major possible dispersal routes by early modern human via Wallacea into Sahul (Oceaania) and the major Pleistocene sites in Wallacea incuding Goa Topogaro

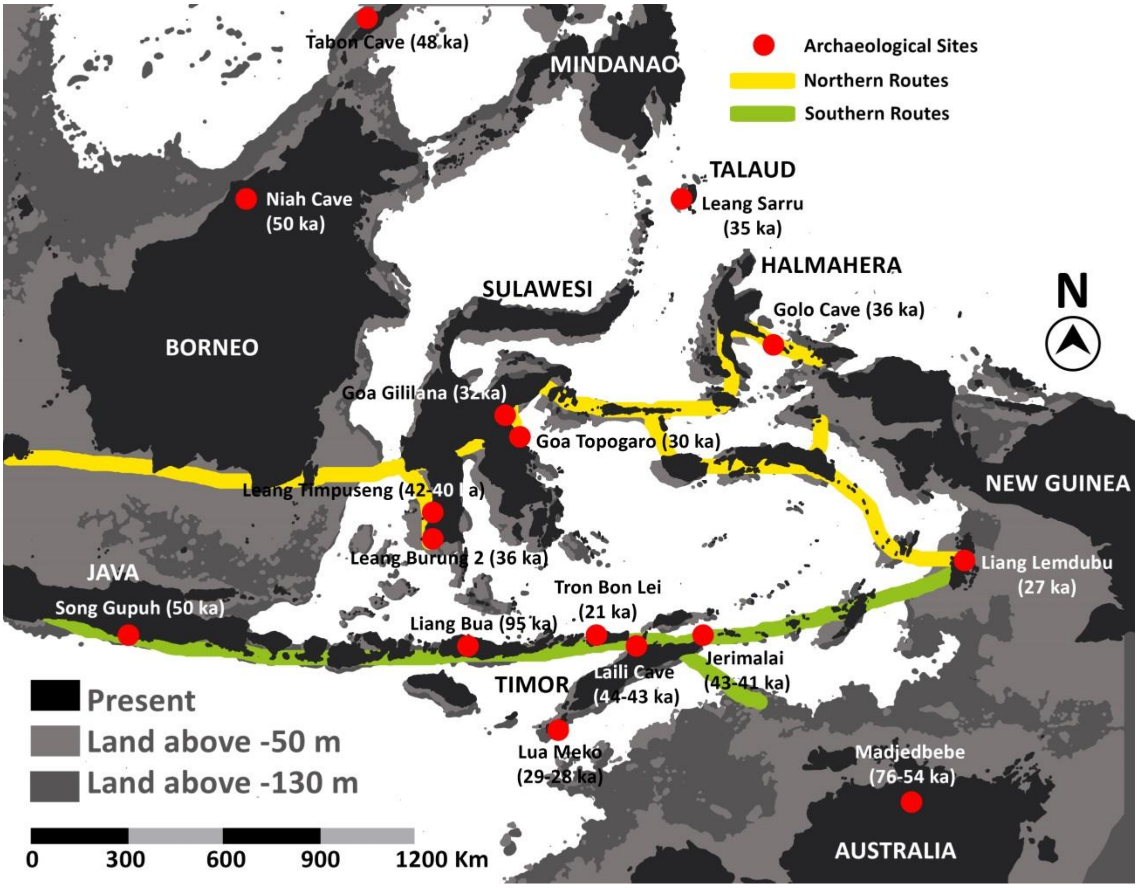


Figure 2 Current locations of the limestone hill and the Goa Topogaro complex with the nearest river and streams (A-C) that constitute possible lithic raw material sources where a variety of chert pebbles are available

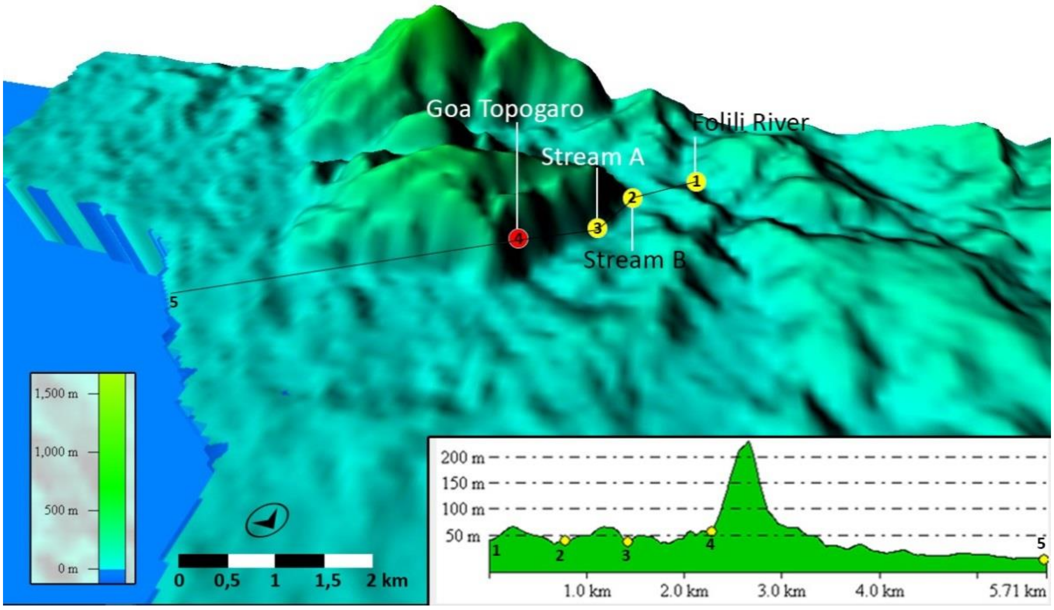


Figure 3 Floor Plan and Excavated Areas in Goa Topogaro 1 & 2

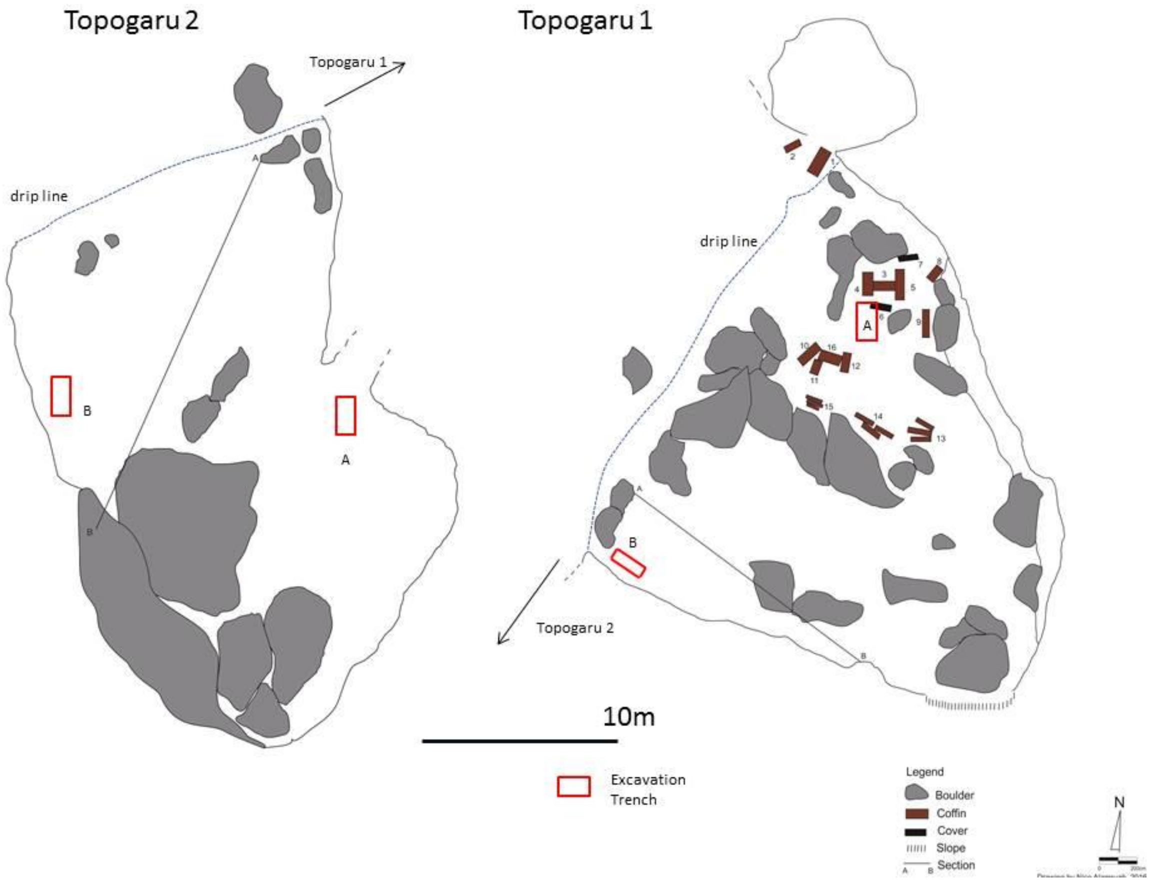


Figure 4 Stratigraphy of Trench B in Topogaro 1

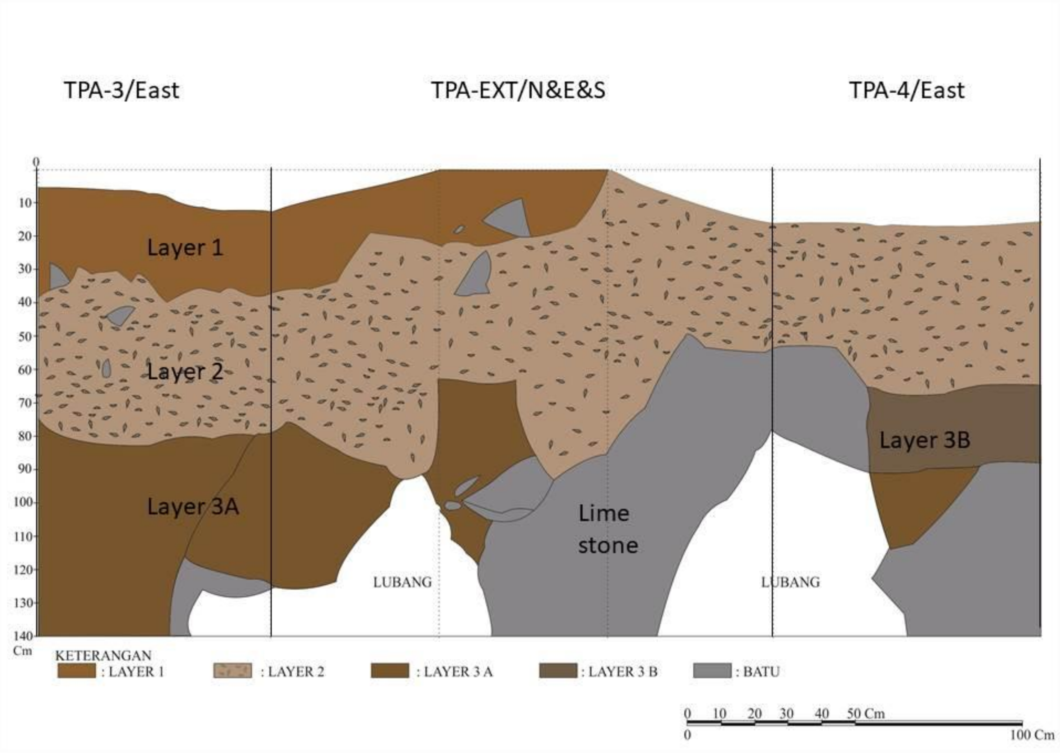


Figure 5 Stratigraphy and location of dated samples in Sector A, Topogaro 2

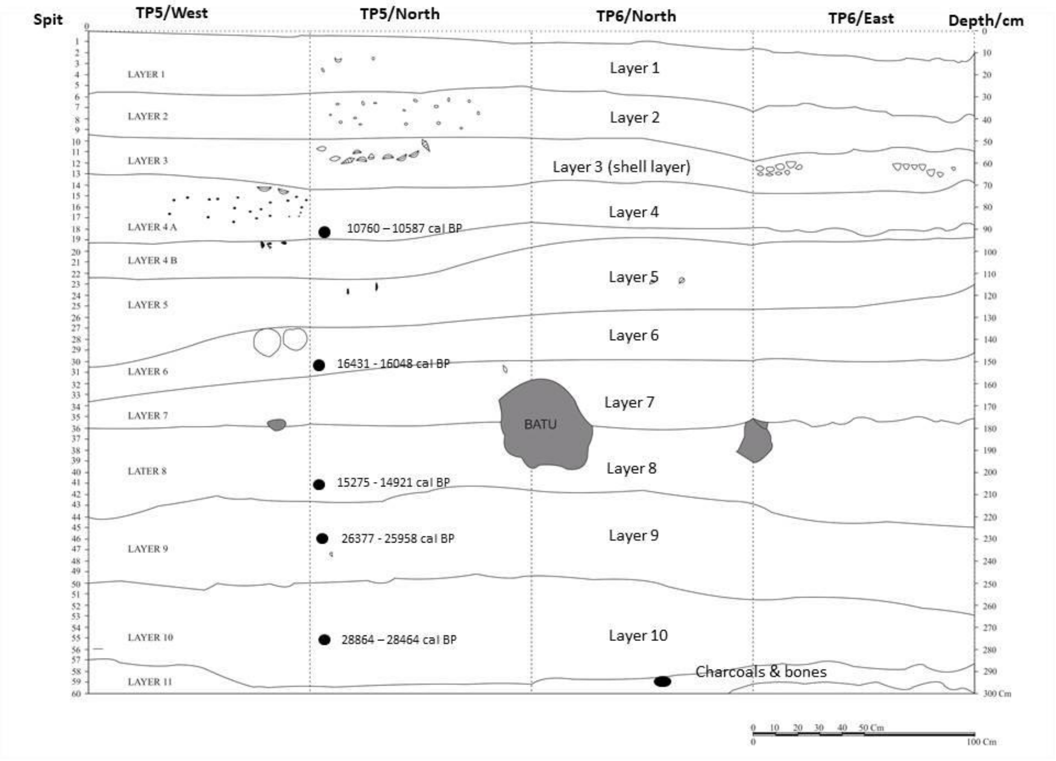


Figure 6 Modified and unretouched chert flakes with concave edges from Trench B in Topogaro 1

