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ACOUSTIC MAPPING OF SUBMERGED STONE AGE SITES. AN ACOUSTIC PHENOMENON RELATED TO WORKED FLINT AND SILICATE MINERALS

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Значительное количество археологических памятников расположено в прибрежных зонах времени последнего оледенения, в настоящее время затопленных, а также на участках, затапливавшихся во время эвстатических колебаний уровня мирового океана в послеледниковье. Для точной локализации таких объектов может быть использован акустический феномен, связанный с продуктами расщепления кремня. Специфический акустический резонанс может быть зафиксирован для расщепленного кремня, перекрытого морскими отложениями. Проведенные эксперименты показали, что измерения акустического резонанса позволяют также различать намеренно расщепленный кремень и кремень, расколовшийся в природных условиях.

Introduction

Stone Age sites are found in national and international waters to depths of around 140 m, corresponding to the lowest sea level during past glaciations. Protection of these submerged remains is increasingly being addressed by national legislation and international initiatives, for example the 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage and the EU-funded SPLASHCOS project.

A growing body of evidence indicates that large numbers of Stone Age sites are concentrated in the now submerged, highly productive and often ice-free coastal zones that existed during these past glaciations (Flemming, 2011; Bailey, 2011; Odum, Barrett, 2005; Tizzard et al., 2015) and that prehistoric communities followed the movement of these zones as the sea level rose and fell. The total number of deep-water sites is therefore likely to be much greater than those presently known, and these sites may represent significant and different cultural developments to those observable in present-day terrestrial (dry-land) areas.

This paper focuses on a hitherto overlooked acoustic phenomenon associated with flint knapped by humans, which facilitates efficient acoustic mapping of Stone Age sites located on, or embedded within, the sea floor. Specifically, evidence is presented here which shows that acoustic responses can reveal the presence of human-knapped flints covered by up to at least 1 m of sediment and which can therefore be used to map submerged Stone Age sites containing substantial concentrations of flint artefacts.

Results

In 1980, a pronounced resonance phenomenon was observed when knapping flint blades and flakes. In 1982, in order to examine this property more closely, 16 knapped flint 'blades' and 'flakes' from nine sites in Denmark, representing different Stone Age periods, were analysed and tested for resonance (Hermand et al., 2015). The results of these investigations showed that: i) flint 'blades' and 'flakes' respond when excited by an appropriate acoustic signal within the interval 3–23 kHz, with the main area of resonance being 7–12 kHz and ii) when damped, the flint blades and flakes still respond to appropriate acoustic signals at the same frequencies, but with less energy than when un-damped.

These findings allowed formulation of the hypothesis that it is possible to register responses from pieces of human-worked flint, and other worked silicate minerals, when these are excited by an appropriate acoustic signal, even though they are embedded within sea-floor sediments.

Recently, the application of acoustic inversion techniques to the characterisation of cultural layers containing Stone Age artefacts, such as knapped flint, has been investigated (Caiti et al., 2006). Finite-element acoustic modelling has shown that a piece of knapped flint embedded in sandy sediments produces a distinctive resonant response, compared to the same sediments with no flint embedded (Hermand, Tayong, 2013).

The results obtained support the idea that the resonance characteristics of the flint, and most likely other silicate mineral pieces knapped by humans, are due to the human knapping technique employed, and are therefore not be found in naturally split/cloven pieces.

In 2015, a field experiment was carried out to test whether the large quantities of human-knapped flint at the well-documented Stone Age settlement of Atlit-Yam, located off Israel's Carmel coast at a depth of approximately 10 m, would provide a recognisable response to an acoustic source sweeping the frequency interval 2–20 kHz. The remains at Atlit-Yam include walls, wells, megaliths etc. and date from 7200–6500 before present. The site is generally covered by up to 1.5 m of sand, but a small but varying part of the cultural layer is normally exposed due to sediment dynamics. Over the years, systematic recording and investigation has been undertaken of most of the 40,000-m2 site (Galili, Rosen, 2011). The experiment was carried out using a small boat and an acoustic setup, whereby the emitter and receiver were placed at the same location. Navigation was with C-Nav calibration so that a precision of ± 10 cm was obtained. Eighty-six profiles were surveyed within the test area during a day when weather conditions were good.

The results were surprisingly clear, as the recorded data showed large and significant 'haystacks' of acoustic noise, of varying vertical and horizontal dimensions, in the water column throughout the investigated area. These phenomena coincided consistently with the distribution of the cultural layer at the site, even though this was covered by up to 1.5 m of sand. One encouraging explanation for this observation could be that the haystacks represent noise in the water column resulting from the knapped flint artefacts being excited by the acoustic signal and emitting the energy received as an acoustic response, with a degree of delay.