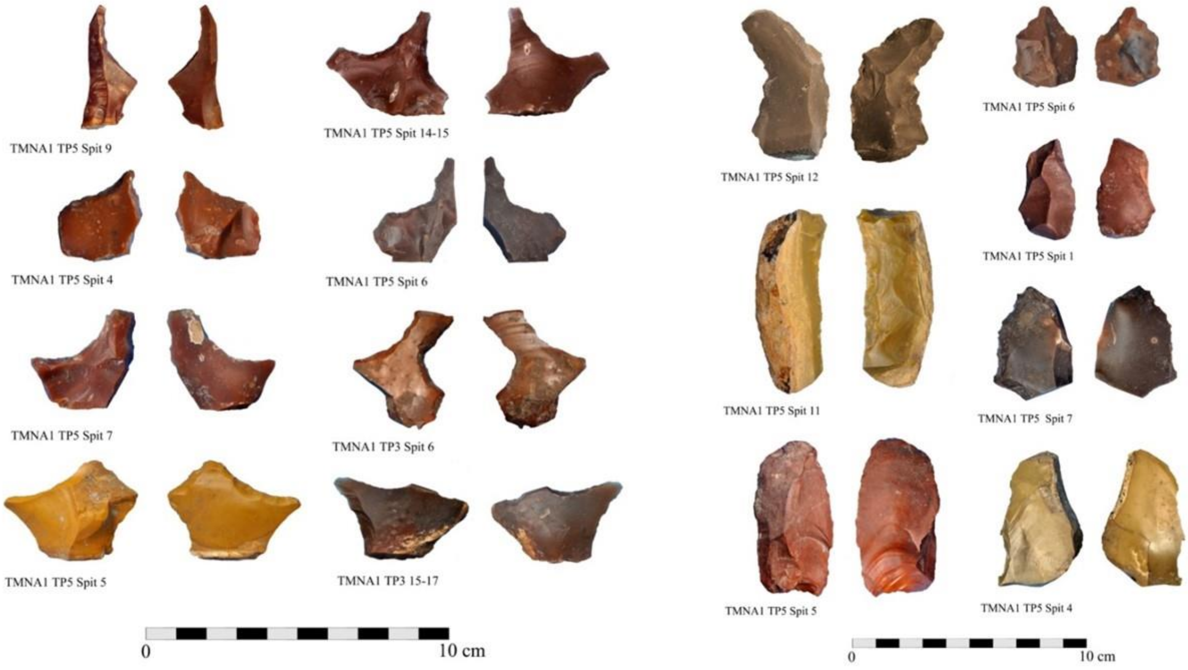


Figure 7 Bone tools: bipoints, unipoints, and spatula from Trench B, Topogaro 1 (Holocene level)

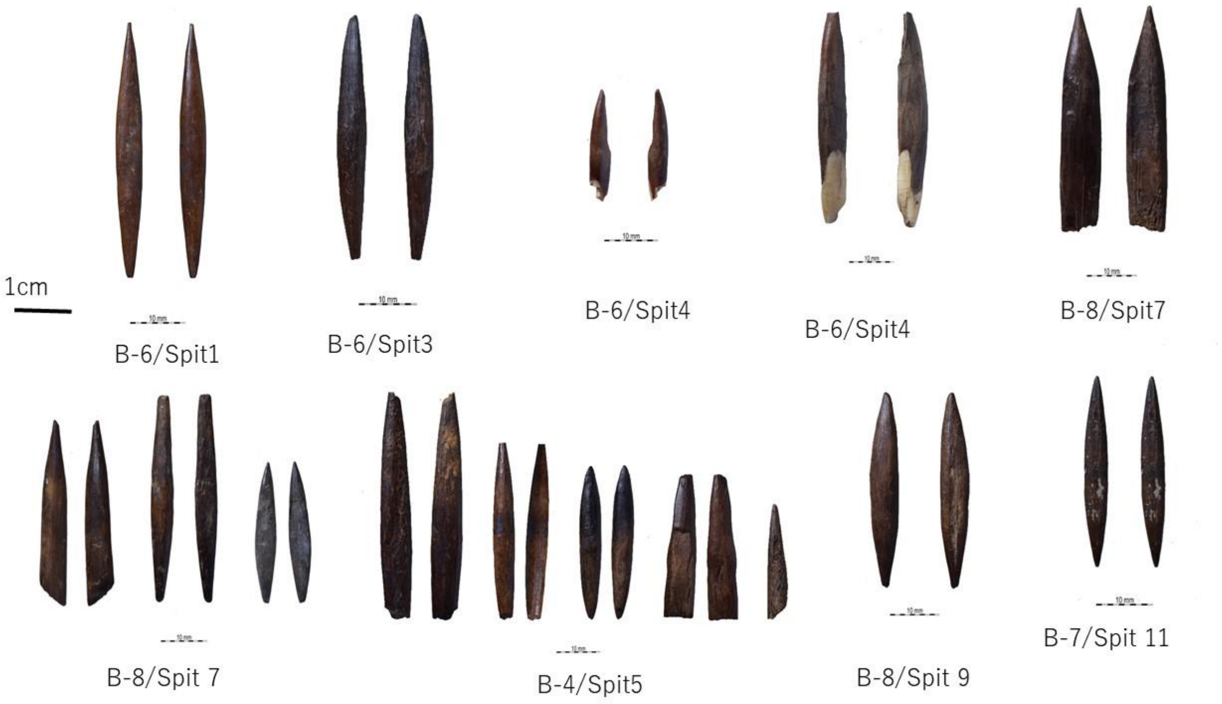
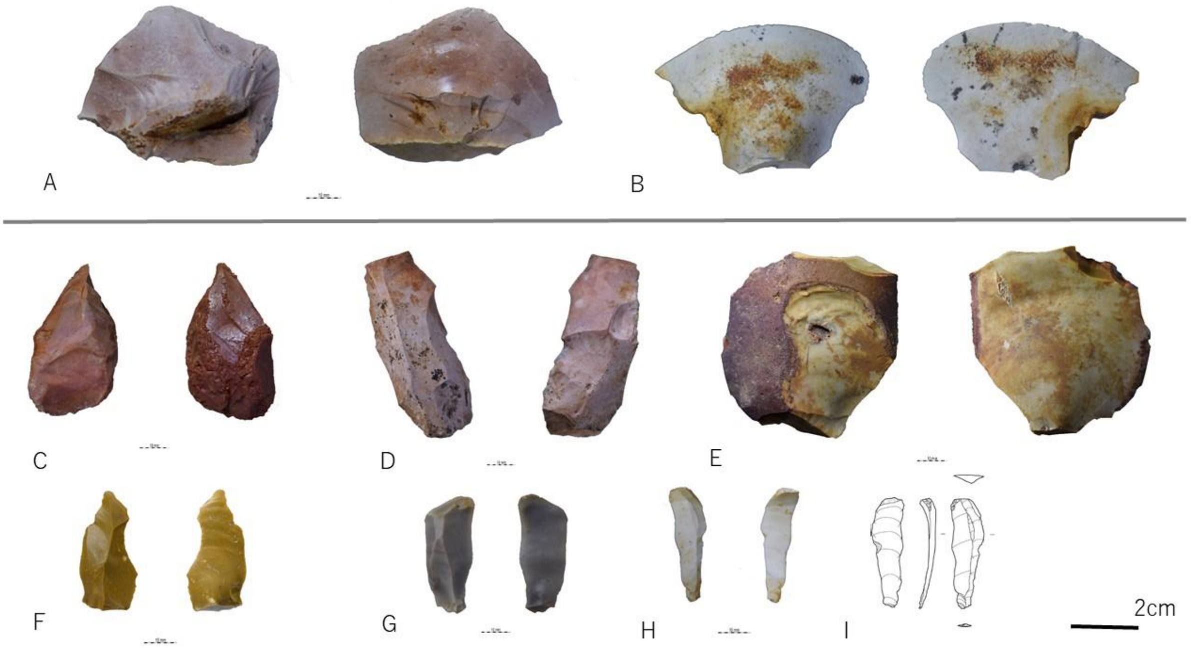
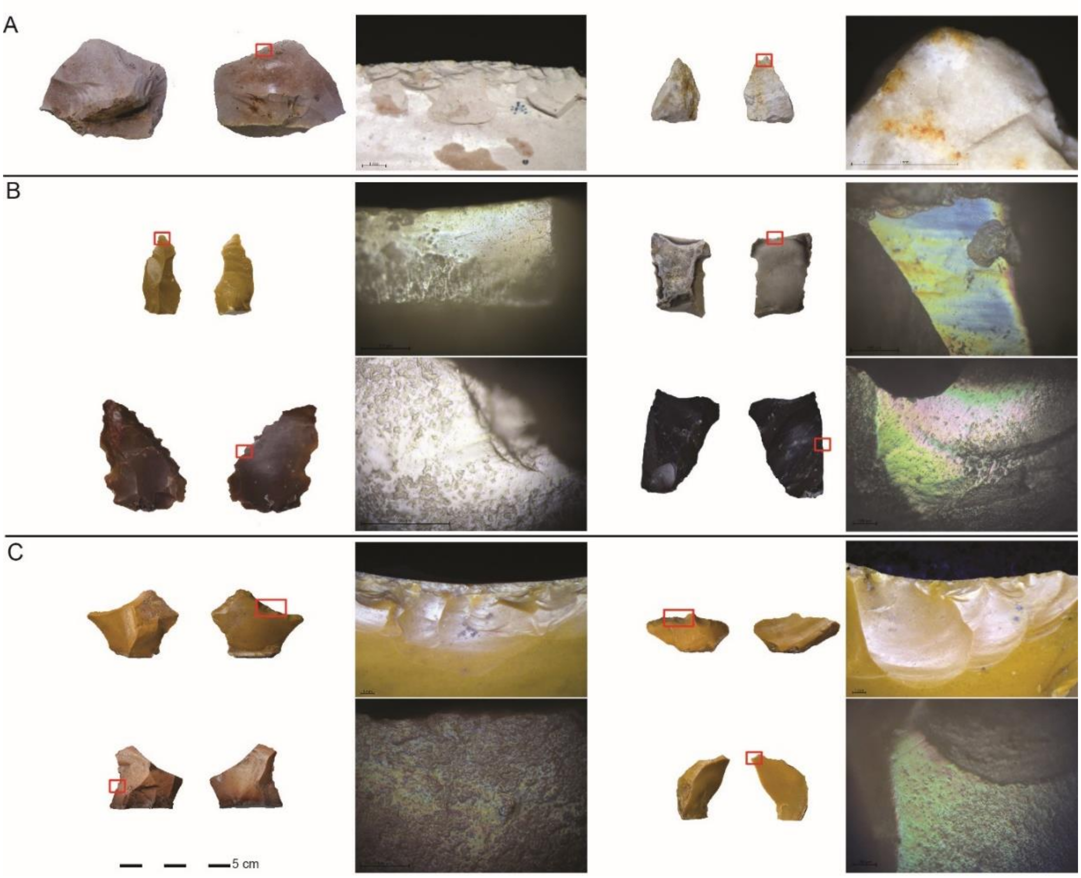


Figure 8 Pleistocene stone artefacts from Sector A in Topogaro 2



A-B: Complete flakes from Layer 10 (28,000 cal BP); C-E: bifacial retouched flakes F-G: blade-like retouched flake; H-I: possible micro-blade (C-H are from the middle layers dated 16000 cal BP ～)

Figure 9. Traces identified on artefacts from Topogaro 2



A. Pleistocene (29-25 kyr) . B. terminal LGM (16 kyr) . C. Holocene (9-5kyr)

Figure 10 Molluscs remains from Square 1/ Trench B in Topogaro 1 (NISP)

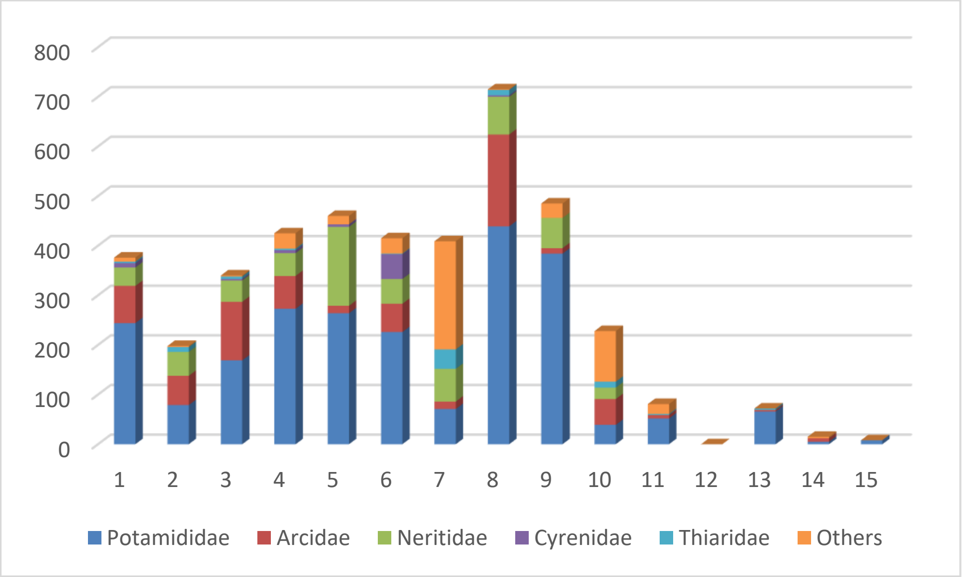
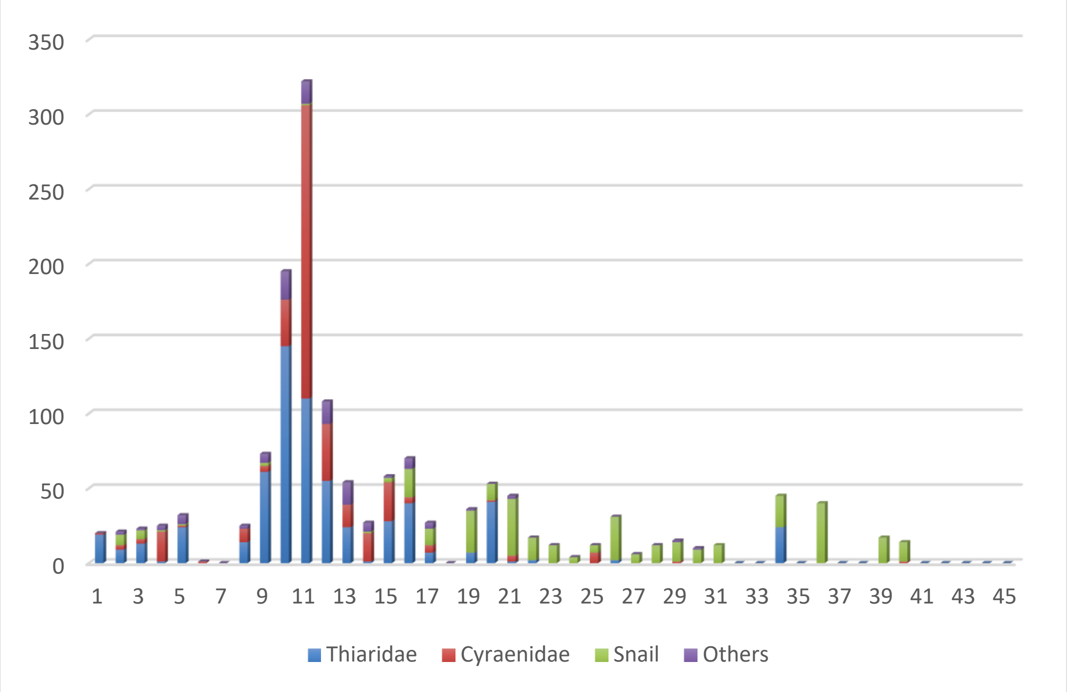


Figure 11 Temporal change of major molluscs remains from Sector A (1 x1 m) in Topogaro 2



Detecting the arrival of anatomically modern humans through use-wear analysis: results from Topogaro, Central Sulawesi from 30 thousand years ago

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Abstract

Recent excavations in Topogaro 1 and 2, Central Sulawesi produced an archaeological sequence dated to c. 30,000 years ago. The site is located in a key location for prehistoric movements of anatomically modern humans through Wallacea. We identified the lithic technology and functions of the assemblage through multi-stage use-wear analysis. Here we report on the first multi-stage use-wear analysis on lithic tools from the Late Pleistocene and Early Holocene of Central Sulawesi. Our results indicate a variety of activities conducted in the site throughout its occupation from c. 30,000 years ago. While most of the artefacts with use-wear traces were unmodified flakes typical for this region, a number of retouched tools provided indication of specialised functions and certain traits of modern behaviour like hafting, projectile use and plant processing. Our results provide an overview of the lithic technology and prehistoric activities in Topogaro. Analysis of the microscopic wear traces and residues indicates an increase in specialisation and tool modification at the end of LGM and in the early Holocene, particularly the use of composite tools and notched tools for plant processing. Overall, the early movements of people from Sunda through Wallacea involved gradual developments of technologies rather than abrupt appearance and disappearance of technologies.

Keywords: Lithic use-wear and residue analysis, Late Pleistocene technology, prehistoric technology, plant processing, Sulawesi

1. Introduction

Sulawesi Island is vital in understanding early anatomically modern human technology and culture in ISEA. Evidence of presence of AMH such as rock art at Leang Timpuseng (Aubert et al., 2014) and stone tools at Leang Burung 2, both dating to c. 40kya (Brumm et al., 2018) were identified in South Sulawesi. Recent investigations and radiometric dating of archaeological sites in Sahul and Wallacea suggest maritime interaction and colonisation by early modern humans as early as c. 65kya (Westaway et al., 2009; Kealy et al., 2016; Wood et al., 2016; Clarkson et al., 2017; Hawkins et al., 2017). The colonisation of Sahul through Island Southeast Asia (ISEA), specifically through Wallacea has been proposed either using Birdsell's southern or the northern route (Birdsell, 1977; Irwin, 1992; Chappell, 2000; Bird et al., 2005; O'Connor, 2010; Kealy et al., 2018). The Topogaro sites, located along the northern route (Kealy et al., 2018), provides evidence of human occupation from c. 30kya (Ono et al., in preparation). Use-wear analysis of tools from a sequence of c. 30kya until the Holocene reveals details on the technologies of AMH during periods of drastic environmental changes.

Lithic technology in ISEA is characterised by simple flake production, lack of secondary modification and elaborate core preparation and the use of amorphous unretouched flakes (Movius, 1944; Fox, 1978; Pope, 1985; Moore et al., 2007, 2009; Xhauflair and Pawlik, 2010; Pawlik, 2010, 2012; Brumm et al., 2010; Marwick et al., 2016; Fuentes et al., in press). This simple flaked tool technology can be observed throughout ISEA and continuously from the earliest assemblages assigned to modern humans like Jerimalai Cave in East Timor at 42,000 years ago (Marwick et al., 2016), until the Late Holocene and Neolithic. While techno-typological analysis has often failed to sufficiently explain this "typology dilemma" (Pawlik, 2009) of Southeast Asia's Palaeolithic, a number of use-wear studies have recently geared towards understanding the reasons behind the absence of formal tools in the region by assessing the functionality and technological capacity of the informal tools as well as their tool makers. A microscopic approach appears as a more suitable method for addressing current issues of ISEA's lithic technology (Haidle & Pawlik, 2009; Pawlik, 2010; Fuentes et al., 2019). For instance, composite tool making using unretouched chert implements and hafting using resinous adhesives were observed in the Terminal Pleistocene at Ille Cave in Palawan and at Niah Caves where stingray spines were attached to shafts (Barton et al., 2009; Pawlik, 2012; Piper, 2016). A bone fishing gorge was found in Bubog 1 rockshelter on the island of Ilin in Mindoro, Philippines dated to before c. 33kya (Pawlik et al. 2014; Pawlik & Piper, 2019). From the same site and the two neighbouring sites of Bubog 2 and Bilat Caves, edge ground shell adzes, directly dated to 7.2-7.4kya, respectively 9kya, and several thousand years before the appearance of ground stone adzes introduced by Austronesian-speaking migrants (Pawlik et al., 2015; Pawlik & Piper, 2019).

Still hypothetical remains the so-called bamboo or lignic industry proposed by various authors to explain the absence of formal lithic tools and a modern tool technology (Narr, 1966; Solheim, 1970; Pope, 1989). More recently, experimental use-wear analysis on stone tools has been applied to address the possibility of an organic- or plant-based tool technology and building of a use-wear database in general (Teodosio, 2006; Borel et al., 2014; Xhauflair 2014; Xhauflair et al., 2016). For the Holocene sites, use-wear studies were conducted to address the issue of continuity and exchange of technologies in cave sites during the Holocene period with the advent of agriculture (Mijares, 2007; Pawlik 2006; Lewis et al. 2008; Fuentes, 2015). Chert tools with glossy edges diagnostic for phytolith-rich plants were reported Leang Burung 2, South Sulawesi within layers dated to c. 35,000 BP (Brumm et al., 2018). This research is one component of an ongoing project (Ono et al., in preparation) to answer key questions in the arrival of humans in Central Sulawesi. Use-wear analysis was employed to identify stone tool functions from c. 30kya until Holocene.

2. Site Information

Topogaro 1 and Topogaro 2 are two adjacent cave sites located within S 02°06′55-4″ and E 121°19′58-5″ at an altitude of c. 90m asl and 3.5 km inland from the shoreline of Topogaro village at Goa (or Vafompogaro), Kacamatan Morowali Barat, Central Sulawesi. Topogaro 1 has a 20m floor to roof height while the north west facing mouth is about 17m in width and 24m in height. Topogaro 2 has a height of 12m, mouth opening of 12m (width) x 7m (height) facing north, and length of 24m. The first excavations were conducted in 2016 as part of a research initiative with the goal of finding evidence for the presence of AMH during the Late Pleistocene. Topogaro 1 was occupied beginning the Holocene period and was used as burial ground during from the Metal Age until the historical period. Topogaro 2 has stratigraphical sequence from c. 30,000 BP at the east section and c. 18,000 BP for the west section (Table 1; Figure 2) (Ono et al., *in preparation*).

[insert here Table 1. Radiocarbon dates associated with the samples.]

[insert here Figure 1. Location of Topogaro sites.]

[insert here Figure 2. Excavation units. A. Topogaro 1. B. Topogaro 2.]

3. Materials and methods

For this traceological analysis were 131 stone tools from the 2016 and 2017 excavations selected - 45 from Topogaro 1 and 86 from Topogaro 2, together 131 pieces (Ono et al., in preparation). The artefacts were made of limestone and chert. The samples from Topogaro 1 were selected from layers dated to c. 9500-9000 BP (beginning Spit 20, 100 cm from surface level) to 430-357 cal. BP in the uppermost layer (Spit 3, or 15 cm from the surface level) (Table 2) due to the presence of retouched tools with similar morphology observed throughout the sequence. For Topogaro 2, the samples include lithics from layers in the east section, dated to 28,864–28,464 cal. BP, and from Early Holocene dated to 10,760-10,587 cal. BP. For the west section, the lithics were recovered from layers dated to 18,149-17,850 cal. BP with the upper layers dated to 2,181-2,107 cal. BP (Table 1; Figure 2; Ono et al., in preparation). These were selected from both in situ and dry-sieved samples. The artefacts are currently stored at the Balai Arkeologi in Manado, North Sulawesi, Indonesia. Prior to use-wear, morphometric analysis of the samples was conducted to characterise the production techniques and blank selection, and to identify potentially used areas on the flakes (Vaughan, 1985; van Gijn, 1993).

Traceological analysis was conducted by optical low power and high power analysis (Semenov, 1964; Hayden et al., 1977; Keeley, 1980; Odell & Odell-Vereecken, 1980; Plisson, 1983; Vaughan, 1985). A PhenomWorld Scanning Electron Microscope and Energy Dispersive X-ray) was used for the assessment of observed residues. For low-power analysis we employed a Euromex NexiusZoom stereo-microscope with a magnification range between 6.7x-45x, while an Olympus BHMJ reflected-light microscope equipped with differential interference contrast attachment and long working distance lenses (110x, 220x, and 440x) for high-power microscopy. A Nikon D5300 with AmScope c-mount adapter and Canon G9 with Promicron adapter, respectively were used for microphotographic imaging. The photos were remotely captured and archived using the open source DigiCam Control software. Prior to analysis, the artefacts underwent cleaning in an ultrasonic bath with dishwashing liquid solution for three minutes, followed by a water bath in distilled water for approximately five minutes. The artefacts were soaked in 70% alcohol for three minutes before being laid out on paper towels and air dried. Prior to high-power microscopy, the artefacts were soaked for approximately one minute in 70% alcohol before being mounted on a cup-stage holder and attached with a tuck. Gloves were used during analysis to avoid contamination and smudging of the artefacts. Recording forms with 1:1 scale illustrations of the specimen were employed to mark the location of use-wear traces.

We identified the activities based on the inferred use for each tool. The categories include activities such as scraping, cutting, chiselling, grooving/drilling, hafted, percussion tools, chopping, multidirectional, undeterminable, and unused. The contact material types include soft, mid, hard, and traces that show mixed signals resulting in interpretation that these were used on soft-mid, mid-hard, and soft-hard. Tools with very limited traces were identified as undeterminable, and with no signals at all categorised as unused. We utilised interpretations per PUA to infer function of the artefact as a whole and sum of parts.

4. Results

4.1. Morphological analysis of stone tool samples

In Topogaro 1, we analysed 41 flakes and two cores coming from spits 5-17 (25-85cm from surface level). Thirty five flakes were identified as complete and mostly (24, 57%) showing distal feather termination, while the rest include hinge (n=2, 5%), plunging (n=1, 2%), and step (n=3, 7%). Retouched tips were also identified (n=5, 12%). Pronounced bulbs of percussion appear on 31 (74%) of the complete and proximal flakes, in seven cases (17%) they are less pronounced. The selection included 16 (38%) artefacts with notched retouching and one (2%) possessing a micronotch, the remaining 25 (60%) flakes were unretouched. Twenty six flakes (62%) have no cortex, 10 with less than 1/3 cortex coverage (24%), two have more than 1/3 and less than 2/3 (5%). Three flakes (7%) have more than 2/3 of the surface covered while one is a cortical flake (2%). The striking platforms of proximal and complete flakes (n=38) were categorised into cortical (n=2, 5%), plain (n=33, 79%), and prepared (n=3, 7%) (Table 2). The striking platform has a median width of 6.5mm and thickness of 16.2mm. Overall, the flakes are relatively small-sized with a median weight of 6.17gms and median dimensions of 39.0mm (length) by 31.4mm (width) by 8.6mm (height). Eighty five PUAs (Vaughan, 1985) were identified and categorised into straight (n=18, 21%), concave (n=27, 32%), convex (n=18, 21%), and irregular (n=22, 26%). The median working edge length is 29.1mm and the median edge angle is 53 degrees (Table 3).

In Topogaro 2, the samples were recovered from west chamber (TP1, TP5, TP6, and TP7; N= 60) and east chamber (TP3, TP4; N=22; Table 2; Figure 3). These are comprised of 79 flakes (96%) and three shattered fragments (4%). We identified sixty seven complete flakes (82%), eleven distal flakes (13%), and one a proximal flake (1%). For the complete and proximal flakes, Hertzian initiation was identified on 65 artefacts (79%), two bending (2%), and absent on 15 samples (medial-distal and shatters, 18%). Fifty is feather-terminated (61%), 16 with hinge (20%), 5 with plunging (6%), 6 with step (7%) while 2 retouched tip (2%), and 3 were classified as absent (4%). Majority of the bulbs of percussion was classified as pronounced (n=70, 85%), six has less pronounced (7%), while six display no remnants of the bulb (7%). Sixty one has plain striking platforms (74%), three with prepared (4%), and three with cortical (4%), and 15 without striking platform (18%). Forty four of the samples has no cortex (54%), 23 with <1/3 of the dorsal face covered (28%), six with $\geq$1/3 and <2/3 (7%), six with $\geq$2/3 <100% (7%), and three with fully covered dorsal faces (cortical flakes, 4%). We classified two samples as notched (2%) while 79 remained as unretouched blanks (96%), and 1 with micro notching (1%). The median dimensions is 39.7mm (length) x 30.0mm (width) x 10.6mm (thickness), while the median weight is 9.54gms. One hundred sixty PUAs were categorised into concave (n=35, 22%), convex (n=35, 22%), straight (n=29, 18%), and irregular (n=61, 38%). The median working edge length is 48mm and edge angle is 30.9 degrees (Table 3).

[insert here Figure 3. Stratigraphical contexts. A. Topogaro 1. B. Topogaro 2.]

[insert here Table 2. Summary of morphological analysis.]