In order to test and refine the signal interpretation of the recordings from Atlit-Yam and Møllegabet, two experiments were undertaken in 2016, using the same acoustic setup. The first experiment was carried out in the Amager Strandpark inlet, Amager, Denmark, while the second was undertaken in the nearby harbour of Sundby Sailing Union. In the first experiment, two water-soaked cotton bags containing no air were placed 43 m apart and at a depth of 3.5 m on the sea floor. One was filled with 14 kg of naturally-cracked flint pieces selected for their resemblance to flint knapped by humans (sample A). The other was filled with 14 kg of all types and sizes of human-knapped flint (sample B). The recordings were made from a small rubber inflatable boat and the bags were crossed as closely as sea conditions permitted. The bag containing naturally-split flint pieces produced no response (fig. 1: A), while the bag containing knapped flint pieces produced a strong acoustic response similar to that observed at Atlit-Yam and Møllegabet (fig. 1: B). The bags were visible on the seafloor in the seismic recordings (fig. 1A-B), confirming that the acoustic setup passed over both of them and that the different responses were due to their content.

The purpose of the second experiment was to establish whether the knapped flint pieces (sample B) would respond to being acoustically excited even when embedded in sediment. The flint sample was placed at a depth of 2.5 m on the sea floor, buried deep in a plastic bucket filled with water-saturated sand and with no air bubbles. When excited with the same acoustic setup as used at Atlit-Yam, it produced a strong, distinctive acoustic response (fig. 1: C).

Discussion

The results presented in this paper demonstrate that acoustic distinction (and thereby mapping) of human-knapped flint embedded up to 1 m into seafloor sediments is possible, given that a larger concentration of knapped flint is present. Furthermore, it shows that it is possible to discriminate between human-knapped flint and naturally-split pieces.

Since silicate minerals other than flint (obsidian, quartzite etc.) were knapped by Stone Age humans using the same technology, it seems likely that these materials can also form the basis for mapping of submerged Stone Age sites containing knapped human artefacts of all silicate minerals in accordance with similar principles to those described here for flint.

Research into the physical processes involved in the acoustic phenomenon that plays such an important role in human knapping of silicate minerals is on-going, aimed at obtaining a better understanding of its basis and characteristics. Further developments aimed at improving the method's ability to detect smaller amounts of knapped silicate mineral pieces embedded deeper into the seafloor sediments than is presently possible would pave the way for regular, efficient and economically effective mapping of submerged Stone Age sites, at depths where this today is extremely expensive and difficult to undertake in a properly controlled manner.

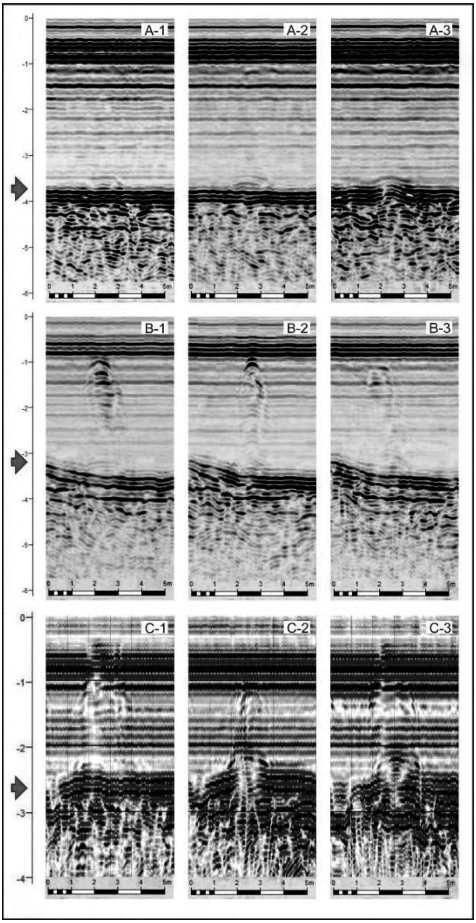

Fig. 1. Upper (A1–3): Experiment 1, bag containing flint sample A, consisting of 14 kg of naturally cracked flint pieces of all sizes. The bag can be discerned on the sea floor, but with no acoustic flint response. Middle (B1–3): Experiment 1, bag containing flint sample B, consisting of 14 kg and types of knapped flint pieces of all sizes. The bag can be discerned on the sea floor below a clear acoustic flint response. Lower (C1–3): Experiment 2, a plastic bucket filled with sand and containing flint sample B placed on the seafloor. The bucket can be discerned below a clear acoustic flint response. Red arrows indicate the level of the seafloor

Рис. 1. Вверху (A1–3): эксперимент 1, мешок с кремневым образцом A, состоящим из 14 кг кусков естественным образом расколовшегося кремня разных размеров. Мешок различим на дне моря, но не дает специфического для расщепленного кремня акустического ответа. В середине (B1–3): эксперимент 1, мешок с кремневым образцом B, представляющим 14 кг продуктов расщепления кремня разных размеров. Мешок различим на дне моря и дает отчетливый специфический акустический ответ. Внизу (C1–3): эксперимент 2, пластиковое ведро, наполненное песком и содержащее кремневый образец B, помещено на дно моря. Ведро хорошо обнаруживается благодаря четкому специфическому акустическому ответу. Красные стрелки указывают на уровень морского дна

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