[inset here Table 3. Measurements of lithic samples]

4.2. Use-wear analysis

4.2.1. Traces on potentially used areas

In Topogaro 1, scarring (n=127) was categorised into crescent (n=10, 8%), steep (n=29,%), break-shallow (n=21, 17%), and shallow (n=39, 31%) (Table 4). Twenty eight PUAs (15%) do not display any form of microscarring. Proximal scarring was categorised into crescent (n=10, 8%), feather (n=54, 42%), hinge (n=18, 14%), and step (n=28, 22%). Rounding was formed on 28 (33%) instances and absent on 58 PUAs (67%). These were categorised into slight (n=11, 13%), mid (n=13, %), and intensive (n=4,%). The polishes were categorised into generic weak (n=25, 18%), smooth-pitted (n=19, 14%), and well-developed (n=26, 19%). Bright spots were absent and 69 edges (50%) have no polish. Diagonal striations were present on 10 PUAs (11%) while transversal type was identified on six PUAs (6%). Parallel striations was identified on three samples (3%) while it is absent on 74 PUAs (80%). Four PUAs have micro-notches while notched edges are present on 14 working edges. Secondary row-edge scarring was identified on 24 tools and absent on 54 samples. Possible residues were present on five samples. Reddish and blackish residues were identified on 15 instances (18%). One artefact has traces of exposure to heat.

For Topogaro 2, in low power analysis, distal scarring (N=214) were categorised into crescent (n=10, 5%), steep (n=34, 16%), break shallow (n=35, 16%), and shallow (n=40, 19%) (Table 4). It is absent on 95 PUAs (44%). While for proximal scars, 66 is feather type (31%), 17 is hinge (8%), and 38 (18%) were classified as step. It is absent on 82 PUAs (38%). Rounding was identified on 36 instances and were grouped into slight (n=18, 11%), mid (n=11, 7%), and intensive (n=7, 4%), while 133 PUAs (79%) have no rounding. For high power analysis, polish formation was categorised as generic weak polish (n=25) (14%), smooth-pitted (n=18, 10%), and well-developed types (n=18, 10%) (Vaughan, 1985), while no bright spots were identified. Polishes are absent on 124 PUAs (67%). The striations were classified as parallel (n=12, 7%), transversal (n=9, 5%), and diagonal (n=12, 7%) while 147 PUAs have no striations (82%. Five tools has micro-notches (3%), 14 with notches (8%), and one with retouch (1%). It was absent on 142 PUAs (82%). Possible residues were present on 17 PUAs (9%) and were identified as possible plant remains. Traces of heat exposure was observed on 24 (13%) samples. This is significantly different from Topogaro 1 where heat exposure is almost completely absent. Blackish and reddish residues account for 43 (32%) samples, however this potentially includes post-depositional mineral deposits like manganese oxide or fungal growth.

[insert here Table 4. Summary of use-wear analysis.]

[insert here Table 5. Identification of function per working edge/ PUA.]

4.3. Prehistoric tool functions

4.3.1. Inferred activity per tool through time

For Topogaro 1, twenty tools were identified as solely used for scraping action. One tool was used on both scraping and grooving actions. Two were identified as possibly hafted. While another two were inferred to be used in a chopping action. Two artefacts were inferred to have been possibly hafted. Two tools with traces of multifunctional use-both cutting and scraping motion, while one artefact has traces indicating scraping and grooving. Five tools have been possibly used in scraping but limited traces also indicate undeterminable action.

Five tools are unused and four are undeterminable while one was identified as undeterminable or unused. Contact with hard materials were identified on 15 artefacts. One has contact with mid-soft, five with mid-hard, and six with soft-hard. Traces of contact that show traces with soft, mid, or hard materials leaning towards undeterminable classification were also identified (n=3). Six artefacts have undeterminable traces while five were unused, while one is either unused or undeterminable (Table 6).

In Topogaro 2, eighteen tools were identified in scraping while one has traces of both cutting and scraping, indicating multidirectionality. One artefact was used in chopping motion, four on grooving and three possibly showing traces of being possibly hafted and one with multifunctional (cutting/ scraping). A combination of activities were also identified – one tool used in scraping and chiselling, two with traces of scraping and possibly hafted. We identified traces on two tools that are not in high resolution and were identified as both scraping and possibly undeterminable. Thirty four were unused, 13 were undeterminable, and three which are either undeterminable/ unused. For the contact materials, six were identified as soft and 11 as hard. Traces that are attributable to several contact materials were also identified – soft-mid (n=3), mid-hard (n=4), and soft-hard (n=4). Three tools were possibly hafted, while 34 were unused, 17 with very limited traces that remained undeterminable (Table 6).

[insert here Figure 4. Chert artefacts from the Late Pleistocene in Topogaro 2.]

[insert here Figure 5. Stone tools made from limestone recovered during the Late Pleistocene in Topogaro 2.]

[insert here Table 6. Interpretation of tool function per tool.]

[inset here Table 7. Function per tool throughout the stratigraphy.]

4.3.2. Highlights of inferred activities

At the earliest occupation phase time, relatively large complete flakes made of chert and smaller limestone flakes were manufactured and used without any further retouching (Figure 6.B). The chert flakes have pronounced bulbs of percussion and were most likely produced through hard hammer percussion. These were recovered in context with animal bones (Figure 6.A). Distal-step scars with second-edge-rows (Vaughan, 1985) on the ventral face point to a contact with hard material through transversal motion. Two triangular limestone flakes with step scars on their tips were also recovered from this layer. Rounding and feather-terminated scars were formed on the tip of these tools. Step scarring was formed on one face with limited development of polishes and absence of striations. The polishes were formed on the upper part of the topography, without fully developing into undulating surfaces. The traces indicate processing of hard materials with transversal action. The artefact also displays residues appearing as globular and organic features. Cores were recovered together with these flakes. This type of technology not only shows the utilisation of limestone and silicified chert as raw material but also the intentional preparation of cores. Production was conducted with the use of soft hammer, similar with production of blade due to the narrow bulb of striking platform remnant and due to the less pronounced bulbs of percussion. Recent excavations shows the presence of production of smaller blade-like flakes with the use of chert.

Within the layer dated to c. 18,000 cal. BP during the later stage of the Last Glacial Maximum, a retouched tool with denticulated edges was recovered (TPGR2-UW41). It is a unifacially modified triangular tool with point tip made from red jasper/ radiolarite. Hard hammer percussion technique was employed in the production of this tool. The researchers conducted initial tests/ experiments to identify possible sources of chert from the area and conducted experiments using this material. The removals were initiated from the ventral face using hard hammer direct percussion technique. Impact scars and step terminated secondary row scarring were identified on the tip of the tool (Figure 6.C). The negatives were initiated from the ventral face. We produced replicas of this artefact using direct percussion with pebble hammerstones (~5cm in diameter). linear impact traces (Dockall, 1997) shows parallel orientation on the stone tool were identified on two spots on the stone tool showing the same orientation. These traces indicate longitudinal motion that involves impact. The striations on one point (the one closest to the proximal section) also shows multidirectional and leaning towards diagonal towards the left of dorsal. The traces show impact on sections toward the distal face and at the medial part on the ventral face. Several artefacts recovered within layers dated to 18,000 cal. BP display glossy parts along the edges similar to sickle gloss. Unretouched edges and tips exhibit scarring and multidirectional, dominantly diagonal and transversal striations . The highly reflecting flat polishes confirm contact with silica-rich grassy plants. Starch grains were found within the proximal base in one of the tools (TPGR2-UW81). These are scattered in the proximal base of the tool and possibly associated with the plant processing (Figure 6.C). Although the sample size is limited, the traces indicate intensive processing of phytolith-rich plants at Topogaro and are qualitatively comparable with results from other studies in ISEA in terms of plant polish. The samples with the most developed polish are unretouched flakes with acute working angles. From the direction of striations and the location of edge wear and polish, a transverse oriented activity like scraping or heckling can be assumed, similar to activities observed in Leang Sarru on Talaud Island that were aimed at fibre extraction (Fuentes et al., *under review*).

4.3.3. Notched scrapers and bone points

Unifacially retouched tools were recovered from the early Holocene in Topogaro 1, c. 9,000 cal. BP (Spit 15, 75 cm from surface level). This resulted in steep working angles on the identified working edges (N=92, median=54 degrees). Retouching was done through direct percussion and/or pressure flaking while creating concave working region designed for transversal actions. Shallow feather-terminated scars were formed through pressure flaking from a unifacial orientation. The working edges show contact with hard material on low power microscopy but no clear indications at higher magnifications (Figure 6.E). An ongoing experimental program to address use in the site in Central Sulawesi shows that the yellowish chert used in the production of these tools are available in the current river location near the site. Replicas of notched tools were produced through direct percussion technique initiated from the ventral face. The steep angle of these tools shows that it was intended to be used in scraping motion with the initiation point of the retouch as the contact face or rake (Figure 6.E). The retouched tools were recovered in the same context with bone points.

[insert here Figure 6. Retouched flake with microlinear impact traces that shows longitudinal orientation of stone tools from 18,000 BP.]

[insert here Figure 7. Unretouched tools used in processing organic materials, especially phytolith-rich plants forming flat polishes with striations.]

[insert here Figure 8. Notched tools from the Holocene in Topogaro 1 associated with bone tools.]

[insert here Figure 8. Possibly hafted retouched tools recovered during the Holocene in Topogaro 1.]

5. Discussion

Topogaro 2 was occupied beginning c. 30,000 BP until the historical period. The adjacent site, Topogaro 1 was occupied since the Early Holocene (9,500-9,000 years ago), and with the same context to retouched lithics and bone tools. We observed that plant processing was appeared as an activity during the LGM. There was no deliberate processing of plants observed at 30,000 BP. Insights into human behaviour and subsistence in the Topogaro sites can be inferred from use-wear analysis. The two sites show continued sequences in relation to lithic production and use – the older Topogaro 2 spanning from 30,000 BP until the historical period. Technologies made from organic materials, such as bones and plants, were being produced based on the use-wear traces and residues. We have identified wear traces associated with retouching and production of composite tools. Other than chert tools, the inhabitants of the cave also produced limestone artefacts. The processing of plants was observed in the site, either for the production of plant-based equipment like cord or nets and/or food processing. The observed residues point to the working of fibrous plant materials and processing of bones for the production of points. The flaked stone tools were used as is and with no modification. The production of organic technology made from osseous materials began during the Holocene in Topogaro 1, associated with notched tools.

Linear impact traces have been variously mentioned as an indicator for projectile point use (e.g. Fischer et al., 1984; Geneste & Plisson 1993; Dockall, 1997; Lombard 2005; Pawlik & Thissen 2011, 2017; Sano, 2012; Lazuen, 2014; Tomasso et al., 2015; Kufel-Diakowska et al., 2016; Rots, 2016). However, such traces have rarely been mentioned in use-wear studies in ISEA with the exception of the traceological analysis of stone tools from the terminal Pleistocene layers of Ille Cave in Palawan Philippines, where a triangular flake was used as projectile point showing impact traces, parallel striations and resinous hafting residues (Pawlik, 2012). Additional evidence is needed to understand to what extent stone tools were utilised as implements for multicomponent tools, the nature of shafts and bonding components such as resin. The production and use of these tools may also provide clues on certain aspects of technological and cognitive development that has been often overlooked in the Pleistocene lithic assemblages from ISEA.

6. Conclusion

Through use-wear analysis, we identified evidence for human occupation beginning from c. 30kya in Topogaro, Central Sulawesi. Further investigations in the area would lead to identification of prehistoric activities beyond 30kya. More samples will provide a clearer picture of the prehistoric technology and tradition in Central Sulawesi. Comparison with other sites in the area shows that there was a recurring tradition of processing plants regardless of presence or absence of large mammals, as in the case of Topogaro wherein plant polishes and remains were also observed. Overall, this study shows that there was early human presence in Central Sulawesi at around 30,000 BP. A diachronic approach to studying lithic functions in the past shows a great deal in understanding not just certain aspects of the role of these technology in the past, but with the complexity of the interaction of cultural traits with environmental changes.

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Table 1. Radiocarbon dates associated with the samples.

Site	Location	Cave wall	Spit	Material	ID	Date	Cal BP (1SD)	Cal BP (2SD)
Topogaro1	TP1	North	3	charcoal	TKA-17032	297 ± 18 BP	426 -393 cal BP	430-357 cal BP
	TP1	North	7	charcoal	TKA-17033	603 ± 24 BP	612 - 588 cal BP	652-580 cal BP
	TP1	North	7	charcoal	TKA-17033	603 ± 24 BP	612 - 588 cal BP	652-580 cal BP
	TP2	North	16	charcoal	TKA-16905	8099 ± 29 BP	9033 - 8998 cal BP	9094 - 8992 cal BP
	TP2	North	11	shell	TKA-17108	8486 ± 23 BP	9134 - 9024 cal BP	9211 - 9005 cal BP
	TP2	North	20	shell	TKA-17109	8752 ± 24 BP	9462 - 9407 cal BP	9492 - 9367 cal BP
Topogaro2	TP1	East	19	charcoal	TKA-17034	9454 ± 30 BP	10734 - 10657 cal BP	10760 - 10587 cal BP
	TP1	East	48	charcoal	x	x	x	x
	TP1	East	55	charcoal	TKA-16906	24642 ± 62 BP	28781 - 28582 cal BP	28864 - 28464 cal BP
	TP2	East	11	human tooth	TKA-17404	1900 ± 20	BP 1871 - 1825 cal BP	1898 -1812 cal BP
	TP3	West	6	charcoal	TKA-17035	2274 ± 19 BP	2343 - 2310 cal BP	2347 - 2306 cal BP
	TP3	West	17	charcoal	TKA-17036	2274 ± 20 BP	2343 - 2310 cal BP	2348 - 2305 cal BP
	TP3	West	27	charcoal	TKA-17037	2160 ± 20 BP	2155 - 2124 cal BP	2181 - 2107 cal BP
	TP3	West	31	charcoal	TKA-16907	2234 ± 16 BP	2240 - 2181 cal BP	2259 - 2158 cal BP
	TP3	West	8	shell	x	x	x	x
	TP3	West	18	shell	TKA-17110	5895 ± 20 BP	6335 - 6275 cal BP	6381 - 6261 cal BP
	TP3	West	25	shell	TKA-17111	6823 ± 20 BP	7386 - 7316 cal BP	7409 - 7283 cal BP
	TP3	West	44	shell	TKA-17112	15204 ± 35 BP	18070 - 17920 cal BP	18149 - 17850 cal BP
	TP3	West	52	shell	TKA-16903	6317 ± 20 BP	6817 - 6735 cal BP	6861 - 6696 cal BP
	TP3	West	60	shell	x	x	x	x
Topogaro 2	TP5	West	1	human tooth	TKA-17408	249 ± 19 BP	306 - 287 cal BP	310 - 281 cal BP
Topogaro 4	Surface			Cassis shell	TKA-16904	4607 ± 17 BP	4843 - 4807 cal BP	4870 - 4784 cal BP
Topogaro 7	TP1	North	14	charcoal	TKA-17415	8377 ± 29 BP	9466 - 9404 cal BP	9476 - 9371 cal BP
	TP2	South	3	charcoal	TKA-17416	1540 ± 19 BP	1517 - 1494 cal BP	1523 - 1452 cal BP
	TP2	South	6	Conus ring	TKA-17411	2153 ± 34 BP	1798 - 1698 cal BP	1846 - 1634 cal BP
	TP2	South	6	charcoal	TKA-17417	128 ± 24 BP	118 - 68 cal BP	151 cal BP(45.8%)57 cal BP

All radiocarbon dates from Ono et al., in preparaton.

Table 2. Summary of morphological analysis.

Trench		Topogaro 1	Percentage	Topogaro 2	Percentage	Total Count	Total Percentage
Type	Flake	40	95%	79	96%	119	96%
	Shatter	0	0%	3	4%	3	2%
	Core	2	5%	0	0%	2	2%
	Count	42	100%	82	100%	124	100%
Flake Completeness	Complete	33	79%	67	82%	100	81%
	Split	0	0%	0	0%	0	0%
	Distal	2	5%	11	13%	13	10%
	Medial	1	2%	0	0%	1	1%
	Proximal	4	10%	1	1%	5	4%
	Absent	2	5%	3	4%	5	4%
	Count	42	100%	82	100%	124	100%
Type of Flake Initiation	Hertzian	38	90%	65	79%	103	83%
	Bending	0	0%	2	2%	2	2%
	Bipolar	0	0%	0	0%	0	0%
	Absent	4	10%	15	18%	19	15%
	Count	42	100%	82	100%	124	100%
Type of Flake Termination	Feather	24	57%	50	61%	74	60%
	Hinge	2	5%	16	20%	18	15%
	Plunging	1	2%	5	6%	6	5%
	Step	3	7%	6	7%	9	7%
	Retouched	5	12%	2	2%	7	6%
	Absent	7	17%	3	4%	10	8%
	Count	42	100%	82	100%	124	100%
Bulb of percussion	Pronounced	31	74%	70	85%	101	81%
	Less pronounced	7	17%	6	7%	13	10%
	Absent	4	10%	6	7%	10	8%
	Count	42	100%	82	100%	124	100%
Type of striking platform	Plain	33	79%	61	74%	94	76%
	Prepared	3	7%	3	4%	6	5%
	Cortical	2	5%	3	4%	5	4%
	Absent	4	10%	15	18%	19	15%
	Count	42	100%	82	100%	124	100%
Cortex	0%	26	62%	44	54%	70	56%
	<1/3	10	24%	23	28%	33	27%
	>1/3 to <2/3	2	5%	6	7%	8	6%
	>2/3 to <100%	3	7%	6	7%	9	7%
	100%	1	2%	3	4%	4	3%
	Count	42	100%	82	100%	124	100%
Retouch type	Notched	16	38%	2	2%	18	15%
	Micro-notched	1	2%	1	1%	2	2%
	Absent	25	60%	79	96%	104	84%
	Count	42	100%	82	100%	124	100%
PUA	Concave	27	32%	35	22%	62	25%
	Convex	18	21%	35	22%	53	22%
	Straight	18	21%	29	18%	47	19%
	Irregular	22	26%	61	38%	83	34%
	Count	85	100%	160	100%	245	100%

Table 3. Measurements of samples.

Topogaro 1	Metrical attributes	Minimum	1st Quartile	Median	3rd Quartile	Maximum	Mean	Standard Deviation
	Weight (gm), N=42	1.95	4.28	6.17	13.56	45.22	10.60	10.04
	Max Length (mm)	18.9	27.9	33.1	39.0	70.2	35.2	11.4
	Max Width (mm)	13.8	23.3	31.4	36.4	67.6	31.8	12.1
	Max Thickness (mm)	4.6	6.6	8.6	11.2	21.5	9.4	3.8
	Striking Platform Thickness (mm), N=38	2	4.5	6.5	8.4	13.9	6.7	2.9
	Striking Platform Width (mm)	7.4	11.3	16.2	19.4	32.4	16.5	6.3
	Edge Length (mm), N=85	7.9	21.9	29.1	34.5	84.9	30.6	13.8
	Edge Angle (deg)	16	40	53	70	80	53	17
Topogaro 2	Metrical attributes	Minimum	1st Quartile	Median	3rd Quartile	Maximum	Mean	Standard Deviation
	Weight (gm), N=82	0.68	4.96	9.54	15.01	46.94	12.43	10.24
	Max Length (mm)	13.6	32.0	39.7	46.7	70.6	40.1	11.3
	Max Width (mm)	3.0	23.7	30.0	38.0	82.0	31.1	11.5
	Max Thickness (mm)	4.4	8.1	10.6	13.5	27.3	11.2	4.1
	Striking Platform Thickness (mm), N=67	1.0	4.7	7.2	9.4	17.1	7.3	3.9
	Striking Platform Width (mm)	3.5	10.9	15.2	22.6	53.6	17.4	10.3
	Edge Length (mm), N=160	10.4	23.9	30.9	37.3	80.6	31.7	12.2
	Edge Angle (deg)	14.0	36.0	48.0	64.0	88.0	48.9	17.4

Table 4. Summary of use-wear analysis.

Use-wear category	Type	Topogaro 1	Percentage	Topogaro 2	Percentage	Total Count	Total Percentage
Distal scarring	Crescent	10	8%	10	5%	20	6%
	Steep	29	23%	34	16%	63	18%
	Break-shallow	21	17%	35	16%	56	16%
	Shallow	39	31%	40	19%	79	23%
	Absent	28	22%	95	44%	123	36%
	Frequency	127	100%	214	100%	341	100%
Proximal scarring	Crescent	10	8%	10	5%	20	6%
	Feather	54	42%	66	31%	120	35%
	Hinge	18	14%	17	8%	35	10%
	Step	28	22%	38	18%	66	19%
	Absent - distal scars	20	15%	82	38%	102	30%
	Frequency	130	100%	213	100%	343	100%
Rounding	Slight	11	13%	18	11%	29	11%
	Mid	13	15%	11	7%	24	9%
	Intensive	4	5%	7	4%	11	4%
	Absent - rounding	58	67%	133	79%	191	75%
	Frequency	86	100%	169	100%	255	100%
Polish	Generic Weak	25	18%	25	14%	50	15%
	Smooth-pitted	19	14%	18	10%	37	11%
	Well-developed	26	19%	18	10%	44	14%
	Bright spots	0	0%	0	0%	0	0%
	Absent - polishes	69	50%	124	67%	193	60%
	Frequency	139	100%	185	100%	324	100%
Striations	Parallel	3	3%	12	7%	15	5%
	Transversal	6	6%	9	5%	15	5%
	Diagonal	10	11%	12	7%	22	8%
	Multidirectional	0	0%	0	0%	0	0%
	Absent - striations	74	80%	147	82%	221	81%
	Frequency	93	100%	180	100%	273	100%
Retouch	Micro-notch	4	4%	5	3%	9	3%
	Retouched	0	0%	1	1%	1	0%
	Microretouch-flat	0	0%	0	0%	0	0%
	Notched	14	15%	14	8%	28	10%
	Multiple scarring-clarify wit	24	25%	11	6%	35	13%
	Absent - retouch	54	56%	142	82%	196	73%
	Frequency	96	100%	173	100%	269	100%
Possible residues	Plant Remains/ Residues	5	6%	17	9%	22	8%
	Reddish	1	1%	7	4%	8	3%
	Blackish residues/ Possible	15	18%	36	19%	51	19%
	Burnt	1	1%	24	13%	25	9%
	Absent - residues	62	74%	101	55%	163	61%
	Frequency	84	100%	185	100%	269	100%

Table 5. Summary of inferred activities in the Topogaro.

Activity	**Topogaro 1**	**Percentage**	**Topogaro 2**	**Percentage**
Scraping	20	48%	18	22%
Chopping	2	5%	1	1%
Grooving	0	0%	4	5%
Possibly hafted	2	5%	3	4%
Cutting	0	0%	0	0%
Scraping/ scraping	2	5%	1	1%
Scraping/ grooving	1	2%	0	0%
Scraping/ chiselling	0	0%	1	1%
Scraping/ possibly hafted	0	0%	2	2%
Scraping/ undeterminable	5	12%	2	2%
Undeterminable/ unused	1	2%	3	4%
Unused	5	12%	34	41%
Undeterminable	4	10%	13	16%
Total	**42**	**100%**	**82**	**100%**
Contact Material	**Topogaro 1**	**Percentage**	**Topogaro 2**	**Percentage**
Soft	0	0%	6	7%
Hard	15	36%	11	13%
Soft-mid	1	2%	3	4%
Mid-hard	5	12%	4	5%
Soft-hard	6	14%	4	5%
Soft/ undeterminable	1	2%	0	0%
Soft-mid/ undeterminable	1	2%	0	0%
Hard/ undeterminable	1	2%	0	0%
Undeterminable	6	14%	14	17%
Unused	5	12%	34	41%
Unused/ undeterminable	1	2%	3	4%
Possibly hafted	0	0%	3	4%
Total	**42**	**100%**	**82**	**100%**

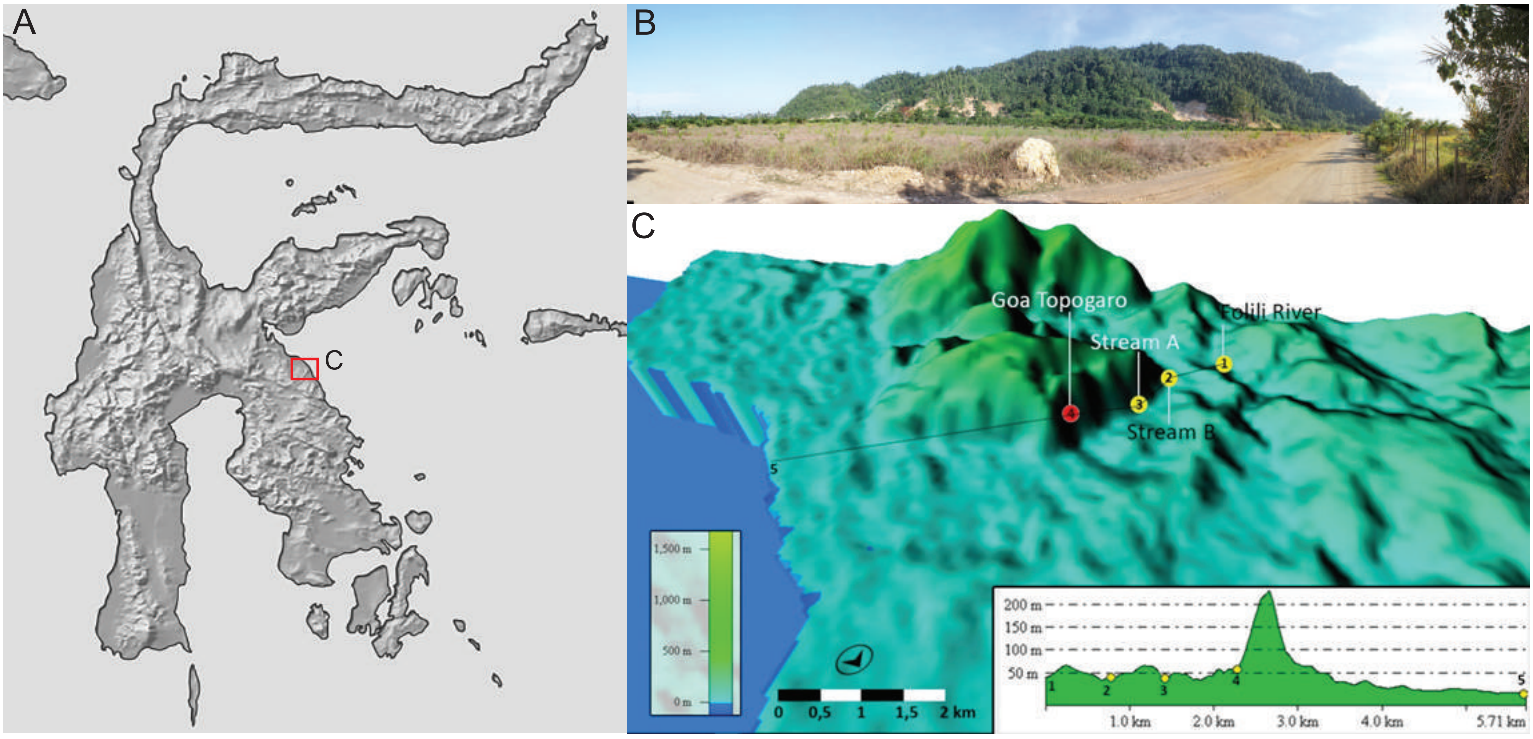

A
C
B
C
Goa Topogaro
Folili River
Stream A
Stream B
1
2
3
4
5
1,500 m
1,000 m
500 m
0 m
0
0,5
1
1,5
2 km
200 m
150 m
100 m
50 m
1.0 km
2.0 km
3.0 km
4.0 km
5.71 km

Figure 1

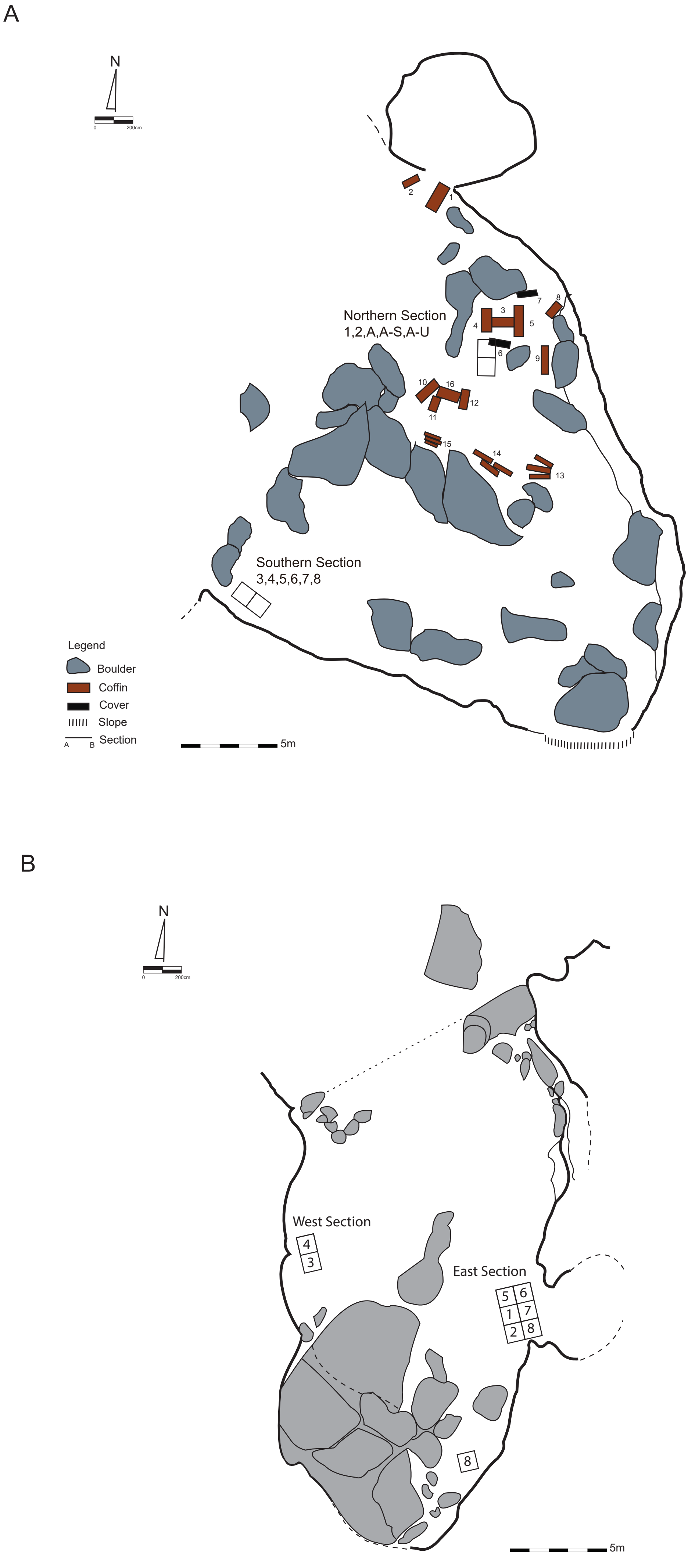
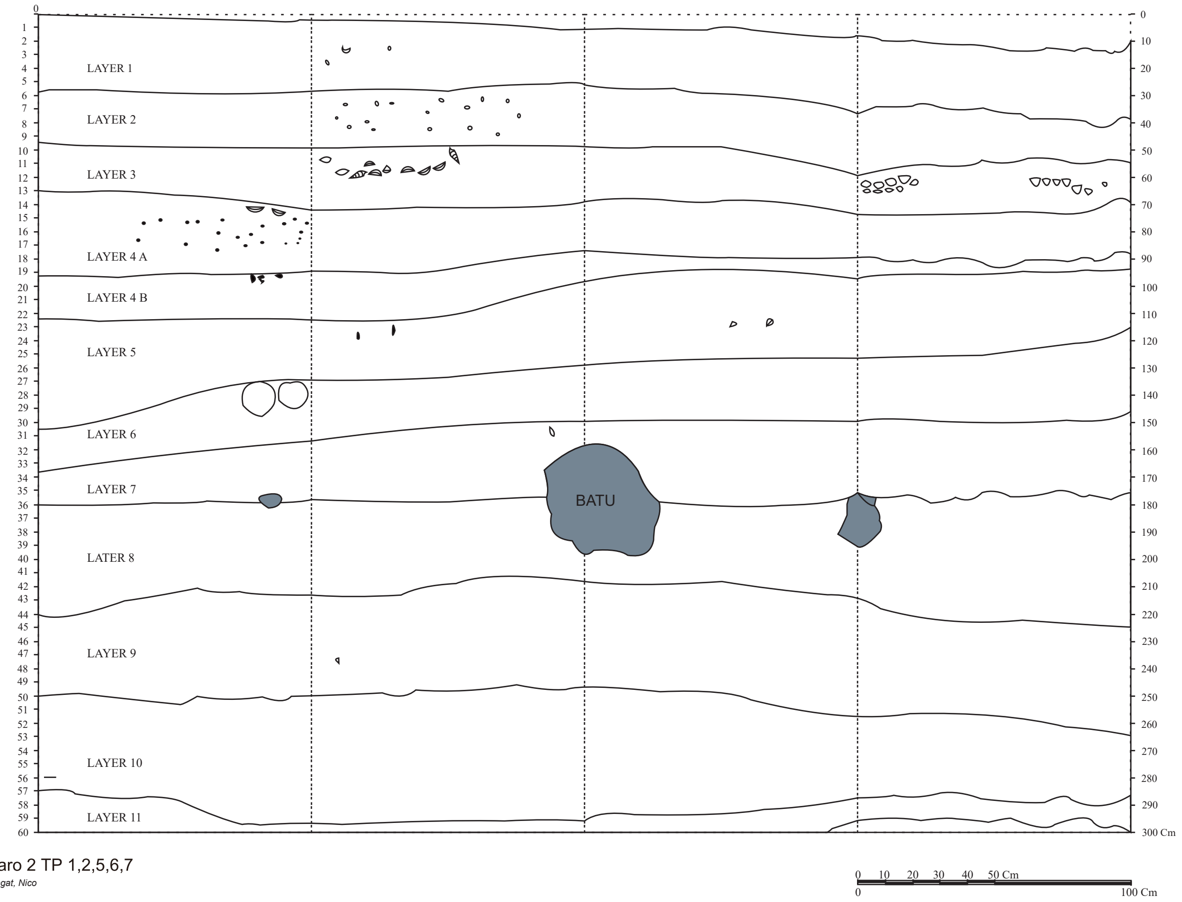

A
N
0
200cm
Northern Section
1,2,A,A-S,A-U
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Southern Section
3,4,5,6,7,8
Legend
Boulder
Coffin
Cover
Slope
A
B
Section
5m
B
N
0
200cm
West Section
4
3
East Section
5
6
1
7
2
8
8
5m

Figure 2

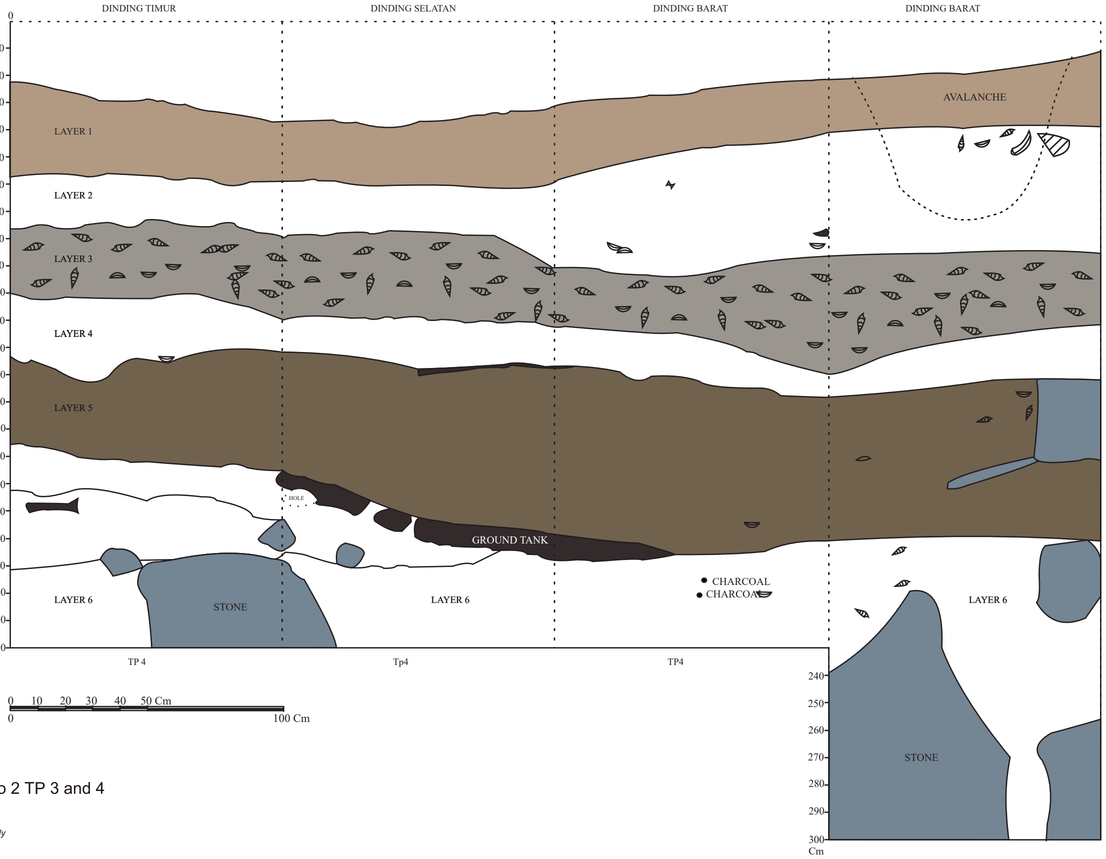
A



Topogaro 2 TP 1,2,5,6,7

Gambar: Jagat, Nico

B



Topogaro 2 TP 3 and 4

Gambar: Sur, Redy

Figure 3

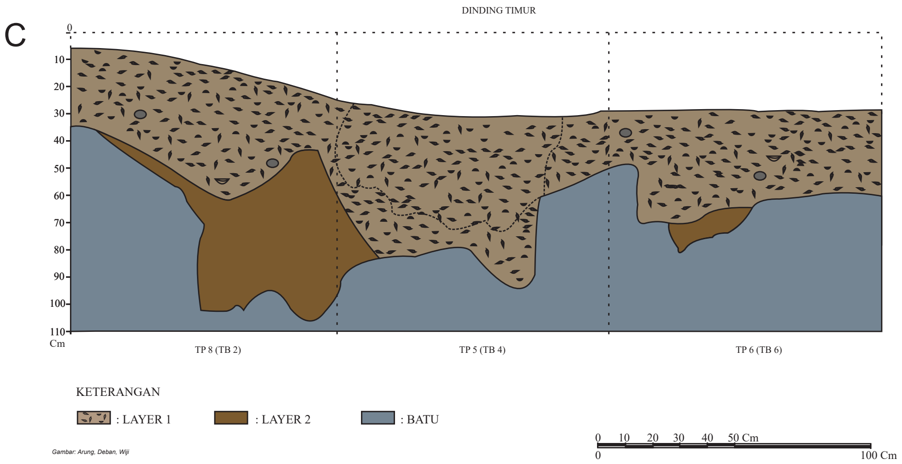


Figure 3 continued

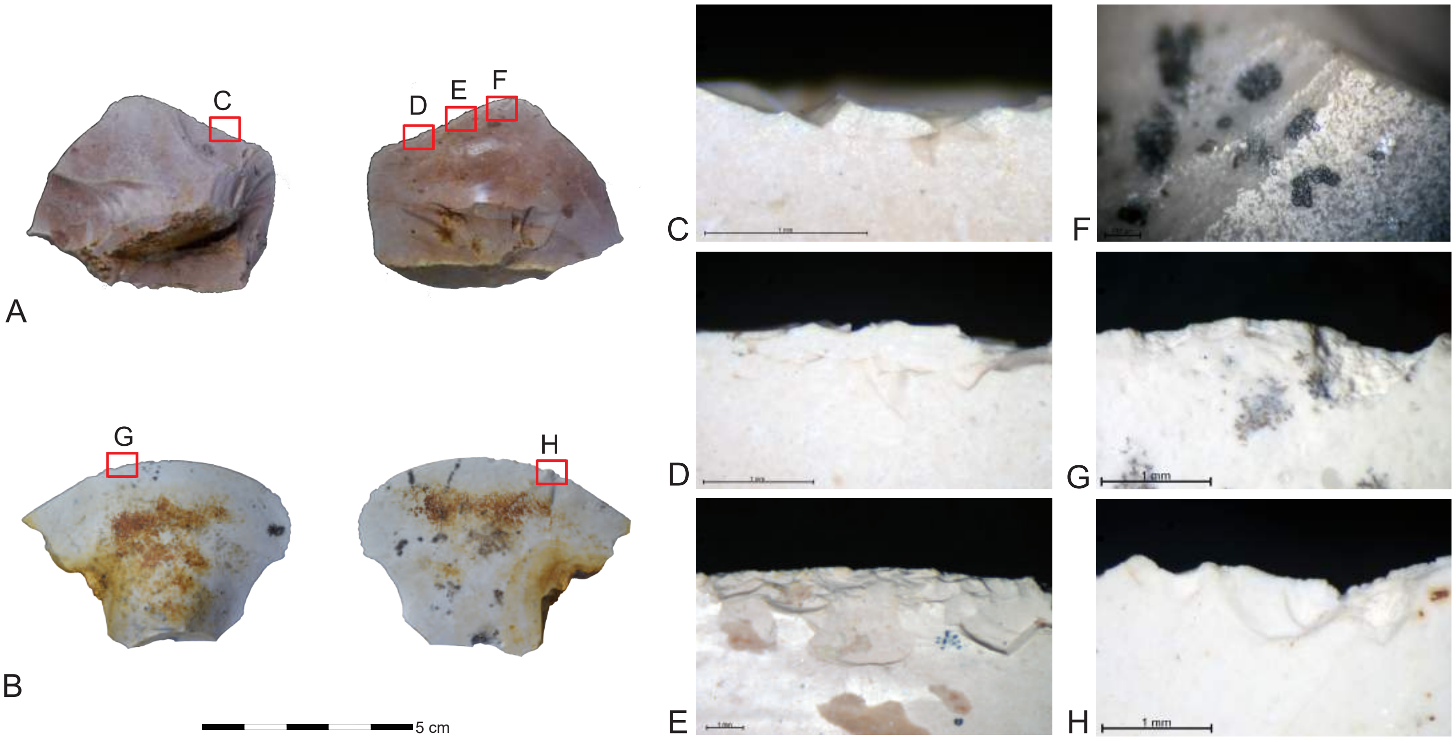


Figure 4

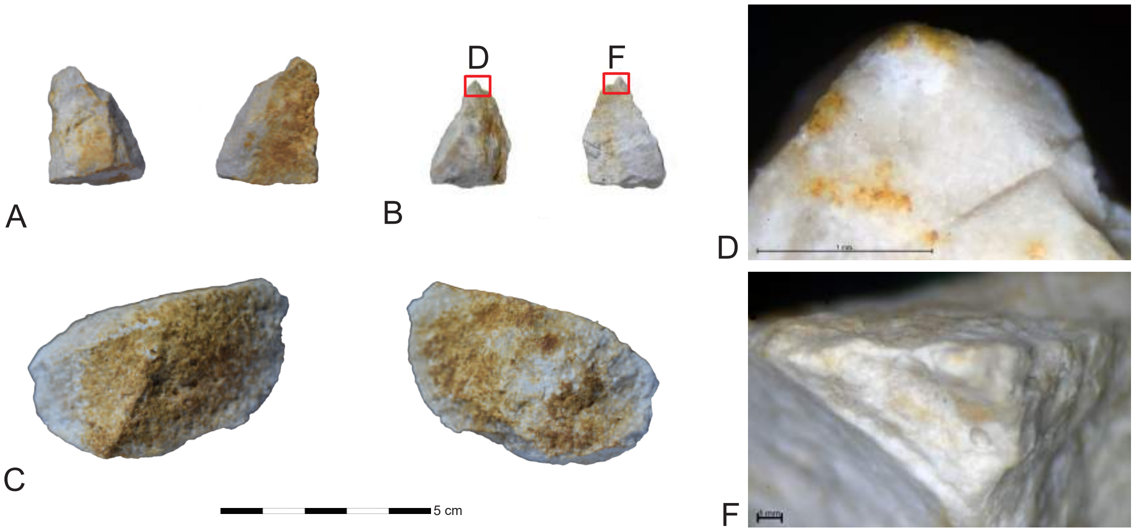


Figure 5

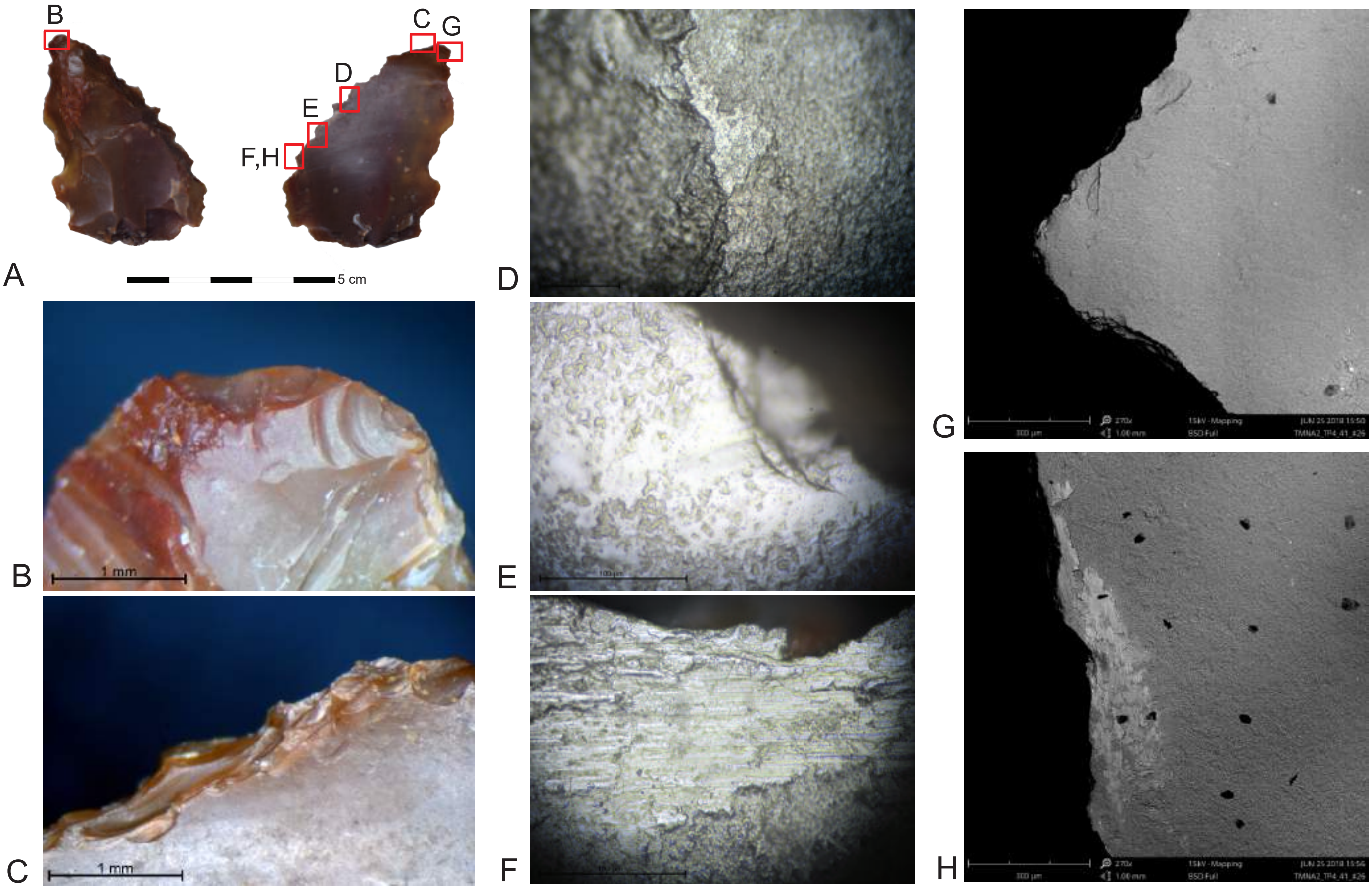

B
C
G
D
E
F,H
A
5 cm
D
B
1 mm
E
C
1 mm
F
G
300 µm
270x
1.00 mm
15kV - Mapping
BSD Full
JUN 25 2018 15:50
TMNA2_TP4_41_#26
H
300 µm
270x
1.00 mm
15kV - Mapping
BSD Full
JUN 25 2018 15:56
TMNA2_TP4_41_#26

Figure 6

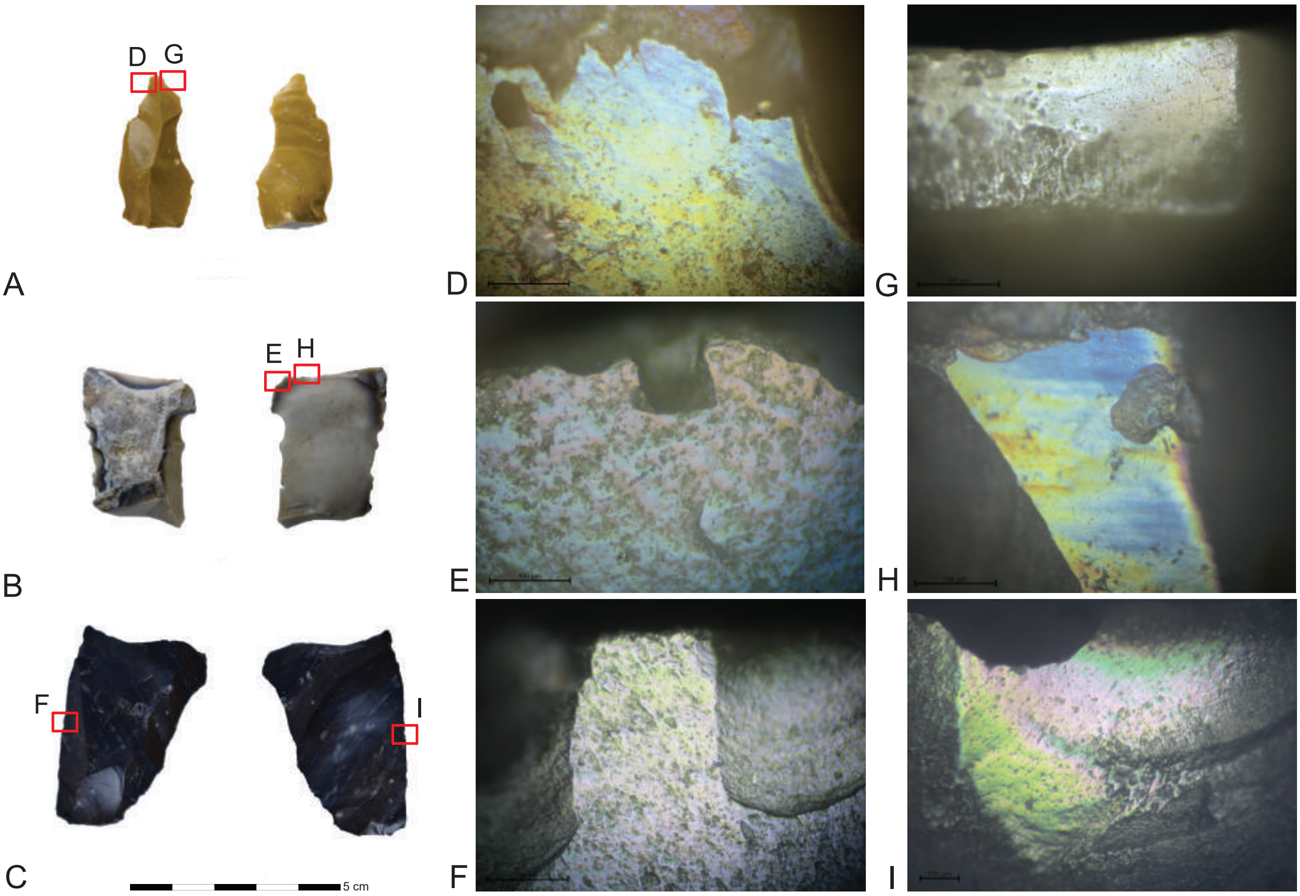


Figure 7

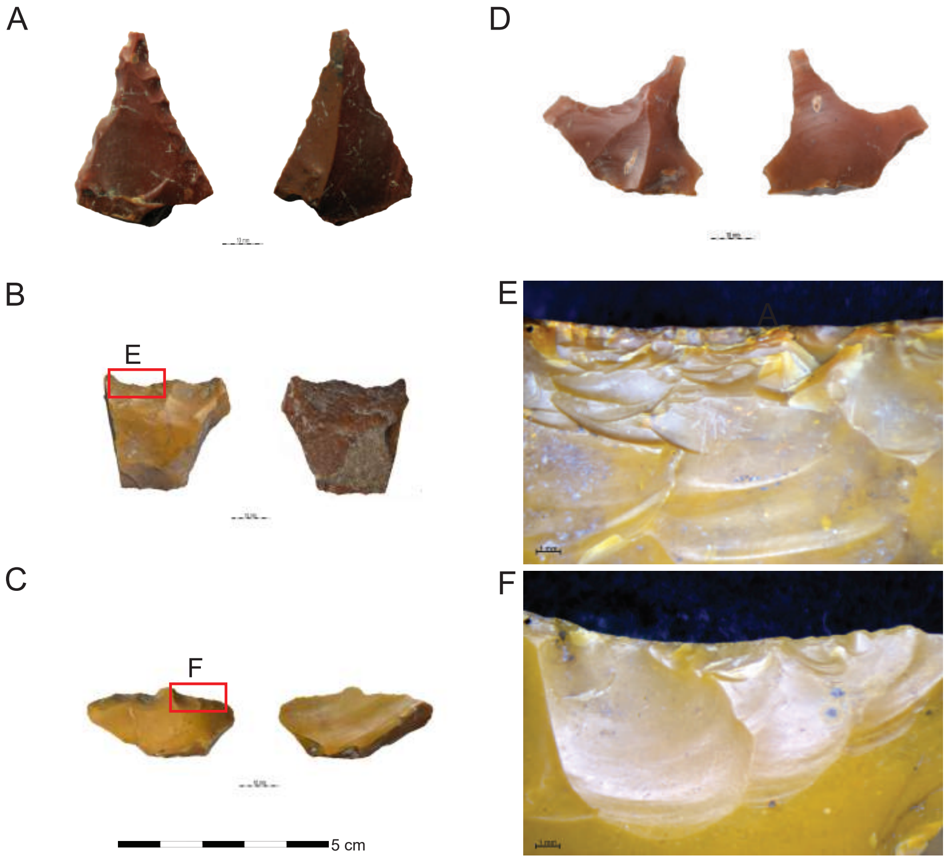


Figure 8

Missing or undetected? A review of microwear traces on composite prehistoric lithic tools from ISEA

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Abstract

The presence of composite lithic tools in ISEA has very limited evidence based on morphological analysis. To find evidence of this elusive technological innovation in ISEA, looking into the microscopic traces has been proposed to be a method more suitable in addressing complexity of lithic technology in the region. However, very few evidence of hafted lithic technology in the region has been recorded through this method in the past 20 years. We review the literature on this topic with emphasis on the role of use-wear research and identification or misidentification of traces associated with plant working. Unretouched flakes were used in a variety of activities and formal tool types to make them morphologically identical with our concept of 'projectiles' or 'hafted' tools may have hindered our views regarding the role of these tools in the cognition and development of complex technologies in the region. A first multi-stage lithic use-wear analysis of lithics from Leang Sarru, North Sulawesi and Topogaro 2, Central Sulawesi reveals lithic tools that have traces of preparation and use as composite tools. Currently, there is no published database for ISEA. We conducted tests to replicate the traces identified on the on artefacts. Although it is limited, we identified possible traces of this technology type on tools from Leang Sarru and Topogaro with analysis of experimental and archaeological materials as case studies and places these in the larger picture to address the issue of 'paucity' of lithic technology in ISEA, in general.

Keywords – composite tools, hafting technology, Island Southeast Asia, use-wear analysis

1. Introduction

The presence of composite tools in ISEA has not been extensively studied due to limited data and assemblages that do not show morphological features associated with points or hafted tools, and the limited use-wear data on hafting traces and residues. Migrations of AMH towards ISEA can be traced back to as early as 50kya. Projectiles and composite tools were identified to as old as 71,000 years ago in South Africa with evidence of microlith production and heat treatment (Brown et al., 2012). Complex tool technology is associated with the developments in human cognition, more than technological invention or innovations . This involves production of formal tool types such as blades and points. In a way, this is a marker for development of technology of cognitive abilities during the prehistoric period. Research on use-wear traces on projectile points and hafting implements has gained its ground in the past decade with establishment of certain laboratories dedicated to experimental programs answering questions on the mechanics of projectile traces and with more controlled experimental programs, prehension, and use of tar. Impact scars (Rots, 2014) and micro linear impact traces (MLIT) are indicators of use as projectile points (Dockall, 1997; Fullagar et al., 2009; Sano, 2012; Lazuen, 2014; Rots, 2013, 2016; Rots et al., 2011; Tomasso et al., 2015; Kufel-Diakowska et al., 2016). Residues, mainly tar, were used as glue to attach stone tools to a shaft. Although impact traces may be caused by other factors (Rots and Plisson, 2014) yet it is still the main indicator of use as composite tool, especially for the function of projectile. Overall, a more contextual approach is necessary to understand tool function especially hafting (Lauzen, 2014).

2. Hafted lithic tools – a missing type?

In ISEA, evidence of lithic composite technology is limited or rare for the Pleistocene period, mostly characterized by an unchanging unretouched flaked tool technology. A few cases have been mentioned based on morphological analysis and the presence of formal tool types (e.g. Toalean lithic industry). However, an unchanging lithic technology in ISEA does not support the argument and trend that hafting technology is associated with ‘sophisticated’ lithic technology - involves core preparation and retouching. Several sites in ISEA show no distinction of lithic technological production from the Late Pleistocene and even until the historical period. One approach to address this issue is to employ lithic use-wear analysis to identify traits associated with the arrival of AMH in the region (Pawlik, 2012).

Figure 1. Archaeological sites with evidence of osseous and lithic composite tool production before the Neolithic in ISEA.

An overview of lithic studies especially of use-wear analysis in ISEA provides insight on the general features of the observed industries associated with the appearance of AMH. The sites associated with early migrations of AMH with evidence of lithic production include Jerimalai, Leang Burung, Niah Cave, Liang Bua, Tabon Cave, Callao Cave (Mijares, 2007; Brumm et al., 2018; Fox, 1970; Barker et al., 2007; Marwick et al., 2016). By the Holocene, more formal tools were identified in few sites in the region such as the Toalean industry in South Sulawesi (Bulbeck et al., 2000). With the introduction of ground tools, we have more evidence of hafting in the periods towards the transition to the 'Neolithic' (Fox, 1978; Pawlik et. al, 2015).

Although formal tools during the early Holocene such as the case of Maros, it is still limited in terms of results showing hafting technology, probably due to limited microscopic data. To address this issue in lithic technology in ISEA, we reviewed use-wear analysis literature on this subject. Also, recent discoveries in North and Central Sulawesi points to occupation of sites dated from c. 35-31kya indicate traces that indicate possible production and use of composite tools. ISEA use-wear research lacks data on this technology due to the almost absence of tools that are morphologically considered as 'points' or 'formal'. The production of unretouched flakes has been consistent from the Late Pleistocene to even the Holocene Period, and with functional edges that can be used in a variety of ways, it is no wonder why the current theme points to this level of technology.

While there is rarity in the evidence of lithic composite tools, there is an abundance of evidence of bone point production (Piper, 2015). There are bone tools using fish spines in Niah Cave (Barton et al., 2009). Bone point traditions such as the Walane in Central Sulawesi during the Holocene (Aplin et al., 2016). The production of these organic technologies maybe as old as 42kya with the oldest fish hooks from Jerimalai in Timor Leste (O Connor et al., 2011). In the case of ISEA, an experimental database to address potential use-wear traces from composite tools – hafted, or even projectile – is lacking.

There are few published research detailing actual use of composite tools in ISEA. Pawlik (2012), addressed this issue by proposing use-wear analysis of simple flake tools in order to detect traces that can be attributed to production of hafted armatures. This typology dilemma is often justified by the presence of plant-based technology that served as complement rather than replacement to the lithic tools (Xhauflair et al., 2016). Hinge and step terminations the tip of tools suggest use as a projectile implement. Furthermore, there are polish spots at the tip of this tool with longitudinal striations on the upper part of the surface topography (Pawlik, 2012).

The traces used in the interpretation of the tools as hafted include impact scars at the tip of the tool, hafting polish located on sections that came into contact with binding or shaft, scars caused by shaft or binding material, and residues that could have been used as hafting tar to attach the stone tool to a shaft (Pawlik, 2012). One main example is the triangular flake (artefact no. 40406) that was interpreted as a projectile point, attached to a shaft using tar as glue. The artefact was made of chert and produced through direct knapping and without retouching, a sample of simple flaked tool technology in ISEA (Figure 2). However, other aspects of composite/ multicomponent tools, such as micro linear impact traces, sliced into scalar scar, and scarring at the hafting boundary, have not been documented for stone tools from ISEA. Such aspects are vital in understanding hafting technology in general because these were already documented in experimental studies (Rots, 2003, 2008) and part of distinct features that should form on tools that were attached to shafts and possibly used.

Figure 2. Composite lithic tools from Ille Cave, Palawan indicating hafting technology (Pawlik, 2012).

3. Micro-traces rather than morphological attributes

Traces associated with preparation, production, and use of composite tools were identified in Leang Sarru, North Sulawesi (Fuentes et al., *in press*) and Topogaro 2, Central Sulawesi (Fuentes et al., *in prep.)*. As part of a multi-stage use-wear study in the region (Fuentes et al., *in press*), we were able to identify use-wear traces associated with composite tools on both unretouched and retouched chert tools. It was not originally part of the goal to identify tools used with 'hafting' or 'projectile' technologies. However, these were encountered along the process and we were able to identify a total of six from Leang Sarru and four from Topogaro, Central Sulawesi. One limitation of this research is the absence of published database of systematic experimental program for projectile or hafted tools or any form of composite tools that addresses assemblages from ISEA. Comparison with published databases on projectile tools and hafted armaments in Europe and Africa yielded results for the assemblages from both Central and North Sulawesi, especially in the basics of fracture mechanics such as scalar scars, micro linear impact traces, and

In Leang Sarru, two chipped artefacts from Spit 5 (D2_TL_S5_0003, D2_TL_S5_0004) display traces associated with use as projectile points and identical in terms of morphology and with use-wear traces (Lazuen, 2012). These tools were recovered in Spit 5, associated with the 1st occupation phase of Leang Sarru dated to c. 35kya. We found fully-developed polishes along the edge outline (Fuentes et al., *in press*). These tools were initially identified as used on plants on diagonal and transversal actions as shown by the direction of polish formation and limited scarring on the tool edges. These tools are morphologically similar with points identified in Africa and Europe for broken distal points (Lauzen, 2012). In the upper layer (Spit 3) (D3_BL_S3_0037, D3_BL_S3_0038), two chert flakes have scalar scars formed on the left and right lateral sections on both the proximal, medial, and distal sections (Fuentes et al., *in press*). These are identical with micronotches on the same locations. Impact scars were formed at the tips of unretouched chert tools. It is located on the negatives at the right lateral section of the ventral face. The tools were found within the 3rd occupation phase (10-8kya) at the main platform of Leang Sarru (Ono et al., 2010). An unretouched tool has impact traces and fungal growth at its tip which may have been used as composite or even projectile tool (D2_BL_S4_0002).

Figure 3. Possible composite technology from Leang Sarru, North Sulawesi.

We identified retouched tools with symmetrical morphology showing negatives on the dorsal face. The tool was initially labelled as Topogaro point due to their recurring pattern of retouched and symmetrical morphology (TPGR2_TP4_41_#26; Fuentes et al., *in prep.*). MLITs with longitudinal orientation is present on three points along the edge outline. These were aligned on at least two locations on the ventral face of the tool. Furthermore, we also identified impact scars with secondary edge features also on the ventral face of the tool. The MLIT is quite a rarity in ISEA, although there are cases of similar striations and polishes, these were attributed to the use as cutting tools although the two types of striations are similar in morphology. The only difference is the abrupt formation that limits sections of intermediate zones often identified as smooth pitted polishes or the mid stage of polish formation.

Figure 4. Retouched tools and micro linear impact traces from Topogaro, Central Sulawesi.

4. What to look for in possible hafted amorphous tools

Results from extensive studies on traces attributed to production and use of projectile traces indicate a combination of traces. The application of these traces could provide a set of guidelines for the identification of hafting traces and for the interpretation of function of amorphous flakes in ISEA.

1. Morphological classification and retouching
2. Impact scars
3. Scalar scars
4. Residues in the same locations with scarring due to hafting
5. Micro linear impact traces

We proposed that these traces be included in use-wear studies being conducted in ISEA, especially for late Pleistocene assemblages.

5. A need for experimental database on amorphous and expedient tools in ISEA

There are several glaring issues with addressing prehistoric composite tool production in ISEA. First, the absence of formal tool types beginning from the late Pleistocene and even until the historical period, with exception of a few sites such as Maros, South Sulawesi with the Toalean tool industry. Most lithic assemblages that undergone use wear analysis do not show any formal morphological feature, the basic aspect that most researchers used to classify non-hafted/ projectile tool with those that were used as projectile points. Second, it is not the main problem in most use-wear studies because the focus is on the identification of traces associated with organic or plant-based tools. Thus we beg to question – 'have we overlooked something?' (Pawlik, 2012). Third, there are no published microwear database on lithic composite tools, so we based our inferences and identification of use-wear traces on experiments conducted elsewhere (Rots, 2006). Fracture mechanics would dictate the results for them to be generally acceptable for ISEAn assemblages. However, the nature of unretouched tools used in a variety of activities, which might include production of hafted tools and use of projectile tools, fails to account for the uniqueness of development of lithic technology in ISEA. So a database from ground up to identify minute details of activities pertaining to a more 'advanced' lithic tradition. Fourth, no microwear study has addressed the relationship of plant remains and plant working with production of bindings one of the components of hafted tool production. Same is true with experiments to produce tar and hafted tools based on this type of manufacturing process. Although archaeobotanical studies has presented results showing domestication of plants with the recovery of macro and micro botanical residues associated with consumption, we cannot discount cases wherein fibres were preserved. It could also address the scenario of plant utilisation for the production of lithic composite tools, fibre extraction for example. Fifth, we need to double check longitudinal striations as these are formed in the same way with MLITs. These were identified as result of cutting motion. However, the same is true with tools used with impact (hafted or projectiles), wherein MLITs can be formed diagonally or longitudinally in several points on the tool. We also tested the chemical composition of the linear traces and compared the results for the experimental tools and for the artefacts to check the hypothesis that these MLIT-looking materials are actually from contact on animal bones. The results show high calcium and carbon content – consistent with composition of bones.

A few attempts have been conducted in terms of experimental analysis in the Philippines, however, the results are still limited. So far the only evidence of composite tool production and use were identified in Ille Cave, Palawan, among other activities such as hide scraping (Pawlik, 2012). In the case of tools from the site, no MLITs were identified yet and the evidence for composite tools are impact scars at the proximal tip and the presence of residues in key points on the tool surface. The region now needs a robust experimental database on use of unretouched/ unmodified flakes as points or composite tools or hafted tools for that matter. In assemblages from the Philippines, use-wear analysis 25 thousand-year-old stone tools from Callao Cave shows traces of contact with plant materials and with similar pattern of striations with longitudinal orientation and interpreted as a cutting tools (Mijares, 2002). Researchers should and must revisit and reanalyse tools with parallel striations, these are possible MLITs caused by use impact. There are no studies on chemical characterisation of possible hafting residues, especially tar Composite does not automatically mean projectiles, could be anything from scraping to cutting tool as long as several components are attached to a shaft.

Use-wear and technological analysis dealing with flaked tool technology of the later Pleistocene or upper Palaeolithic in ISEA, it would be ideal to present an outline for future researchers on which traces should be checked. We proposed that these features should be looked upon – 1) impact scars on triangular flakes, with pre-removal negatives, 2) Parallel striations as these have the same morphology with MLITs, 3) residues should be documented (caused by contamination or not), 4) an extensive experimental database to compare MLIT and parallel striations, 5) an experimental database on unretouched flakes to test the presence of scarring associated with composite tools, 6) production and replication of residues used in production of composite tools (tar-based). These also points to the role of use-wear analysis in addressing ongoing issues and debates in ISEAn archaeology. Specific traces can only be identified through this method without the formal tool features such as point type that usually involves retouching.

More research on composite tools is needed to address the absence or presence of composite tools. The notion that unretouched tools served a variety of tasks would also mean that these had functions beyond tasks such as scraping or cutting. Experiments are needed to address this seemingly lacking data, and moreover archaeological evidence also has equal value. Thus, the need to check more assemblages with the same framework and with this basic question – are there slightest indication that unretouched tools were used as a component of more complex tools? ISEA lithic assemblages lacks this due to the absence of formal tool types observed somewhere else. Use-wear analysis thus plays a vital role in addressing issues in cognition and technological advancements of the modern humans in ISEA. It begins by double checking previous microwear studies that may or may have traces that indicate use other than simple menial tasks with single-action uses. It is about time to address this issue, other than the presence of organic based technologies other than bone points that exist in the archaeological record. Plant working in relation to stone tool production is more complex than just employing simple and repetitive activities such as cutting and scraping or the variants of these two. Complex technologies may not be obvious on the macroscopic scale but with use-wear analysis this technological innovation that has not been systematically studied in ISEA. Experimental database is still lacking but this is slowly being addressed with the use of both retouched and unretouched flaked tools made of chert.

List of Figures

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D. Manuscripts being prepared (abstracts)

1. Quantification of polishes on unretouched flakes from Island Southeast Asia

2. A technique for quantification of polish bevel from plant working

Quantification of polishes on unretouched flakes from Island Southeast Asia

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Abstract

Plant working has been proposed to either replace and or complement the use of lithic tools in ISEA. With the absence of formal tools, bamboo technology or the use of plant-based technologies were proposed to have been practiced during the prehistoric period in ISEA. Plant polishes, often associated with phytolith-rich material have been identified in Leang Sarru. The initial interpretation is that these were used in a transversal action in processing plants that include monocots, palm, with the polishes associated with grass or bamboo processing. In this paper, we attempt to combine both approaches with the use of a database of qualitative photomicrographs and the use of laser scanning confocal microscope to differentiate polishes formed through working different kinds of plants. We employed two stages of lithic microwear identification and categorisation with focus on polishes. A combination of these two techniques provides more datasets for which to test our hypothesis that different kinds of plants were used.

Keywords: plant polish, use-wear analysis, lithic analysis, laser scanning confocal microscopy, quantification technique

A technique for quantification of polish bevel from plant working

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Abstract

Upon testing the technique for quantification of polishes from Sulawesi on our previous research, we noticed that the current techniques for quantification does not address the presence of polish bevels on tools that has well developed polishes. Current techniques account for polishes on the dorsal or ventral faces, on areas considered as contact face during experiments and for artefacts. Now, the problem some tools from Sulawesi do not display well developed polishes on an area enough for scanning. These tools however display polish bevel that may provide clues to the contact material that was processed in the past. This study aims at testing the technique of measuring cross sections of polish bevel through the use of laser scanning confocal microscopy. We analysed experimental tools to assess and compare experimental polish bevels and archaeological samples. Main problem – while scanning for polish surface roughness, we noticed that the steep working angle and/ or absence of polished areas in some tools inferred to have been used for plant working. For some tools without 'flat' areas that would allow surface roughness measurement. A possible solution is to measure polish bevels – which have an undulating cross section very similar with cut marks, thus we test the technique of recording polish bevels on archaeological samples to develop a technique on quantification and recording of polish bevels. This research is not attempting to identify the contact material as experimental database is still lacking due to the research design which was designed to answer questions of surface roughness rather than polish bevel quantification.

Keywords: use-wear analysis, laser scanning confocal microscopy, quantification technique, surface metrology